# Zero-Emission Battery Bus Preliminary Implementation Plan

September 30, 2020

King County

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## II. Proviso Text

P9 PROVIDED FURTHER THAT:
Of this appropriation, $250,000 shall not be expended or encumbered until the executive transmits a zero emission battery bus preliminary implementation plan and a motion that acknowledges receipt of the plan is passed by council. The motion should reference the subject matter, the proviso's ordinance, ordinance section and proviso number in both the title and body of the motion.
The implementation plan shall include, but not limited to:
1. Identification of major milestones through the 2021-2022 biennium related to planning, testing, procurement and deployment of battery buses and the installation of charging infrastructure;
2. A preliminary fleet procurement plan by type of bus through 2040;
3. A high-level schedule through 2040 for the anticipated installation of charging infrastructure at new, existing and interim bases as well as in-route charging;
4. A summary of the results of any studies or evaluations related to zero emission battery bus implementation completed after December 1, 2019, and a summary of the scope of any ongoing studies or evaluations;
5. Updated cost projections comparing the cost of a zero-emission fleet and continuing Metro transit department's current fleet practice;
6. A preliminary high-level financing plan for transition to zero emission bus fleet by 2040 that evaluates financing options.

2019-2020 Biennial Budget Ordinance, Ordinance 18835, Section 109, as amended by Ordinance 19021, Section 64, King County Metro, Proviso P9[1]

[1] Link to Ordinance 19021

## III. Executive Summary

In 2017, King County Metro Transit Department (Metro) committed to making its fixed-route vehicles (buses) zero-emission by 2040. Metro is one of the largest contributors of greenhouse gas emissions (GHGs) in County Government, and this commitment was made in support of the 2015 King County Strategic Climate Action Plan (SCAP). This goal will be met through a combination of Battery Electric Buses (BEBs) and zero-emission Trolley Buses (Trolleys).

**Fixed-Route Fleet**
Since that commitment, Metro has been making progress towards the 2040 zero-emission goal. The agency has launched 11 short-range BEBs on the Eastside of King County, with supporting charging infrastructure at Eastgate park-and-ride. Metro has announced the purchase of 40 longer-range BEBs that will begin service in South King County in 2022. To charge these buses, Metro is building a nine-charger installation at South Base known as the South Base Test Facility (SBTF). This location will not only charge the first 40 long-range BEBs, but will demonstrate interoperability between various charger and bus manufacturers. Metro is also working with various internal and external groups on information technology (IT) solutions to manage electrical usage and lower electrical costs as the program grows.

With the impacts of COVID-19 (COVID), Metro no longer expects service growth projected in Metro Connects and instead faces a structural deficit that limits service growth in the near term and could require service reductions by 2025-2026 unless a new revenue source is secured. This has resulted in a plan for minimal fleet growth in the near term and reduced fleet size in 2025-2026 and outyears, consistent with the anticipated service levels. This report shows how Metro plans to meet its target of electrifying the resulting fixed-route fleet by 2040. Based on current capital planning, the newly constructed Interim Base at South Campus (Interim Base) will be electrified in 2025, and South Annex Base at South Campus (South Annex base) will open as an electrified base in 2027. Subject to additional funding, existing bases will begin converting in 2028 and continue through the decade. At the same time, the fleet will be converted to zero-emission buses and Metro will purchase no more diesel-hybrids after 2023 (13 RapidRide coaches will be purchased for the opening of Madison G line in 2023). Section 2 and Section 3 of this report provide fleet plans and construction milestones to support zero-emission by 2040 and 2035.

The tables below describe two scenarios to reach electrification. Table 1 describes construction milestones required to support full electrification by 2040, and Table 2 describes construction milestones required to support full electrification by 2035.

*Table 1: 2021–2022 Executive Budget—2040 Electrification Plan*

| Year | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|
| **Number of Metro BEBs** | 51 | 156 | 156 | 156 | 311 | 341 | 488 |
| **New Metro BEBs** | 0 | 105 | 0 | 0 | 155 | 30 | 147 |
| **Number of ST BEBs** | | | | | | | |
| **Approximate Infrastructure Capacity for BEBs** | 9 at SBTF<br>3 on the Eastside | 156 | 156 | 311 | 311 | 311 | 590 |
| **Budget Requirements** | Funding in 3rd supplemental approved in Q3 2020 | Funding for Interim Base and South Annex Base in 2021-2022 budget | | | | | |
| **Notes** | 40 BEBs at South Base and 11 at Eastside<br><br>Charging supported through additional operational staff moving buses at SBTF | Interim Base fully electrified | | South Annex Base electrified | | | Atlantic and Central Base electrified |

*Table 1 continued on next page*

*Table 1 continued*

| Year | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number of Metro BEBs** | 540 | 705 | 765 | 765 | 863 | 868 | 887 | 925 | 940 | 940 |
| **New Metro BEBs** | 52 | 165 | 60 | 0 | 98 | 5 | 19 | 38 | 15 | 0 |
| **Number of ST BEBs** | | | | | 80 | 80 | 80 | 80 | 80 | 80 |
| **Approximate Infrastructure Capacity for BEBs** | 590 | 816 | 816 | 973 | 973 | 1157 | 1157 | 1278 | 1278 | 1393 |
| **Budget Requirements** | | | | | | | | | | |
| **Notes** | | East Base electrified | | North Base electrified | | Ryerson Base electrified | | Bellevue Base electrified | | South Base fully electrified |

*Table 2: 2021 2022-Executive Budget– 2035 Electrification Plan*

| Year | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|
| **Number of Metro BEBs** | 51 | 156 | 156 | 156 | 311 | 341 | 488 |
| **New Metro BEBs** | 0 | 105 | 0 | 0 | 155 | 30 | 147 |
| **Number of ST BEBs** | | | | | | | |
| **Approximate Infrastructure Capacity for BEBs** | 9 at SBTF<br>3 on the Eastside | 156 | 156 | 311 | 311 | 590 | 590 |
| **Budget Requirements** | Funding in 3rd supplemental approved in Q3 2020 | Funding for Interim Base and South Annex Base in 2021-2022 budget | | | | | |
| **Notes** | 40 BEBs at South Base and 11 at Eastside<br><br>Charging supported through additional operational staff moving buses at SBTF | Interim Base fully electrified | | South Annex Base electrified | | Atlantic and Central Base electrified | |

*Table 2 continued on next page*

*Table 2 continued*

| Year | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number of Metro BEBs** | 540 | 705 | 765 | 765 | 940 | 940 | 940 | 940 | 940 | 940 |
| **New Metro BEBs** | 52 | 165 | 60 | 0 | 177 | 0 | 0 | 0 | 0 | 0 |
| **Number of ST BEBs** | | | | | 80 | 80 | 80 | 80 | 80 | 80 |
| **Approximate Infrastructure Capacity for BEBs** | 816 | 973 | 973 | 1157 | 1157 | 1272 | 1393 | 1393 | 1393 | 1393 |
| **Budget Requirements** | | | | | | | | | | |
| **Notes** | East Base electrified | North Base electrified | | Ryerson Base electrified | | Bellevue Base electrified | South Base electrified | | | |

Metro has also embarked on testing of various BEB manufacturers including New Flyer, Proterra, and BYD. All manufacturers met range requirements in most weather conditions. However, Metro learned through testing that at some extreme cases, such as very cold weather or aged batteries, range was impacted. And some BEBs did not perform as well in the County's hilly topography.

Since 2017, Metro has analyzed various charging methods. The agency found that overhead, pantograph down charging was the best option because it provided the most efficient and safest power transfer method available in the industry. This decision will provide the basis for base design and conversion moving forward.

The fixed-route sections of this report finishes with an overview of the costs associated with BEBs and various financial structures Metro can use for financing BEBs. At this time, any model would involve debt financing, primarily for charging infrastructure. The updated cost models show that BEBs are more expensive than diesel-hybrids, even when societal benefits are factored in. It is estimated that BEBs, when using current data, in the most favorable case, when societal costs are included, is one percent less expensive than diesel-hybrids. In the moderate case, when societal costs are included, BEBs are 42 percent more expensive than diesel-hybrids. The report ends with an overview of the state of BEB technology including procurement rates in the last ten years and various BEB styles.

Metro is optimistic that zero-emission buses can deliver world-class transportation benefiting drivers, mechanics, passengers, and residents living along the routes served, and, when fully implemented, a 100 percent zero-emission fleet can further improve the quality of life of all residents in King County.

# IV. Background

**Department Overview:** King County Metro is among the ten largest transit agencies in the United States, with approximately 1,500 buses and 215 routes. Metro operates a diverse service profile, including: local bus routes, RapidRide (similar to bus rapid transit), van pools and rideshare, ADA paratransit (Access) vans, and marine routes, serving a 2019 daily average of 332,000 bus passengers.[2] The bus fleet includes diesel-hybrids, trolleys, and battery-electric buses (BEB). Fifty-five percent of Metro buses are 60-foot, articulated buses. The non-bus revenue fleets include approximately 2,040 vanpool and rideshare vehicles and the ADA paratransit program, Access, which includes about 400 active vehicles. As noted below, Metro is forecasting service hour reductions in future years and, therefore, bus fleet reductions in 2025-2026. More detail about the underlying service hours assumptions and fleet plan can be found in Section 2.

*Table 3: King County Metro Fleet*

| | |
|---|---|
| **Fall 2020 Metro Operated Bus Fleet** | 1,486 |
| **Trolleys** | 174 |
| **ST Buses** | 125 |
| **Total Current Metro Buses to Electrify (total fleet–trolleys)** | 1,187 |
| **Current Metro and ST Buses to Electrify** | 1,312 |
| **Long-term Metro Buses to Electrify[1]** | 940 |

1. Does not include the trolley bus fleet

**Key Context:** In 2004, Metro became an early adopter of diesel-hybrid buses to reduce Greenhouse Gas (GHG) emissions. Originally starting service in 1940, Metro renewed its commitment to the trolley fleet by purchasing 174 new zero-emission trolley buses in 2015. The trolley and diesel-hybrid fleets have reduced the agency's GHG emissions and supported Metro's climate goals.

King County's 2015 Strategic Climate Action Plan (SCAP)[3] set targets and priority actions for reducing emissions and increasing efficiency. In the 2015 SCAP, the County committed to reducing GHGs for its own operations by 25 percent by 2020 and 50 percent by 2030, relative to a 2007 baseline. The updated SCAP, submitted to Council in August 2020, strengthen those targets, and it includes goals for Metro's non-bus fleets to begin transitioning to zero-emission operations as well. In the 2015 SCAP, Metro committed to increasing ridership without increasing operational GHG through fleet fuel efficiency, increased adoption of alternative fuels for fleets including electricity, and the transition to an all diesel-hybrid and electric bus fleet by 2018. Additionally, Metro committed to a BEB pilot. An overview of BEB Technology can be found in Appendix D: Overview of BEB Technology.

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[2] Link to APTA ridership

[3] Link to SCAP

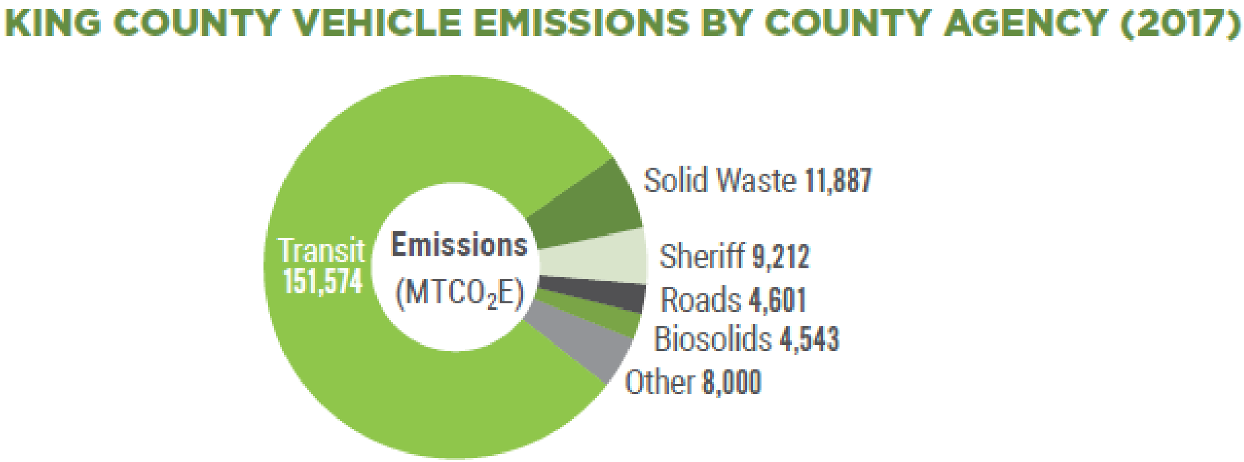


*Figure 1: 2020 SCAP*

In 2016, Metro purchased three short-range BEBs currently running in Bellevue. Metro-operated BEBs increased to 11 in the ensuing years. A short-range BEB generally has a smaller fast-charging battery pack, which lowers bus cost as batteries are the most expensive component of a BEB; a smaller battery pack also reduces the bus range. These BEBs have a range of approximately 25 miles and a charge time of 10 minutes.

In 2017, Metro released a report on the "Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet" (2017 Study) in response to Council Motion 14633, requesting an assessment of the feasibility of achieving either a carbon-neutral or zero-emission Metro vehicle fleet. The 2017 Study found a zero-emission fleet was attainable by 2040, and BEBs with a range of 140 miles satisfied 70 percent of service needs without changing service profiles. The 2017 Study also acknowledged that BEB technology was rapidly changing and Metro's zero-emission strategy could change based on technology shifts. Based on this information, Metro developed an internal strategy to electrify its bus fleet. The internal strategy had electrification beginning in South King County and expanding throughout the County over time. Each base was to be electrified one-half at a time, and all bases would be converted by 2040. In concert with base electrification, the bus fleet would transition to BEBs.

As part of the 2017 Study, Metro conducted an equity impact review, which included assessment of Metro bus routes and the vulnerability to air pollution of communities along routes. The analysis found that local communities located along corridors of routes served from Metro's South Base have historically been disproportionately affected by air pollution. Metro conducted a public stakeholder process, and a primary recommendation of this group was to focus service out of South Campus to prioritize the benefit of improved air pollution in communities disproportionately burdened.[4]

In Figure 2 below from the 2017 study, darker shaded areas are more vulnerable to air pollution than lighter shaded areas. Red bus routes are the highest priority quintile to be served by zero-emission buses, green routes are the lowest.[5] In the 2017 Study, the Executive and Metro recommended – and

[4] King County Department of Transportation, Metro Transit Division, "Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet," (2017): 58 Link to 2017 Study
[5] Metro, "2017 Study," 16.

the Council approved – the goal of transitioning to an all zero-emission bus fleet powered by renewable energy by 2040, to order 120 BEBs by 2020, and to scale up electrification first in South King County.

The 2017 Study emphasized that several requirements must continue to be met by Metro and the bus industry for this target to be achievable, including: vehicle and charging technology meeting operational needs especially for 60-foot vehicles, standardization of charging infrastructure, and availability of renewable energy supplies. The 2017 Study also highlighted that Metro and partners would need to continue to assess: safety for customers and employees, staff training, equity impacts, emergency preparedness planning, and total costs of transitioning to a zero-emission fleet to ensure that incremental costs do not limit Metro's ability to deliver and expand service.

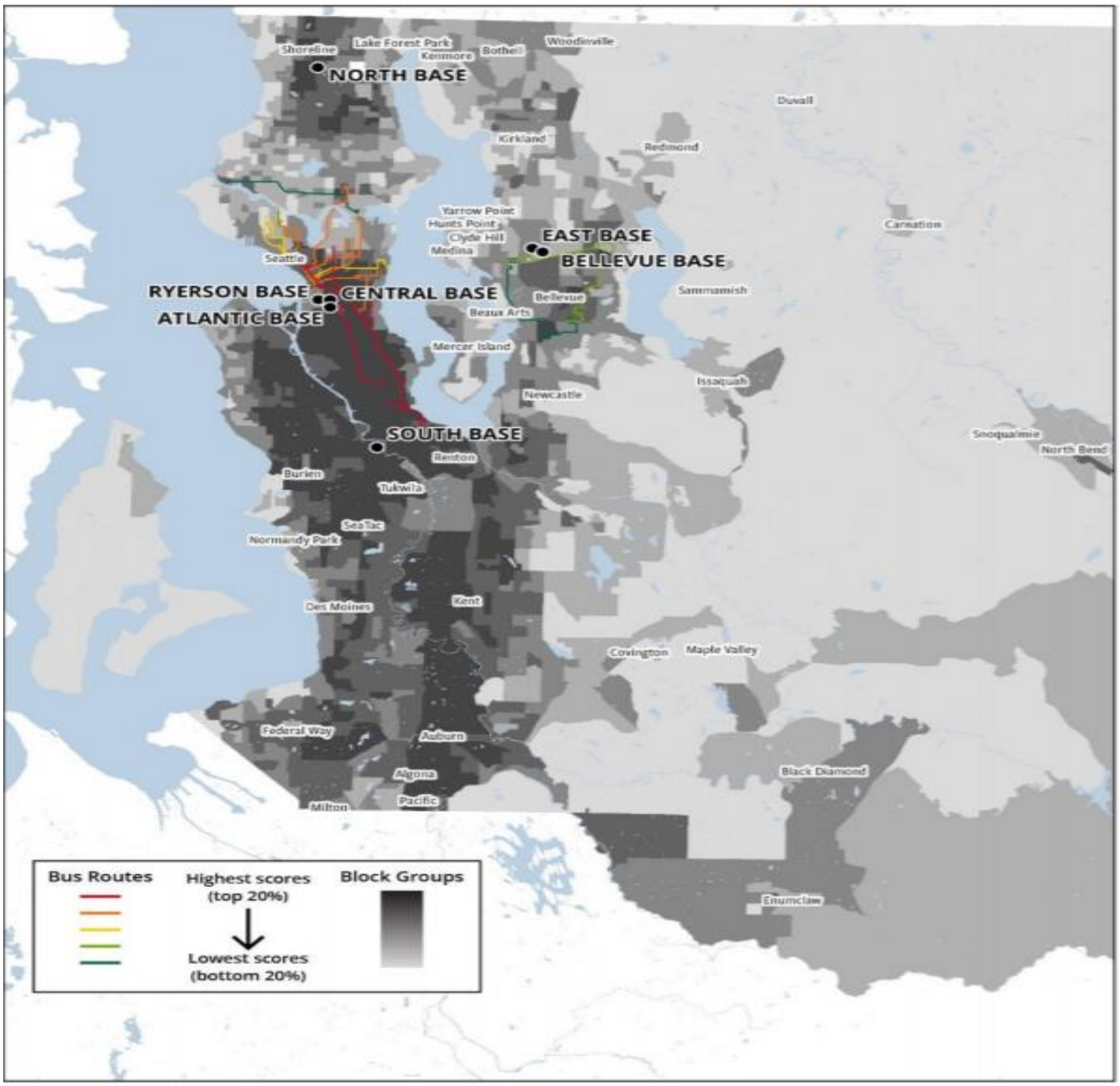


*Figure 2: Map of air pollution vulnerability and bus routes in King County*

Metro announced its first large-scale purchase of 40 long-range BEBs in January 2020. These BEBs, a mix of 40-foot and 60-foot buses, will have a range of 140 miles, and service will begin in South King County.

As recently as April 2020, King County was considering a ballot measure to support regional transit service and system expansion along with other elements of the Metro Connects long-range vision. Consistent with this service growth, Metro intended to grow its fleet to approximately 1,800 zero-emission buses by 2040. The procurement of the first 40 BEBs was to be followed by an additional 80 BEBs in 2021. Simultaneously, base electrification and installation of layover (i.e., on route) charging was to occur throughout the County beginning with South King County and ending in the East.

Due to the unprecedented budgetary impacts of COVID – and the forecasted sales and property tax revenue declines – Metro's budget forecast for service hours and a fleet to support service has significantly reduced. Once COVID-suspended service hours are restored in 2021-2022, service levels are anticipated to be held fairly constant through 2024. However, a structural deficit between current revenue forecasts and service costs will require service levels to decline between 2024 and 2027 unless additional revenues are obtained. After these reductions, Metro is not forecasting any service increases in the out years. This revenue decline forced Metro to reduce over 30 percent of budget expenditures across its Capital Improvement Program (CIP) through 2028, resulting in cuts across all capital programs. In addition, the cost to electrify the fleet and provide required charging infrastructure was not funded in earlier financial planning. The significant reductions to sales tax and fares within the current year, upcoming biennium, and outyears has impacted Metro's ability to fund fleet electrification costs. In the near term, Metro has funded the first 40 BEB and associated charging infrastructure, and in the longer term (mid 2020s), Metro has proposed funding in the CIP of another 260 BEBs and associated charging. In the out years of the proposed budget, no additional BEB fleet or charging infrastructure projects are funded beyond those noted above.

**Report Methodology:** This report was written and compiled by Metro staff. Additionally, Metro staff worked with consultants from WSP Global Inc. (WSP) and The Center for Transportation and the Environment (CTE) to update cost projections in Section 5. Metro also worked with CTE, Nelson Nygaard, and DKS Consulting on the evaluation of Access services and reviewed opportunities to increase electric vehicle charging at Metro park-and-rides. The cost projections have been reviewed by the Office of Performance, Strategy, and Budget. Additional information on analysis methodology is provided in the appendices.

## 1. Identification of major milestones through the 2021-2022 biennium related to planning, testing, procurement and deployment of battery buses and the installation of charging infrastructure

In the next two years, Metro will begin building large-scale electrical charging infrastructure and continue developing information technology (IT) solutions for charge management. Metro has completed testing of multiple bus manufactures BEBs, which informed procurement decisions. Further detail can be found below.

**Ongoing Infrastructure Development – South and Interim Bases**

The South Base Test Facility (SBTF), located on Metro's South Base in Tukwila, is approaching final design, and a construction permit application will be submitted to Tukwila in Fall 2020. This facility will have nine charge locations supported by three charger manufacturers and the capability to charge the

40 BEBs beginning service in January 2022. Construction is estimated to begin in Q4 2020, with phase 1 completed by Q2 2021. Phase 1 consists of three mast-style overhead and three plug-in charging dispensers from three charger Original Equipment Manufacturers (OEM). Phase 2 consists of overhead gantries and six additional charging dispensers and is expected to be completed by the end of Q4 2021.

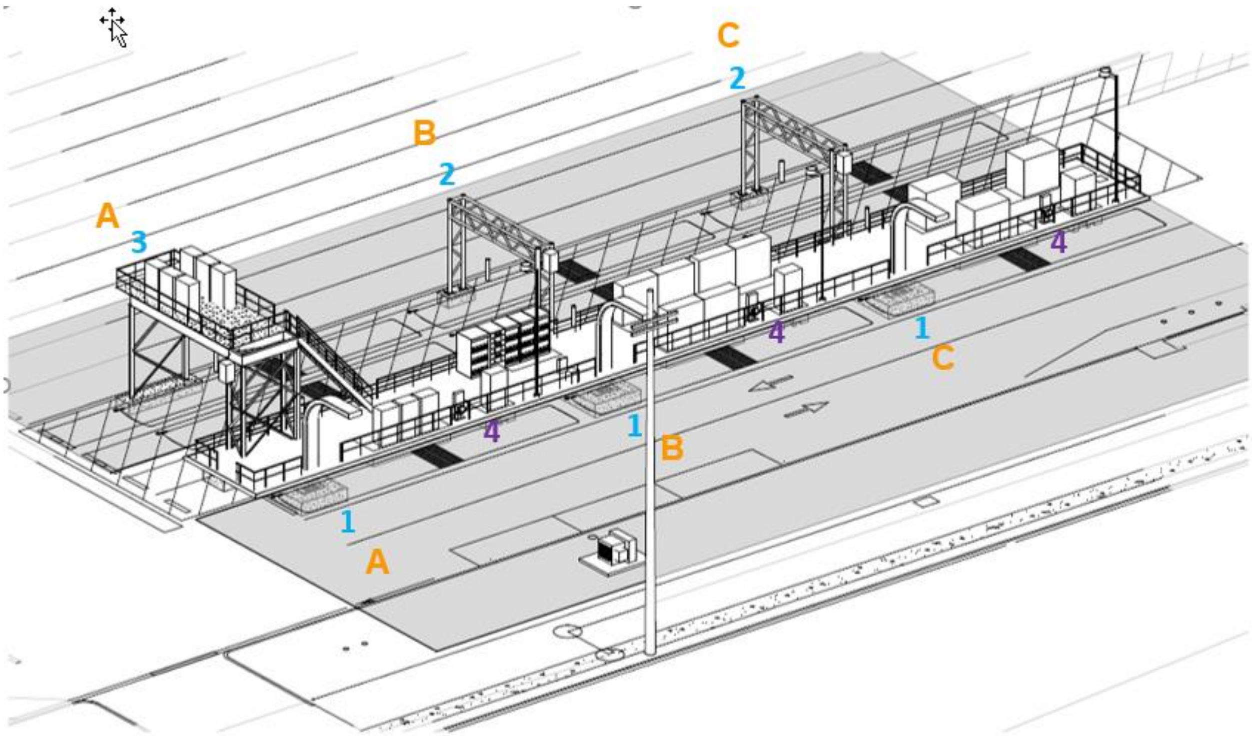


*Figure 3: South Base schematic*

The SBTF provides the following benefits to Metro:

- The size of SBTF is large enough to provide charging infrastructure for the 40 BEBs without affecting operational integrity;
- It allows Metro to test compatibility between various charger and bus manufacturers demonstrating interoperability[6];
- In the next decade as charger software develops, Metro can deploy new or upgraded charge management software in a controlled environment removed from base charging infrastructure. Like all software upgrades there is a chance of an IT failure, and this testing facility ensures the failure is localized to a non-essential facility; and
- It serves as a facility for the development of training and maintenance practices.

[6] Interoperability ensures that products from different bus and charger manufacturers work together and allows Metro to purchase buses and chargers based on quality and cost of a product and not be tied to a single manufacturer.

The Interim Base at South Campus (Interim Base) is currently being built as a diesel-hybrid base and will be electrified by 2025. The Interim Base will support the 105 BEBs arriving in 2025.

**IT Planning**

A charge management system (CMS) is a software/firmware/hardware system that provides control mechanisms over the amount of power being deployed by the charge heads. In theory, this system can prevent unnecessary utility fees and efficiently manage power to batteries while communicating with the utility to avoid peak demand or grid instability. At its most basic, a CMS can be deployed at the charger level; the charger is prevented from providing above a preset amount of power, thus preventing multiple chargers from charging at high levels and triggering utility demand fees. The technology for this type of charge management exists and is expected to be deployed at SBTF.

Moving forward, a more sophisticated CMS will be required to ensure quality operations. In this version of charge management, a backend cloud service integrates with the utility, and, based on signals from the utility, charging is decreased or increased. Additionally, these systems can reduce or increase power to specific chargers based on the needs of the attached bus, helping maximize battery life while ensuring buses are charged sufficiently to support service. These systems also provide alerts when charging infrastructure is not working. This type of CMS exists in the electric vehicle space but is not as robust in the bus space. Charger manufacturers, third-party software companies, and some bus manufacturers are developing competing solutions that Metro will evaluate in the upcoming years.

**Current BEB Testing**

In addition to the data that Metro has obtained from operating the 11 fast charge BEBs noted above, Metro has just finished testing a total of 10 long-range, slower-charging BEBs – four 60-foot and six 40-foot buses – from a mix of Build Your Dreams (BYD), New Flyer, and Proterra. From BYD, two 40-foot long and two 60-foot long coaches were tested. One of each length was operated with passengers (also known as revenue service), and the other BYD buses were tested by drivers in various conditions. The tests ran for approximately six months. Additionally, Metro completed testing of four New Flyer buses – two 40-footers and two 60-footers – and two 40-foot Proterra buses (Proterra does not manufacture 60-foot buses) in revenue service in various conditions. The tests for New Flyer and Proterra ran for approximately one year to gather seasonal data and were completed in spring 2020. The test buses and charging infrastructure were leased from the bus manufacturers, and all leased equipment was returned to the manufacturers. Key performance indicators (KPIs) were captured for each bus manufacturer, and these results are summarized in Section 4.

**Procurement and Deployment**

In January 2020, the purchase of 40 BEBs, twenty 40-foot BEBs and twenty 60-foot BEBs, manufactured by New Flyer, was announced. These buses are expected to begin service in early 2022 in South King County and will charge, as described above, at SBTF.

## 2. A preliminary fleet procurement plan by type of bus through 2040

Currently, Metro operates 185 zero-emission buses, which is 12 percent of the fleet. Eleven are short range, faster-charging Proterra 40-foot buses deployed on the Eastside with a range of approximately 25 miles, requiring a charge time of 10 minutes. The remainder (174) are zero-emission trolley buses providing service throughout Seattle. When the 40 long-range BEBs begin service in January 2022, Metro will have 225 zero-emission buses, which will be approximately 15 percent of the fleet.

Two fleet plans are described below. The 2021-2022 Executive Budget – 2040 Electrification Fleet Plan (2040 Electrification Fleet Plan) was reviewed by the Office of Performance, Strategy, and Budget and is part of Metro's proposed budget. To answer Council's question about meeting zero-emission by 2035, a separate fleet plan was developed using the same service levels as the 2040 Fleet Plan and accelerating electrification to 2035. This plan is referred to as the 2021-2022 Executive Budget – 2035 Electrification Plan (2035 Electrification Fleet Plan). To support these plans, electrical charging infrastructure is required. See Section 3 for additional detail.

**Underlying Service Assumptions for the Fleet Plans**

The 2040 Electrification Fleet Plan and the 2035 Electrification Fleet Plan reflect the following underlying service assumptions. Service during 2020-2024 will focus on COVID recovery and ongoing integration with Link light rail expansions. Some service reduced because of Covid-19 impacts is anticipated to return in 2021. Service reductions are assumed in 2021 as the Seattle Community Mobility Contract (CMC) ends with the Seattle Transportation Benefit District (STBD) funding expiration. Further service reductions in Metro-funded service will occur between 2024 and 2026, driven by the structural deficit noted above. The Metro forecast assumes no service growth between 2027 and 2040 (i.e., service remains at the 2026 levels through 2040). The Madison RapidRide G-Line is implemented in 2023, requiring the purchase of 13 RapidRide diesel-hybrid buses. There is some continued investment in the Rapid Ride program (RR I and RRH) by converting existing routes to Rapid Ride and restructuring other services. In aggregate, all these assumptions result in a long-term bus fleet of 940 vehicles requiring electrification (excluding trolley buses).

**Description of 2021-2022 Executive Budget – 2040 Electrification Fleet Plan**

For Metro to reach zero-emission by 2040, it will require both trolley and BEB buses. Metro will purchase its last 13 RapidRide diesel-hybrid coaches in 2023 to support the RapidRide G line. In 2022, 40 BEBs will begin service from South Base Test Facility (purchased in the 2021-2022 budget biennium). Beginning in 2025, Metro will resume purchasing electric fleet with ten 40-foot BEBs, sixty-five 60-foot BEBs, and the first 30 RapidRide BEBs. Metro will continue to replace its diesel-hybrids with BEBs through 2040. In addition, Metro will grow its trolley fleet in Fall 2029, from 174 to 204, with the purchase of an additional thirty 60-foot trolleys.

Table 4 below summarizes anticipated BEB purchases. A full fleet plan for implementing a zero-emission fleet by 2040 can be found in Appendix A: 2040 Electrification Fleet Plan. Column AB in Appendix A shows that Metro is operating a 100 percent zero-emission trolley and BEB fleet by 2040. This is based on an assumption that Sound Transit will electrify its 80 Metro-operated buses in 2035. If Sound Transit chooses not to electrify, all Metro-owned buses will be zero-emissions by 2040.

*Table 4: BEB Purchase Rate for 2040 Electrification Fleet Plan*

| | Fall 2021 | Fall 2022 | Fall 2023 | Fall 2024 | Fall 2025 | Fall 2026 | Fall 2027 | Fall 2028 | Fall 2029 | Fall 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| **New BEB** | 0 | 40 | 0 | 0 | 105 | 0 | 0 | 155 | 30 | 147 |
| **Total BEB** | 11 | 51 | 51 | 51 | 156 | 156 | 156 | 311 | 341 | 488 |

| | Fall 2031 | Fall 2032 | Fall 2033 | Fall 2034 | Fall 2035 |
|---|---|---|---|---|---|
| **New BEB** | 52 | 165 | 60 | 0 | 98 |
| **Total BEB** | 540 | 705 | 765 | 765 | 863 |

| | Fall 2036 | Fall 2037 | Fall 2038 | Fall 2039 | Fall 2040 |
|---|---|---|---|---|---|
| **New BEB** | 5 | 19 | 38 | 15 | 0 |
| **Total BEB** | 868 | 887 | 925 | 940 | 940 |

*Table 5: Total Number of Zero-Emission Buses Operated by 2040*

| | |
|---|---|
| **Metro-owned BEBs** | 940 |
| **Metro-owned Trolleys** | 204 |
| **Metro operated Sound Transit Buses** | 80 |
| **Total zero-emission buses** | 1,224 |

**Description of 2021-2022 Executive Budget– 2035 Electrification Fleet Plan**

Similar to the 2040 electrification fleet plan, to reach zero-emission by 2035 Metro will continue to operate and upgrade its trolley fleet and stop purchasing diesel-hybrids after 2023. BEB purchases from 2025-2034 remain the same as the 2040 Electrification Fleet Plan. However, in 2035, Metro would purchase 177 BEBs to reach its zero-emission goal.

Table 6 below summarizes the purchases of BEBs under the 2035 fleet plan. A detailed fleet plan for 2035 zero-emissions can be found in Appendix B: 2035 Electrification Fleet Plan. Column AB in Appendix B shows that Metro is operating a 100 percent zero-emission fleet by 2035.

*Table 6: BEB Purchase Rate for 2035 Electrification Fleet Plan*

| | Fall 2021 | Fall 2022 | Fall 2023 | Fall 2024 | Fall 2025 | Fall 2026 | Fall 2027 | Fall 2028 | Fall 2029 | Fall 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| **New BEB** | 0 | 40 | 0 | 0 | 105 | 0 | 0 | 155 | 30 | 147 |
| **Total BEB** | 11 | 51 | 51 | 51 | 156 | 156 | 156 | 311 | 341 | 488 |

| | Fall 2031 | Fall 2032 | Fall 2033 | Fall 2034 | Fall 2035 |
|---|---|---|---|---|---|
| **New BEB** | 52 | 165 | 60 | 0 | 177 |
| **Total BEB** | 540 | 705 | 765 | 765 | 940 |

*Table 7: Total Number of Zero-Emission Buses Operated by 2035*

| | |
|---|---|
| **Metro-owned BEBs** | 940 |
| **Metro-owned Trolleys** | 204 |
| **Metro operated Sound Transit Buses** | 80 |
| **Total zero-emission buses** | 1,224 |

## 3. A high-level schedule through 2040 for the anticipated installation of charging infrastructure at new, existing and interim bases as well as in-route charging

**Recent Electrification Developments**

When Metro first purchased BEBs, the industry standard was short-range, fast-charging buses like the 11 Proterra buses currently servicing the Eastside. Use of the Proterra buses requires layover (i.e., on route), higher-powered chargers installed at Eastgate park-and-ride to ensure batteries have enough range to complete the service profile without returning to the base to charge (see Figure 4 below). If not properly managed through a CMS, higher-power charging at layover facilities will lead to unnecessarily high electrical bills.[7] The CMS collects data from chargers and batteries at a centralized location and can determine if certain charge locations are approaching electrical load limits that lead to fees from the utility. The software can automatically lower or stop power levels to buses that do not require charging (i.e., batteries with enough charge to complete assigned work) and prioritize buses that require the most charging.

Layover charging without CMS controls leads to buses charging in brief spurts all day and at times of peak electrical demand, like the evening, which could result in extra costs. Additionally, with small battery-pack buses, routes are limited. Smaller battery packs can only support charging on lower mileage routes and on routes where charging can be accommodated every 25 miles (i.e., routes would have to be adjusted to accommodate the range of small battery-packs, which hinders operational efficiency). Recently, transit agencies and bus OEMs have begun moving towards large battery-pack, slower-charging buses. These buses charge overnight at lower power, and the large battery packs allow for longer ranges. While on-base charging lowers electricity costs, the current battery packs do not have the range to support all service profiles without some midday charging.

[7] Jean-Baptiste Gallo, Ted Bloch-Rubin and Jasna Tomić, "Peak Demand Charges and Electric Transit Buses" (2014), https://calstart.org/wp-content/uploads/2018/10/Peak-Demand-Charges-and-Electric-Transit-Buses.pdf.

*Figure 4: Eastgate park-and-ride charging*

To mitigate this issue, North American transit agencies are moving towards a mixed approach to electrical infrastructure consisting of both on base charging as well as on route charging.[8] It is worth noting another change in technology that occurred since the 2017 Study. At that time, charging and fleet types were viewed as distinct, either slow or fast charge options. Now BEB battery types and charging have converged to allow for both charging options within the same bus. In general, the industry is moving to having most of the charging located on bases with low-power, overnight charging. However, for longer blocks of work, layover charging locations are available. At layover locations buses charge during regularly scheduled driver breaks. This approach does not keep batteries in a full state of charge, but provides enough energy to allow the batteries to complete blocks of work and return to base for most charging.

The decision regarding battery-pack sizing versus layover charging is a balance. The battery-pack must be large enough to support all blocks of work. However, an overly large battery is expensive and heavy. Batteries also deteriorate over time and lose range. By building layover charging infrastructure strategically throughout the County, operational efficiency will not be impacted as buses can charge as needed during scheduled layovers. However, battery packs must be large enough to support significant blocks of work, unlike the first 11 Proterras. This strategy also allows Metro to purchase the smallest battery packs needed to support these blocks of work, thereby reducing the cost and weight of the bus. An additional benefit to this approach is the resulting resiliency – if a charging location is unavailable,

[8] Metro's BEB Strategic Program Manager regularly meets with other transit agencies developing BEB programs and most are pursuing a strategy of base and on route/layover charging.

the layover sites provide alternate locations to charge the buses and, as batteries degrade and require more charging, the layover locations can be used more frequently to support the ranges these buses need to meet.

North American transit agencies have begun settling on civil infrastructure to support charging. Generally, large, North American transit agencies like Los Angeles Metro, New York City Metropolitan Transportation Authority, and the Chicago Transit Authority are designing charging infrastructure with an overhead bridge-like structure (gantry), like that at the Eastgate Park-and-ride. This system allows for either higher or lower powered charging and provides operational efficiency for bases because, unlike plug-in charging, there are no cords to manage. At layover locations, either a gantry or mast-style can be used.[9] Metro will be building overhead gantry charging infrastructure at its bases and layover locations to support BEBs. Section 4 below describes the study that led to this conclusion.


*Figure 5: Mast charging*

**Base Capacity Considerations**

When planning to upgrade or build a base, operational impact to the system needs to be considered as electrification infrastructure and charging activities may require reconfiguring space and other changes at bases. One way to measure this impact is to track Level of Service (LOS), which is a measurement of system-wide base capacity and, in the case of electrification, reflects charge capacity. Metro targets LOS C where there is an optimal balance between system capacity and demand. In the construction milestones found below in Figure 6 and Figure 7, LOS C (the green line) is compared to the fleet plan

[9] Metro's BEB Strategic Program Manager regularly meets with other transit agencies developing BEB programs and most are building overhead charging infrastructure.

(blue line). The fleet plan includes Sound Transit buses but excludes trolleys because trolleys do not require the same charging infrastructure. These two markers are what Metro's Capital Planning department uses to ensure that capital projects do not impact existing operations.

**Electrification Construction Milestones 2021-2022 Executive Budget Service – 2040 Electrification Fleet Plan**

The 2040 Electrification Fleet Plan construction milestones are shown in Figure 6 below. This plan provides the electrical infrastructure to support a fleet that is zero-emission by 2040. As shown below, Interim Base will be electrified in 2025 with charging capacity for 105 buses. South Annex base follows in 2027 with capacity to charge 155 buses. Under this plan, 62% of the capacity of SAB would be electrified in 2027. Based on forecasted 2040 system capacity, this level of electrification would be the peak required to support service. Should service demands increase and South Annex Base be forecast to exceed a fleet size of 155 BEBs, Metro would then need consider further electrification of the site. Beginning in 2030, with electrification of Atlantic and Central bases, Metro coverts bases every two years and concludes with South Base in 2040 for a total of 1,393 charging locations to support 940 Metro-owned BEBs and 80 Metro-operated Sound Transit BEBs. In addition, required layover (i.e., on route) charging will be built as bases electrify. The graphic below shows the system-wide charging infrastructure needs and demonstrates that Metro can build enough charging infrastructure to support the whole fleet. However, the timing of bringing electrical infrastructure on-line may not support operational needs, and Metro anticipates reassessing these infrastructure milestones as the agency further plans and deploys charging infrastructure.

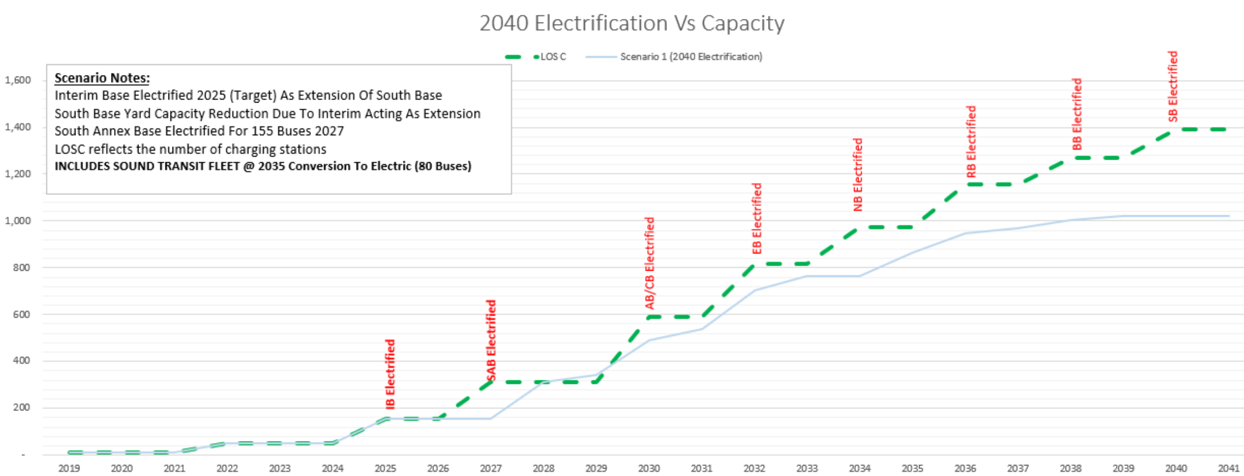


*Figure 6: Electrification construction milestones, 2040 Electrification Fleet Plan*

**Electrification Construction Milestones 2021-2022 Executive Budget Service – 2035 Electrification Fleet Plan**

To support full electrification by 2035, Interim Base is electrified by 2025, followed by South Annex Base in 2027. Those two bases along with the SBTF will have charging infrastructure to support 311 BEBs. This is followed by Atlantic and Central Base electrifying in 2029. Between 2031 and 2036, East Base, North Base and Ryerson Base and Bellevue Baseare converted. South Base completes electrification in 2037 for a total of 1,393 charging locations. Associated layover (i.e. on route) charging will be built throughout the County. This graphic is meant to demonstrate the amount of charging infrastructure required to support full electrification. However, this may not support Metro's operational needs and adjustments to this schedule are anticipated as infrastructure is planned and deployed in conjunction with operational requirements.

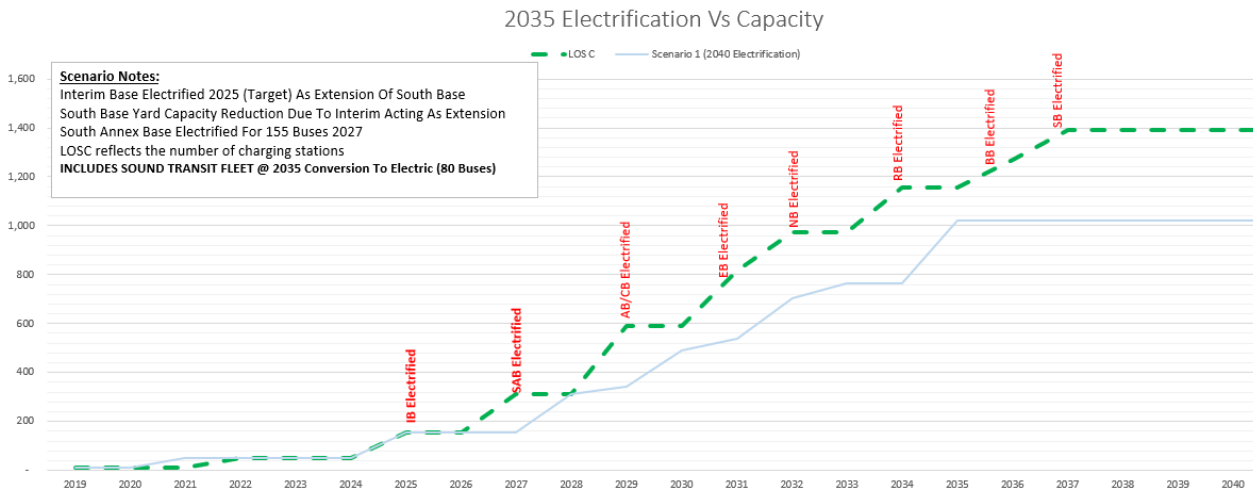


*Figure 7: Electrification construction milestones, 2035 Electrification Fleet Plan*

## 4. A summary of the results of any studies or evaluations related to zero-emission battery bus implementation completed after December 1, 2019, and a summary of the scope of any ongoing studies or evaluations

### *Electric Base Conceptual Design Study*

In 2019, Metro commissioned a study relating to electrification of a proposed 120 BEB base located at Interim Base. Though specific to Interim Base, the study's analysis regarding power levels, base layouts, IT, and charging infrastructure are applicable to all Metro bases. SBTF is not using this layout because the charging infrastructure occupies a small part of a larger base. Future electrification efforts at Metro will likely use Layout 2, described below, as a starting point for design.

The study modeled various charging profiles that would allow Metro to meet operational needs while minimizing energy costs. It was concluded that 7.5 megawatts of power supported service needs with minimal midday, higher-cost charging. Three types of civil charging infrastructure, including plug-in cables, T-Poles, and gantry/bridges, were analyzed (Layouts 1-3 described in Figure 9 below). Though the infrastructure costs for Layout 2 (gantry/bridge) are the most expensive, the alternatives analysis examined additional factors and led Metro to choose Layout 2 for its base design. Overall, Layout 2 scores high for site use/operational efficiency and power distribution complexity, two factors that were very important to Metro's operations. Layout 2 also allows each charger to charge multiple buses, maximizing charger efficiency. A chart summarizing these factors can be found at Table 8: Alternatives Analysis for Interim Base LayoutsTable 8 and detail about these factors can be found in Appendix E: Alternatives Analysis for Charging Infrastructure and Layout. A picture of Layout 2 is shown in Figure 8 below.

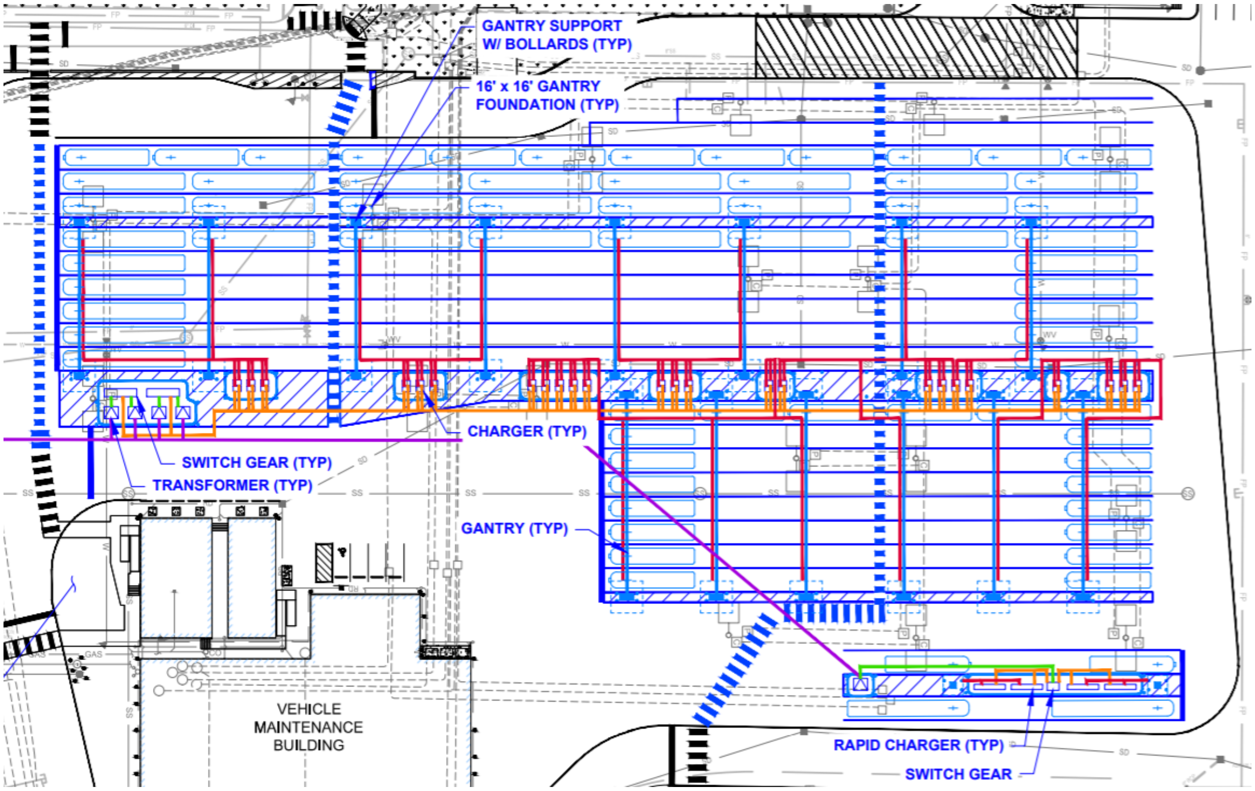


*Figure 8: Layout 2*

**Comparison of Physical Parameters for each Alternative Layout**

| Feature/Layout | Layout 1 (T-Poles and Pantographs) | Layout 1 (Plug-In Cable) | Layout 2 (Bridges and Pantographs) | Layout 3 (Bridges and Pantographs – Limited) |
|---|---|---|---|---|
| **Charging Positions** | 100 | 100 | 100 | 57 |
| **Chargers (base)** | 48 | 48 | 48 | 53 |
| **Chargers (rapid)** | 4 | 4 | 4 | 4 |
| **Total Parking Spaces** | 129 | 129 | 135 | 129 |
| **Estimated Additional FTE Labor Requirement** | 0 | 1 | 0 | 3 |
| **Concept Level Construction Cost** | $ 30.1 M | $ 20.2 M | $ 33.6 M | $ 28.3 M |
| **Concept Level 10-year Life Cycle Cost** | $ 21.3 M | $ 20.9 M | $ 21.3 M | $ 24.5 M |
| **Concept Level Total Cost** | $ 51.4 M | $ 41.1 M | $ 54.9 M | $ 52.8 M |

*Figure 9: Comparison of physical parameters for each alternative layout*

*Table 8: Alternatives Analysis for Interim Base Layouts*

| Alternative Analysis Factors | Layout 1 | Layout 1A | Layout 2 | Layout 3 |
|---|---|---|---|---|
| **Semi-formal Name** | T-poles | Plug-in | Bridge/Gantry | Ltd. Bridge/Gantry |
| **Site Use and Operational Efficiency** | 3.0 | 3.0 | 4.0 | 2.0 |
| **Power Distribution Complexity** | 2.0 | 2.0 | 4.0 | 3.0 |
| **Construction Risks** | 3.0 | 3.0 | 1.0 | 1.0 |
| **Site Disruption** | 2.0 | 2.0 | 3.3 | 3.7 |
| **Construction Schedule** | 3.0 | 3.0 | 3.0 | 4.0 |
| **Future Proofed** | 3.0 | 3.0 | 4.0 | 1.0 |
| **Decommissioning** | 1.0 | 1.0 | 3.0 | 4.0 |
| **Cost** | 2.5 | 3.0 | 2.5 | 2.5 |
| ***Total Score*** | **19.5** | **20** | **24.8** | **21.2** |

*Scores were from 1 to 4, with 4 being the highest*.

The study also concluded that CMS-developed software should be deployed at Metro bases. This software is necessary to minimize electrical usage and costs. See IT Planning in Section 1 above.

### *Key Performance Indicators from Leased Bus testing*

Metro tested 10 buses from three bus manufacturers over the last 18 months: two 40-foot and two 60-foot buses manufactured by New Flyer, two 40-foot and two 60-foot buses manufactured by BYD, and two 40-foot buses by Proterra (Proterra does not manufacture 60-foot buses). The Proterra and New Flyer buses were returned to the manufacturers in March 2020 after a year of testing. The BYD buses, which arrived later than the Proterra and New Flyer buses, concluded testing in July 2020.

Through June 2020, the buses were in service for over 7,000 hours and drove nearly 120,000 miles. The 40-foot buses averaged nearly 2 kWh/mile. The 60-foot buses averaged approximately 3 kWh/mile. The 60-footers, as expected, required more energy than the 40-footers. Additional Key Performance Indicator (KPI) data can be found in Appendix C: Key Performance Indicators.

The buses were driven in all types of weather, including snow, and on all route types from freeways to local service with hills – all factors that impact battery performance. The New Flyer and Proterra buses performed to expectations. The Proterra and New Flyer 40-foot buses met and exceeded range expectations in all weather and routes types, while the 60-footers met range expectations in most cases but did not perform as well in cold weather. However, because of the multi-axle configuration of the New Flyer 60-foot buses, they perform better in snow than 60-foot diesel-hybrid buses. The BYD buses met range expectations but did not perform well in the County's hilly topography. A change in the traction power motor is required for better performance on hills, but a change of this sort may impact battery range.

Generally, drivers were happy driving the BEBs. Operations and maintenance were given an opportunity to work with the charging infrastructure and buses to learn the new technology. The buses and infrastructure had various failures, but all were able to return to testing. This testing allowed Metro to provide feedback to New Flyer regarding the placement of battery packs in passenger compartments of 60-foot buses. Based on this feedback, New Flyer agreed to remove battery packs from the passenger compartments, and the purchased BEBs will have a different battery configuration than the leased test buses.

## 5. Updated cost projections comparing the cost of a zero-emission fleet and continuing Metro transit department's current fleet practice.

The 2017 Study provided an initial cost benefit analysis of transitioning to a zero-emission fleet using battery-electric technology. That study examined the capital, operating, disposal, and societal costs between a zero-emission fleet and a diesel-hybrid fleet. At the time, it was found that the total life-cycle costs to Metro would increase six percent by transitioning to a zero-emission fleet from a diesel-hybrid fleet.[10] The 2017 Study concluded the 194 million dollar difference, if spread over the lifetime of the bus fleet replacement horizon of approximately 30 years, was equivalent to 55,000 annual service hours.[11] When factoring in societal costs (tailpipe and utility emissions and noise) the 2017 study found the total incremental costs for BEBs to be two percent higher. With the 2017 Study, Metro committed to continued monitoring of the total costs for transitioning to a zero-emission fleet; this will ensure incremental costs do not limit Metro's ability to deliver and expand service.

Metro has updated this model based on the current cost of BEBs and associated electrical infrastructure. The analyzed fleets included: 35-foot, 40-foot, and 60-foot diesel-hybrid fleets and 35-foot, 40-foot, and 60-foot BEB fleets consistent with the fleet plans contained in Appendix F: Data Model Memo. The BEB fleet costs are based on the bus and infrastructure costs from Metro's 40 BEB order and the SBTF. The cost estimates for the SBTF have been validated with other agencies building overheard charging infrastructure. The attached memo in Appendix F: Data Model Memo includes detail about all data used for this model.

The analysis assumes fueling and charging infrastructure are amortized over the life of the infrastructure. Electrical infrastructure has an assumed asset life of 40 years, direct vehicle charging infrastructure has an assumed asset life equivalent to the vehicle life of 15 years, and diesel underground storage and pumps have an assumed asset life of 40 years. Additionally, the costing is based on maintaining the current diesel-hybrid fueling infrastructure compared to building new BEB charging infrastructure. The initial cost of designing and installing the supporting electrical infrastructure is included in the analysis while conventional fueling infrastructure is excluded from the analysis as storage tanks and pumps have already been installed at each of the bases and only future replacements to maintain these assets are assumed. Amortization assumes a set number of vehicles per base that does not change over the life of the asset. Cost per each BEB would include the total cost of electric infrastructure divided by the assumed number of vehicles per base, divided by the assumed 40 year life of the asset and applied each year for the 15 years the vehicle is operational. The 2017 Study assumed a single capital cost for each base divided by the number of vehicles per base in the year the vehicle was purchased.

[10] Metro, "2017 Study," 42.
[11] Metro, "2017 Study," 43.

Metro ran two scenarios: the moderate case and a favorable BEB case, where input variables were adjusted to favor BEBs. The diesel-hybrid was the control, or zero-value fleet, and the BEB was compared to the diesel-hybrid fleet. The moderate case modeled current data for both diesel-hybrid and BEBs. The favorable BEB modeled favorable capital, fueling, and operating pricing for BEBs compared to current data for diesel-hybrids. This favorable scenario assumes the costs for BEBs decrease over time as the technology develops.

In the favorable BEB case, a BEB fleet is more expensive than a diesel-hybrid fleet by six percent. When including societal costs like emission and noise reduction in the favorable scenario, a BEB fleet is one percent less expensive than a diesel-hybrid fleet. In the moderate case, where input variables were based on current data, the BEB buses and associated infrastructure are 53 percent more expensive than diesel-hybrid buses. The 660 million dollars that this percentage represents could purchase approximately 270,000 annual service hours over 19 years (2021-2040). When including societal benefits, the BEB buses are 42 percent more expensive than diesel hybrid buses. This cost delta, 574 million dollars, could purchase approximately 237,000 annual service hours over 19 years (2021-2040). See Table 9 below for a summary table and additional detail about both scenarios.

*Table 9: 2019–2040 Fleet Replacement Cost Comparison*

| 2019-2040 Fleet Replacement and Associated Infrastructure Cost Comparison between Diesel-Hybrid and BEBs (2019 $ million); assuming electrification by 2040 | | Favorable BEB | | Moderate Case | |
|---|---|---|---|---|---|
| | | BEB - Battery Electric Bus Replacement | Continuing Current Fleet Use of Hybrids | BEB - Battery Electric Bus Replacement | Continuing Current Fleet Use of Hybrids |
| **Capital** | Vehicle Purchase Price | $666 | $646 | $832 | $656 |
| | Modifications & Contingency | $35 | $33 | $36 | $33 |
| | Charging/Fueling Infrastructure | $131 | $10 | $163 | $12 |
| | *Total Capital Costs* | *$832* | *$689* | *$1,032* | *$701* |
| **Operating** | Vehicle Maintenance | $286 | $348 | $636 | $372 |
| | Vehicle Tires | $19 | $19 | $19 | $19 |
| | Vehicle Fuel/Charging Costs[12] | $104 | $172 | $88 | $132 |
| | Charging/Fueling Infrastructure | $1 | $0 | $2 | $0 |
| | Battery Replacement[13] | $32 | $3 | $80 | $6 |
| | *Total Operating Costs* | *$444* | *$541* | *$824* | *$529* |
| **Disposal** | Battery Disposal | $24 | $2 | $24 | $2 |
| | Bus Disposal | $28 | $24 | $36 | $24 |
| | *Total Disposal Costs* | *$53* | *$25* | *$60* | *$26* |
| **Total Cash Costs** | | **$1,328** | **$1,255** | **$1,916** | **$1,256** |
| ***Comparison to Base*** | *Dollars* | *$73* | *$0* | *$660* | *$0* |
| | *Percent* | *6%* | *-* | *53%* | *-* |
| **Total Cash Cost per Mile** | | **$2.25** | **$2.13** | **$3.25** | **$2.13** |
| **Environmental** | Emissions - Tailpipe | $11 | $82 | $11 | $82 |
| | Emissions - Refining/Utility | $1 | $12 | $1 | $12 |
| | Noise | $15 | $20 | $15 | $20 |
| | *Total Env. Costs* | *$27* | *$113* | *$27* | *$113* |
| **Total Cash and Non-Cash Costs** | | **$1,355** | **$1,368** | **$1,943** | **$1,369** |
| ***Comparison to Base*** | *Dollars* | *-$13* | *$0* | *$574* | *$0* |
| | *Percent* | *(1%)* | *-* | *42%* | *-* |
| **Total Cash and Non-Cash Costs per Mile** | | **$2.29** | **$2.32** | **$3.29** | **$2.32** |

BEB costs are driven by the price of the bus, the cost of electrical charging infrastructure, and overall maintenance fees. A BEB is more expensive to procure. The charging infrastructure requires a large capital outlay due to the civil and electrical engineering work required to support overhead charging. Currently, Metro is assuming that for the moderate case, BEBs are more expensive to maintain; however, there is much volatility in maintenance cost forecasts. Some reports show BEB maintenance costs to be significantly lower than diesel maintenance costs,[14] and there is a good chance that BEB maintenance costs will be lower than diesel-hybrid maintenance costs as the technology becomes more widely adopted and transit agencies become familiar with it. Additionally, battery replacement costs are higher for BEBs than for other bus fleets. In total, these higher costs for BEBs are not fully offset by the fact that electricity is cheaper than diesel or by the societal benefits of eliminating emissions and noise. The 2017 study significantly underestimated the cost of electrical charging infrastructure, assuming charging equipment that more resembles light-duty vehicles, whereas now the industry has moved to overhead gantry systems and more of a blend of slow and fast charging. Metro has better data for the 2020 update to the cost projection model and has higher confidence in the accuracy of the charging infrastructure costs, as they are based on contractor estimates for SBTF and these estimates are validated by other transit agencies, which are further in their construction projects of overhead charging than Metro is. Metro feels confident that the current modeling for the moderate scenario is an accurate estimate for the cost to procure, maintain, and operate a fully BEB fleet.

A June 2020 study produced by the National Renewable Energy Lab[15] found that BEBs, after three years of service, made up the difference in upfront costs between BEBs and diesels. According to this study, from the three-year point forward BEBs should be less expensive than diesel buses. The study attributed this to operating, maintenance, and energy costs which, during the first three years, were low enough to compensate for the up-front capital costs. Metro has concerns about the applicability of these findings to the agency for the following reasons:

1. The price of diesel in the study was much higher than Metro's current forecast and, unlike transit agencies that buy diesel wholesale, this model assumed retail prices for diesel. The difference between retail and wholesale prices can be as much as a dollar per gallon;[16]
2. The modelers assumed an annual decline in electricity charges, which is counter to what Metro has seen with Seattle City Light and Puget Sound Energy.

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[12] In these scenarios, the cost forecasts for fuel and electricity are tied together based on macro-level economic trends and assumptions on demand and supply for various energy products. The "favorable electric case" assumes overall higher energy cost escalation but significantly higher increases in crude/refined products (30%) compared to electricity (18%).

[13] For the forty BEBs beginning service in 2021, Metro is considering purchasing a 12 year extended warranty. Since exact battery life is still unknown, when modeling battery replacement cost Metro took a conservative approach and assumed 90% of batteries would need to be replaced after the 12 year warranty expired. With a 15 year bus lifecyle, this results in new batteries being on buses for three years when the bus carriage is retired. However, batteries can be reused on different bus carriages and Metro will explore this option.

[14] Caley Johnson, Erin Nobler, Leslie Eudy, and Matthew Jeffers, "Financial Analysis of Battery Electric Transit Buses" (Golden: National Renewable Energy Laboratory, 2020) https://www.nrel.gov/docs/fy20osti/74832.pdf.

[15] Caley Johnson, Erin Nobler, Leslie Eudy, and Matthew Jeffers "Financial Analysis of BEBs," 13-14.

[16] http://www.seattlegasprices.com/index.aspx?fuel=D versus https://des.wa.gov/services/contracting-purchasing/current-contracts/fuels-pricing

3. The BEB charging equipment cost was much lower than Metro estimates, which is likely related to modeling plug-in electrical infrastructure costs previously considered by Metro and found to be more costly in the long term (see Section 4); and
4. The authors included grant funding to lower the purchase cost of BEBs. Generally, grants should not be included in cost projections as they are an unreliable source of funding.

## 6. A preliminary high-level financing plan for transition to zero-emission bus fleet by 2040 that evaluates financing options.

**Policies Guiding Metro Finance Options**

Generally Metro uses cash financing and some grant funding for bus procurement and capital projects. These revenue options will be discussed below. Alternative capital financing structures include debt financing and leasing. Within each of these broad categories, there are numerous options discussed below. Metro's financing is guided by the following policies:

- **Motion 12660 (2007): Debt Management Policy for King County** describes the appropriate uses of debt (construction of acquisition of capital assets and not operations), the term of the debt, level debt payments, and states debt should be tax exempt. The policy states that refinancing shall be pursued when savings occur. The policy also covers the use of variable rate debt, general obligation and revenue debt, and credit enhancement.[17] Metro's use of debt would need to comply with this overarching Debt Management Policy.

- **Comprehensive Financial Management Policies (2018)** describe the appropriate uses of debt, the use of debt as an option for financing the acquisition and construction of the County's capital assets and that these assets should have a lifespan of at least seven years. The policies state that short-term needs can be financed by bond anticipation notes, or similar, while longer term debt should be tax-exempt municipal debt. The issuing agency should designate a fund manager to ensure the use of bond proceeds and compliance with the County's post-bond issuance procedures.

- **Ordinance 18321 (2016): Fund Management Policies for Public Transportation Fund** require Metro to create and prioritize a 10-year needs list and a 20-year fleet replacement funding methodology. These needs are reflected in the six-year CIP. A bond sub-fund is created, which has a balance, "sufficient to meet the obligations of the Transit Division's bond requirements." The requirements are addressed in the bond official statement and cover principal and interest balances. Short-term bond proceeds can be used to smooth peak fleet acquisition needs. This ordinance supersedes many elements of Ordinance 17225 (2011), an earlier set of fund management policies for the public transportation fund.

- **CIP Processes and Procedures (2017):[18] Bonding Guidance** is a 2017 document prepared by PSB and Finance. The document describes in detail the process by which debt issuances should be

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[17] The policy also describes the Counterparty Policy: although this policy was followed it still resulted in an ongoing loss in the Victoria investment.

[18] Link to Bonding Guidance

developed, issued, and managed from concept to retirement. It describes an extensive process between the department and PSB/Finance.

- **Written procedures for post-bond issuance compliance with Federal tax law (2019)** is currently under consideration by the Executive Finance Committee (EFC). The procedures provide detailed guidance on the management, record keeping, expenditure, and reporting requirements associated with debt issuance consistent with changes in federal tax law from the Tax Cuts and Jobs Act of 2017.

- **County Code 2.96.010** addresses leasing and requires that numerous conditions be met including that there are economic advantages to leasing, that it meets a temporary need, and shifts risk. Departments considering leasing must perform a lease versus purchase cost analysis and provide written explanation of why a lease is needed.

**Current Metro Financing Practices**

As noted above, Metro has historically financed fleet acquisitions from cash and grants. Debt financing has been used for property and physical assets. Debt could be used for rolling stock as well as BEB charging equipment, consistent with policies described above. Metro purchases approximately 100 buses per year using local and federal funds. However, bus needs are dependent on retirable fleet and service growth, so larger purchases may be followed by several years with no purchases.

Table 10 below notes that between 2013 and 2018, fleet capital expenditures ranged from 54 million dollars to over 254 million dollars. To date, there have been no major electrification infrastructure projects completed. The first, SBTF, will begin construction in Q4 2020.

*Table 10: Revenue Historic Fleet Capital Spending*

| Revenue Fleet Expenditures in Millions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| **Expenditures** | $119.88 | $54.23 | $67.22 | $122.35 | $233.22 | $132.07 | $254.51 | $109.84 |
| **Grants** | | | | | | $43.01 | $110.75 | $38.57 |

As part of this proviso response, a cash flow forecast for the various scenarios described in Section 5 has been prepared (see below). The annual expenditures for fleet purchases are summarized in Table 11 below.

*Table 11: Annual Expenditures for Fleet Purchases*

| 2019-2040 Fleet Replacement Cost Comparison (2019 $ million) | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Moderate Case BEB** | | | | | | | | | | | |
| **Capital (2019 $s)** | *$1.7* | *$1.7* | *$6.1* | *$7.1* | *$7.1* | *$18.9* | *$18.8* | *$18.7* | *$36.5* | *$39.4* | *$55.3* |
| **Operating (2019 $s)** | *$0.6* | *$0.8* | *$3.3* | *$4.0* | *$4.5* | *$10.9* | *$11.9* | *$13.4* | *$23.1* | *$26.8* | *$37.5* |
| **Disposal (2019 $s)** | *$0.1* | *$0.1* | *$0.3* | *$0.4* | *$0.4* | *$1.1* | *$1.1* | *$1.1* | *$2.1* | *$2.3* | *$3.3* |
| **Environmental (2019 $s)** | *$0.3* | *$0.3* | *$0.4* | *$0.5* | *$0.5* | *$0.8* | *$0.8* | *$0.8* | *$1.1* | *$1.2* | *$1.5* |
| **Moderate Case HYB** | | | | | | | | | | | |
| **Capital (2019 $s)** | *$1.7* | *$1.7* | *$6.1* | *$7.1* | *$7.1* | *$14.6* | *$14.6* | *$14.5* | *$25.8* | *$27.7* | *$37.7* |
| **Operating (2019 $s)** | *$0.6* | *$0.8* | *$3.3* | *$4.0* | *$4.5* | *$8.3* | *$9.5* | *$10.7* | *$16.9* | *$19.1* | *$25.7* |
| **Disposal (2019 $s)** | *$0.1* | *$0.1* | *$0.3* | *$0.4* | *$0.4* | *$0.6* | *$0.6* | *$0.6* | *$1.0* | *$1.1* | *$1.4* |
| **Environmental (2019 $s)** | *$0.3* | *$0.3* | *$0.4* | *$0.5* | *$0.5* | *$1.8* | *$1.8* | *$1.8* | *$3.7* | *$4.0* | *$5.8* |

*Table 11 continued*

| (2019 $ million) | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Moderate Case BEB** | | | | | | | | | | | |
| **Capital (2019 $s)** | *$59.8* | *$76.5* | *$81.9* | *$81.0* | *$89.0* | *$88.8* | *$87.1* | *$88.9* | *$88.8* | *$78.4* | *$1,031.6* |
| **Operating (2019 $s)** | *$41.7* | *$54.5* | *$63.4* | *$65.3* | *$73.6* | *$77.2* | *$78.7* | *$80.3* | *$79.9* | *$72.8* | *$824.3* |
| **Disposal (2019 $s)** | *$3.5* | *$4.5* | *$4.8* | *$4.7* | *$5.2* | *$5.2* | *$5.1* | *$5.2* | *$5.1* | *$4.5* | *$60.1* |
| **Environmental (2019 $s)** | *$1.6* | *$2.0* | *$2.1* | *$2.0* | *$2.0* | *$2.0* | *$1.9* | *$1.8* | *$1.8* | *$1.6* | *$27.0* |
| **Moderate Case HYB** | | | | | | | | | | | |
| **Capital (2019 $s)** | *$40.6* | *$51.5* | *$55.0* | *$54.4* | *$59.1* | *$59.1* | *$56.6* | *$57.6* | *$57.6* | *$51.0* | *$701.3* |
| **Operating (2019 $s)** | *$28.4* | *$35.3* | *$40.9* | *$41.6* | *$45.8* | *$47.8* | *$46.9* | *$49.0* | *$47.2* | *$42.9* | *$529.2* |
| **Disposal (2019 $s)** | *$1.5* | *$1.9* | *$2.0* | *$2.0* | *$2.1* | *$2.1* | *$1.9* | *$2.0* | *$2.0* | *$1.7* | *$25.6* |
| **Environmental (2019 $s)** | *$6.4* | *$8.3* | *$9.0* | *$8.9* | *$9.9* | *$9.9* | *$10.1* | *$10.2* | *$10.2* | *$9.1* | *$113.0* |

*Table 12: Cost Differential between BEB and Diesel-Hybrids*

| Total Costs (2019 $) ($ Million) | Moderate Case BEB | Moderate Case Diesel Hybrid | Difference |
|---|---|---|---|
| **Capital** | $1,032 | $701 | $331 |
| **Operating** | $824 | $529 | $295 |
| **Disposal** | $60 | $26 | $34 |
| **Environmental** | $27 | $113 | ($86) |
| **Total** | $1943 | $1369 | $574 |

The pending executive budget proposal provides a financing plan for an additional 260 BEBs and associated infrastructure by 2028 but does not address BEB and associated infrastructure in the out years. This proviso response does not develop a specific financing plan, as that will be developed in the context of future budget processes. However, financing these projects will require new revenue and various financing methods that Metro could use are described below. Historically, Metro has paid for buses using cash and, per current practice, utilizes the revenue fleet replacement reserve for years where large fleet expenditures are incurred. The revenue fleet replacement reserve was developed to help mitigate the impact of variability in the replacement costs from year to year. Metro prefers to finance long-life infrastructure using debt. The exact mix of cash funding, reserve use and debt financing will be developed based on Metro's financial condition and other economic considerations.

**Financing Methods**

There are four general financing models that public agencies can use to fund capital infrastructure like electrification. These are cash financing, which is Metro's current model; debt financing where Metro sells bonds to fund electrification; leasing buses and charging infrastructure from bus manufacturers; or grant funding, which Metro uses for bus procurement. There are also private partnerships which are not included in these models.

Table 13 below summarizes the benefits and risks of each method of financing.

*Table 13: Benefits and Risks of Financing Methods*

| | Benefits | Risks |
|---|---|---|
| **Cash Financing** | • Lowest cost since it doesn't incur interest or leasing costs<br>• Consistent with existing practice | • Requires large up-front capital expenditures<br>• Doesn't match expenditures with beneficiaries (Intergenerational equity) |
| **Debt Financing** | • Debt financing costs currently low<br>• Future users pay for capital costs<br>• Can use "Green Bonds"<br>• TIFIA funding provides guaranteed rates prior to project construction at favorable terms | • Incurs long-term obligations, which if large, impair Metro's financial flexibility<br>• Some types of debt require complex reporting requirements<br>• Higher overall cost because of interest costs |

| | | |
|---|---|---|
| **Leasing** | • Lifespan and price risks are transferred to vendor<br>• Maintenance costs paid by lessor<br>• Lessor may gain tax advantages which are passed on to Metro<br>• Metro doesn't maintain batteries, vehicles, or charging infrastructure<br>• Leases may be faster to execute<br>• Leases can be for less than the full lifespan | • Market prices for batteries may be lower than in a lease<br>• Metro pays higher private cost of capital<br>• Potential labor contract issues with outside maintenance |
| **Private Partnership** | • Private equity may provide financing under beneficial terms | • Requires significant expertise to evaluate transaction |
| **Grant Funding** | • Provides low cost funding | • Highly competitive, limited sources<br>• Can restrict uses |

Within each of these broad categories, tax exempt and taxable debt, and/or grants and other funding sources are often used for transportation purposes. These are described in Table 14 and Table 15 below.

*Table 14: Tax Exempt and Taxable Debt Funding Sources*

| **Tax exempt and Taxable Debt** | |
|---|---|
| | • Metro and King County have excellent access to credit due to their high credit ranking. Metro has issued debt for some assets<br>• Taxable debt is generally discouraged by policy and has not been pursued. Depending on the type of asset there may be situations where this is preferred. Wastewater frequently issues both short and long-term debt |
| **Commercial paper or bank debt** | • Short term debt from commercial sources could be used.<br>• Other agencies in the County have used short-term debt |
| **TIFIA loans** | • These loans provide low interest rates and guaranteed rates prior to expenditures.<br>• Sound Transit and many other transportation agencies have used this source |
| **Green Bonds** | • These bonds have appealed to purchasers due to their linkage with environmentally friendly projects.<br>• Sound Transit has issued these bonds at favorable rates |
| **Private Activity Bonds** | • These bonds provide municipal rates to private borrowers.<br>• Metro is not aware of US funded electrification projects using this source |
| **Private equity** | • Transit Oriented Development projects have used private equity to finance joint development.<br>• Metro is not aware of US funded electrification projects using this source |

*Table 15: Grants and Other Funding Sources*

| Grants and Other Funding Sources | |
|---|---|
| **Grants** | • Numerous federal, state, and private sources exist for funding electrification. Metro has successfully used these sources in the past (like Federal Transit Administration's Low or No Emission Vehicle Program) |
| **Value capture mechanisms such as Local Improvement District (LID) and Tax increment Financing (TIF)** | • LID/TIF financing has been used for several local projects, such as the Alaskan Way Viaduct and the Seattle Streetcar. These projects must determine the benefits which accrue to property owners and the assessments must be related to those benefits. These types of mechanisms have been used with fixed guideway systems, but Metro is not aware of bus related US projects |
| **Naming Rights** | • Many local projects have used naming rights, such as the stadiums and in transportation, the Pronto bikes funded by Alaska Airlines (and others). Metro sells advertising on buses |
| **Pass pricing for green programs** | • Metro could consider the sale of carbon offsets similar to that done by ski resorts or some airlines |

# V. Conclusion/Next Steps

Supporting zero-emission transit is integral to the County's SCAP and ESJ goals. Transportation is a significant driver of GHG emissions throughout the County, and Metro is one of the largest contributors to GHG emissions in County government. Additionally, the impacts of these pollutants disproportionately impact historically marginalized populations. Moving to zero-emission fleets will be costly and take time, but this is at the core of the County's values.

The COVID budgetary climate has impacted the agency's finances, Metro has included investments in the six-year capital improvement plan that would support the implementation of an additional 220 BEB (in addition to the 40 BEBs within the 2021-2022 biennium by 2028. The capital program also includes a number of projects that support ongoing planning efforts to advance electrification of the fleet and implementation of associated charging infrastructure. This will continue Metro down the path to becoming a zero-emission bus fleet by 2040. Under Metro's proposed fleet plan (2021-2022 Executive Budget Service – 2040 Electrification Fleet Plan) Metro's last purchase of diesel-hybrids is in 2023 and, beginning in 2025 ,only zero-emission fleet (either trolly buses or BEBs) are procured. All Metro-owned vehicles will be zero-emission by 2040. Electrical infrastructure begin as South Campus, located in Tukwila, with electrification of Interim Base and South Annex Base. Base electrification continues throughout the County to support a zero-emission fleet and is completed by 2040. With current commitments and current resources, the CIP Plan is recommended to move electrification forward and allows Metro meet its SCAP and emissions goals.

Metro is a leader in transit and adopting BEBs is a value statement demonstrating the agency and the County's commitment to the one of the most pressing issues of this generation: the reduction or elimination of tailpipe greenhouse gas and air pollution emissions providing both environmental and health benefits to the population, particularly historically, underserved populations. BEBs and their supporting infrastructure cost more than diesel-hybrids. Nearly two decades ago, transit agencies supported diesel-hybrids as a bridge technology that would allow for the maturation of BEB technologies. King County Metro was a leader in adopting this technology and currently operates one of the largest hybrid fleets in North America. At this time, hybrid buses, while still more expensive than diesels, are just as reliable diesels and provide reductions in emissions.

BEBs are now reaching their prime as evidenced by larger scaling efforts in New York City, Chicago, Los Angeles, Toronto, Edmonton, and other North American agencies. They have reached deeper market penetrations in Europe, South America and China, where there are thousands. This should result in procurement costs beginning to lower in the near term.[19]

The transition of Metro's non-bus revenue fleets is an important component of achieving the County's SCAP goals. Metro continues to consider opportunities to electrify balanced with a pace that is affordable given Metro financially constrained reality and that is in step with the industry. The Access vehicles are an emerging market that continues to develop. There is currently only one ADA compliant paratransit vehicle that has passed federal testing. However, Metro continues to monitor the market and explore opportunities to pilot vehicles. Metro could potentially pilot vehicles that are not federally tested to continue to assess available technology and push the industry. It would take further consideration however about whether it would be appropriate for system-wide use of a vehicle that was

[19] https://www.sustainable-bus.com/electric-bus/electric-bus-public-transport-main-fleets-projects-around-world/

not Altoona tested. The electric Access vehicle options are costly and there is a large capital cost to installing charging infrastructure. Metro needs to continue to evaluate the best locations to install this charging infrastructure and the property ownership (lease versus owning) model that supports such large capital investments.

Metro is actively working towards a zero-emission future. Metro will move forward in a way that balances its current fiscal reality with its desire to meet its SCAP and ESJ goals to make King County a more equitable place for all its citizens. The agency has taken it first step by ordering 40 BEBs which begin service in early 2022 from South Base Test Facility in Tukwila. Additionally, in its proposed 2021-2022 budget, Metro plans to support 260 BEBs by 2028. While additional resources will be needed to reach the zero-emission goal, Metro will continue to work towards a zero-emission future.

## VI. Appendices

***King County Metro Transit***
***Future Fleet Planning***



**Color Key**
- **OLDEST -** Retirable Fleet
- **CURRENT -** Fleet under FTA requirement
- **COMMITTED -** Planned/Incoming Purchases
- **PROJECTED -** Uncommitted Future Purchases

**Major Fleet Assumptions:**
* 20% Spare Ratio as ongoing target
* 55% Artic Target
* Seattle CMC Svc/Fleet ends in 2020/21
* Madison/G Line, 13 hybrid coaches, 2023
* 20 60' & 20 40' Extended Range Battery Buses in 2022
* RapidRide Program Continues to grow and adds 40' Fleet
* The fleet is very old in '24 in anticipation of major reductions in '25-'26
* NO Service Growth 2027-2040
* 30 new 60' Trolley Coaches in '29
* All Procurements in 2025 or later are ZEV (Battery & Trolley)
* 60 35' Battery Bus replace 35' Hybrid Fleet in '30-'31 (North, Bellevue, South)
* 100% ZEV in 2040

| | Fleet Name | Fleet # | Fall 2019 | Spr 2020 | Fall 2020 | Spr 2021 | Fall 2021 | Spr 2022 | Fall 2022 | Fall 2023 | Fall 2024 | Fall 2025 | Fall 2026 | Fall 2027 | Fall 2028 | Fall 2029 | Fall 2030 | Fall 2031 | Fall 2032 | Fall 2033 | Fall 2034 | Fall 2035 | Fall 2036 | Fall 2037 | Fall 2038 | Fall 2039 | Fall 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Small (<40') Fleet | 30' Diesel Gillig | 1100 | 4 | 4 | - | | | | | | | | | | | | | | | | | | | | | | |
| | 35' Hybrid New Flyer | 3700 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 30 | - | | | | | | | | | |
| | 40' Diesel New Flyer | 3600 | 31 | - | | | | | | | | | | | | | | | | | | | | | | | |
| | 40' Hybrid Daimler-Orion | 7000 | 199 | 199 | 199 | 199 | 199 | 199 | 199 | 199 | 179 | 50 | 20 | 20 | - | | | | | | | | | | | | |
| | 40' Hybrid New Flyer | 7200 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 41 | 26 | 21 | 20 | - | | | | | | | | |
| | 40' Hybrid Gillig | 7300 | 177 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 134 | 103 | 103 | 47 | 42 | 38 | - | | |
| Artic (60') Hybrid Fleet | 60' Hybrid New Flyer | 2600 | 188 | 158 | 7 | 7 | 7 | 7 | - | | | | | | | | | | | | | | | | | | |
| | 60' Hybrid New Flyer | 6800 | 187 | 187 | 187 | 187 | 187 | 187 | 154 | 146 | 146 | 35 | 17 | 17 | - | | | | | | | | | | | | |
| | 60' Hybrid New Flyer (ODOT) | 8000 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 72 | 35 | 8 | - | | | | | | | | | |
| | 60' Hybrid New Flyer (WSDOT, 2 Door) | 8100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 15 | 5 | - | | | | | | | | |
| | 60' Hybrid New Flyer (WSDOT, 3 Door) | 8200 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 21 | 17 | 17 | - | | | | | |
| Electric Fleet (Trolley & Battery) | 40' Proterra Fast Charge (2016) | 4600 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 8 | 5 | | | | | | | | | |
| | 40' Trolley New Flyer | 4300 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | - | | | | | | | | |
| | 60' Trolley New Flyer | 4500 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | - | | | | | | | | |
| | 60' Battery | 4800 | | | | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 14 | 13 | 4 | 1 | 1 | - |
| | 40' Battery | 4900 | | | | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 19 | 15 | 14 | 12 | 7 | - |
| | 60' Future Trolley | 100 | | | | | | | | | | | | | | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 40' Future Battery | 1000 | | | | | | | | | | 10 | 10 | 10 | 45 | 45 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 36 | 36 | 10 |
| | 60' Future Battery | 5000 | | | | | | | | | | 65 | 65 | 65 | 95 | 95 | 200 | 200 | 200 | 200 | 200 | 200 | 185 | 174 | 151 | 115 | 105 |
| | 35' Future Battery | 1200 | | | | | | | | | | | | | | | 30 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| | 60' Future Battery | 5200 | | | | | | | | | | | | | | | | | 80 | 90 | 90 | 125 | 140 | 140 | 165 | 185 | 185 |
| | 40' Future Battery | 1300 | | | | | | | | | | | | | | | | | 90 | 90 | 90 | 110 | 120 | 120 | 180 | 180 | 200 |
| BRT/RapidRide Hybrid or | 40' RapidRide Battery Replacement+Growth | 6500 | | | | | | | | | | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 24 | - |
| | 60' RapidRide Battery Replacement+Growth | 6600 | | | | | | | | | | | | | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 87 | - |
| | 60' RapidRide Battery Replacement + Growth | 6700 | | | | | | | | | | | | | | 10 | 15 | 40 | 40 | 65 | 65 | 80 | 80 | 115 | 115 | 145 | 250 |
| | 40' RapidRide Battery Replacement + Growth | 6800 | | | | | | | | | | | | | | 20 | 20 | 20 | 20 | 45 | 45 | 80 | 80 | 85 | 85 | 100 | 130 |
| | **METRO TOTAL FOR 2017/2018 BUDGET** | | **1,552** | **1,516** | **1,361** | **1,361** | **1,361** | **1,361** | **1,361** | **1,366** | **1,346** | **1,211** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** |
| Sound Transit | 40' Sound Transit LF | 90/91 | 5 | 5 | 3 | 3 | 3 | 3 | 3 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 40' Hybrid Sound Transit LF | 9200 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 60' Diesel Sound Transit LF | 9500 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 31 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| | 60' Hybrid Sound Transit LF | 9600 | 60 | 60 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 |
| | **ST TOTAL** | | **119** | **119** | **125** | **125** | **125** | **125** | **125** | **100** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** |
| | **ST Peak Signout** | | 100 | 100 | 105 | 105 | 105 | 105 | 105 | 84 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 |
| | **TOTAL METRO OPERATED** | | **1,671** | **1,635** | **1,486** | **1,486** | **1,486** | **1,486** | **1,486** | **1,466** | **1,426** | **1,291** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** |
| | **Metro Peak Signout** | | 1,231 | 1,228 | 1,000 | 1,080 | 1,135 | 1,135 | 1,135 | 1,139 | 1,122 | 1,009 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 |
| | **Metro Spare Ratio** | | 26.1% | 23.5% | 36.1% | 26.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
| | **Metro Artic Ratio** | | 58% | 58% | 53% | 53% | 53% | 53% | 52% | 52% | 53% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% |
| | **Metro Retireable Fleet Ratio** | | 14% | 11% | 1% | 1% | 14% | 14% | 24% | 23% | 33% | 16% | 17% | 18% | 20% | 15% | 16% | 15% | 19% | 14% | 14% | 10% | 9% | 9% | 13% | 10% | 0% |
| | **% Electric (Battery + Trolley)** | | 12% | 12% | 14% | 14% | 14% | 14% | 17% | 16% | 17% | 25% | 26% | 26% | 32% | 37% | 50% | 55% | 69% | 74% | 74% | 83% | 83% | 85% | 88% | 90% | 100% |
| | **Battery Buses** | | 11 | 11 | 11 | 11 | 11 | 11 | 51 | 51 | 51 | 156 | 156 | 156 | 311 | 341 | 488 | 540 | 705 | 765 | 765 | 863 | 868 | 887 | 925 | 940 | 940 |

*King County Metro Transit*
*Future Fleet Planning*

**Appendix B: 2035 Electrification Fleet Plan**

**Color Key**
- **OLDEST -** Retirable Fleet
- **CURRENT -** Fleet under FTA requirement
- **COMMITTED -** Planned/Incoming Purchases
- **PROJECTED -** Uncommitted Future Purchases

**Major Fleet Assumptions:**
* 20% Spare Ratio as ongoing target
* 55% Artic Target
* Seattle CMC Svc/Fleet ends in 2020/21
* Madison/G Line, 13 hybrid coaches, 2023
* 20 60' & 20 40' Extended Range Battery Buses in 2022
* RapidRide Program Continues to grow and adds 40' Fleet
* The fleet is very old in '24 in anticipation of major reductions in '25-'26
* NO Service Growth 2027-2040
* 30 new 60' Trolley Coaches in '29
* **All Procurements in 2025 or later are ZEV (Battery & Trolley)**
* 60 35' Battery Bus replace 35' Hybrid Fleet in '30-'31 (North, Bellevue, South)
* **100% ZEV in 2035**

| | Fleet Name | Fleet # | Fall 2019 | Spr 2020 | Fall 2020 | Spr 2021 | Fall 2021 | Spr 2022 | Fall 2022 | Fall 2023 | Fall 2024 | Fall 2025 | Fall 2026 | Fall 2027 | Fall 2028 | Fall 2029 | Fall 2030 | Fall 2031 | Fall 2032 | Fall 2033 | Fall 2034 | Fall 2035 | Fall 2036 | Fall 2037 | Fall 2038 | Fall 2039 | Fall 2040 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Small (<40') Fleet | 30' Diesel Gillig | 1100 | 4 | 4 | - | | | | | | | | | | | | | | | | | | | | | | |
| | 35' Hybrid New Flyer | 3700 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 30 | - | | | | | | | | | |
| | 40' Diesel New Flyer | 3600 | 31 | - | | | | | | | | | | | | | | | | | | | | | | | |
| | 40' Hybrid Daimler-Orion | 7000 | 199 | 199 | 199 | 199 | 199 | 199 | 199 | 199 | 179 | 50 | 20 | 20 | - | | | | | | | | | | | | |
| | 40' Hybrid New Flyer | 7200 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 41 | 26 | 21 | 20 | - | | | | | | | | |
| | 40' Hybrid Gillig | 7300 | 177 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 195 | 134 | 103 | 103 | - | | | | | |
| Artic (60') Hybrid Fleet | 60' Hybrid New Flyer | 2600 | 188 | 158 | 7 | 7 | 7 | 7 | - | | | | | | | | | | | | | | | | | | |
| | 60' Hybrid New Flyer | 6800 | 187 | 187 | 187 | 187 | 187 | 187 | 154 | 146 | 146 | 35 | 17 | 17 | - | | | | | | | | | | | | |
| | 60' Hybrid New Flyer (ODOT) | 8000 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 72 | 35 | 8 | - | | | | | | | | | |
| | 60' Hybrid New Flyer (WSDOT, 2 Door) | 8100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 15 | 5 | - | | | | | | | | |
| | 60' Hybrid New Flyer (WSDOT, 3 Door) | 8200 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 21 | 17 | 17 | - | | | | | |
| Electric Fleet (Trolley & Battery) | 40' Proterra Fast Charge (2016) | 4600 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 8 | 5 | - | | | | | | | | |
| | 40' Trolley New Flyer | 4300 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | - | | | | | | | | |
| | 60' Trolley New Flyer | 4500 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | - | | | | | | | | |
| | 60' Battery | 4800 | | | | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 19 | 15 | 10 | 5 | 5 |
| | 40' Battery | 4900 | | | | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 16 | 11 | 9 | 4 | 1 |
| | 60' Future Trolley | 100 | | | | | | | | | | | | | | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 40' Future Battery | 1000 | | | | | | | | | | 10 | 10 | 10 | 45 | 45 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 5 | 5 | - |
| | 60' Future Battery | 5000 | | | | | | | | | | 65 | 65 | 65 | 95 | 95 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 184 | 166 | 140 | 124 |
| | 35' Future Battery | 1200 | | | | | | | | | | | | | | | 30 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| | 60' Future Battery | 5200 | | | | | | | | | | | | | | | | | 80 | 90 | 90 | 120 | 120 | 120 | 135 | 150 | 150 |
| | 40' Future Battery | 1300 | | | | | | | | | | | | | | | | | 90 | 90 | 90 | 155 | 160 | 160 | 220 | 220 | 220 |
| | 40' Future Trolley | 200 | | | | | | | | | | | | | | | | | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 |
| | 60' Future Trolley | 400 | | | | | | | | | | | | | | | | | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| BRT/RapidRide Hybrid or Battery | 60' RapidRide (2010-2014) | 6000 | 113 | 113 | 113 | 113 | 113 | 113 | 113 | 113 | 113 | 113 | 94 | 94 | 8 | - | | | | | | | | | | | |
| | 60' RapidRide (2016) | 6200 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 39 | 39 | 14 | 14 | - | | | | | |
| | 60' Hybrid (RapidRide Ready) (2018) | 620+ | 21 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | - | | | | | |
| | 60' RapidRide 5-Door Hybrid (Madison BRT) | 6400 | | | | | | | | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | - | | | | | |
| | 40' RapidRide Battery Replacement+Growth | 6500 | | | | | | | | | | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 21 | - |
| | 60' RapidRide Battery Replacement+Growth | 6600 | | | | | | | | | | | | | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | - |
| | 60' RapidRide Battery Replacement + Growth | 6700 | | | | | | | | | | | | | | 10 | 15 | 40 | 40 | 65 | 65 | 110 | 110 | 130 | 130 | 145 | 260 |
| | 40' RapidRide Battery Replacement + Growth | 6800 | | | | | | | | | | | | | | 20 | 20 | 20 | 20 | 45 | 45 | 80 | 80 | 85 | 85 | 100 | 120 |
| | **METRO TOTAL FOR 2017/2018 BUDGET** | | **1,552** | **1,516** | **1,361** | **1,361** | **1,361** | **1,361** | **1,361** | **1,366** | **1,346** | **1,211** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** | **1,144** |
| Sound Transit | 40' Sound Transit LF | 90/91 | 5 | 5 | 3 | 3 | 3 | 3 | 3 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 40' Hybrid Sound Transit LF | 9200 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 60' Diesel Sound Transit LF | 9500 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 31 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| | 60' Hybrid Sound Transit LF | 9600 | 60 | 60 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 |
| | | **ST TOTAL** | **119** | **119** | **125** | **125** | **125** | **125** | **125** | **100** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** | **80** |
| | | **ST Peak Signout** | 100 | 100 | 105 | 105 | 105 | 105 | 105 | 84 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 |
| | | **TOTAL METRO OPERATED** | **1,671** | **1,635** | **1,486** | **1,486** | **1,486** | **1,486** | **1,486** | **1,466** | **1,426** | **1,291** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** | **1,224** |
| | | **Metro Peak Signout** | 1,231 | 1,228 | 1,000 | 1,080 | 1,135 | 1,135 | 1,135 | 1,139 | 1,122 | 1,009 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 | 953 |
| | | **Metro Spare Ratio** | 26.1% | 23.5% | 36.1% | 26.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
| | | **Metro Artic Ratio** | 58% | 58% | 53% | 53% | 53% | 53% | 52% | 52% | 53% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% | 55% |
| | | **Metro Retireable Fleet Ratio** | 14% | 11% | 1% | 1% | 14% | 14% | 24% | 23% | 33% | 16% | 17% | 18% | 20% | 15% | 16% | 15% | 19% | 14% | 14% | 3% | 3% | 21% | 27% | 23% | 11% |
| | | **% Electric (Battery + Trolley)** | 12% | 12% | 14% | 14% | 14% | 14% | 17% | 16% | 17% | 27% | 29% | 29% | 42% | 48% | 60% | 65% | 79% | 85% | 85% | 100% | 100% | 100% | 100% | 100% | 100% |
| | | **Battery Buses** | 11 | 11 | 11 | 11 | 11 | 11 | 51 | 51 | 51 | 156 | 156 | 156 | 311 | 341 | 488 | 540 | 705 | 765 | 765 | 940 | 940 | 940 | 940 | 940 | 940 |

King County Metro Zero-Emissions Fleet

**Battery Electric Bus Leased Testing KPIs**

**From:** 9/23/2019
**To:** 6/20/2020

| | Bus # 1750 | Bus # 1751 | Bus # 1752 | Bus # 1753 | Bus # 1754 | Bus # 1755 | Bus # 1756 | Bus # 1757 | Bus # 1758 | Bus # 1759 | New Flyer | BYD | Proterra | Total Program |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Miles | 948.10 | 7,958.10 | 12,815.99 | 12,281.48 | 10,556.37 | 9,683.28 | 8,887.79 | 7,785.36 | 3,393.10 | 617.70 | 45,337.12 | 20,683.95 | 8,906.20 | **74,927.27** |
| Hours | 67.98 | 428.84 | 770.06 | 608.60 | 544.16 | 475.95 | 680.58 | 630.34 | 323.22 | 40.35 | 2,398.77 | 1,674.49 | 496.82 | **4,570.08** |
| kWh | 1,812.70 | 14,311.75 | 27,050.85 | 24,822.53 | 31,529.96 | 26,878.98 | 17,988.69 | 15,490.14 | 8,324.47 | 1,412.10 | 110,282.32 | 43,215.40 | 16,124.45 | **169,622.17** |
| kWh/mile | 1.91 | 1.80 | 2.11 | 2.02 | 2.99 | 2.78 | 2.02 | 1.99 | 2.45 | 2.29 | 2.43 | 2.09 | 1.81 | **2.26** |
| kWh/hr | 26.67 | 33.37 | 35.13 | 40.79 | 57.94 | 56.47 | 26.43 | 24.57 | 25.75 | 35.00 | 45.97 | 25.81 | 32.46 | **37.12** |
| In Service | 94 | 119 | 170 | 172 | 142 | 102 | 145 | 141 | 73 | 21 | 586 | 380 | 213 | **1,179** |
| OOS | 178 | 153 | 102 | 100 | 130 | 170 | 1 | 5 | 73 | 125 | 502 | 204 | 331 | **1,037** |
| Total days | 272 | 272 | 272 | 272 | 272 | 272 | 146 | 146 | 146 | 146 | 1,088 | 584 | 544 | **2,216** |
| Availability (%) | 35% | 44% | 63% | 63% | 52% | 38% | 99% | 97% | 50% | 14% | 54% | 65% | 39% | **53%** |
| Utilization (%) | 66% | 71% | 88% | 76% | 56% | 53% | 86% | 32% | 0% | 19% | 69% | 40% | 69% | **59%** |
| Failures | 5 | 7 | 2 | 1 | 2 | 2 | 1 | 2 | 4 | 3 | 7 | 10 | 12 | **29** |
| MDBF | 189.62 | 1,136.87 | 6,408.00 | 12,281.48 | 5,278.19 | 4,841.64 | 8,887.79 | 3,892.68 | 848.28 | 205.90 | 6,477 | 2,068 | 742 | **2,584** |
| OEM | Proterra | Proterra | New Flyer | New Flyer | New Flyer | New Flyer | BYD | BYD | BYD | BYD | | | | |
| Length | 40' | 40' | 40' | 40' | 60' | 60' | 40' | 40' | 60' | 60' | | | | |
| Passenger/Shadow | Shadow | Passenger | Passenger | Shadow | Shadow | Passenger | Shadow | Passenger | Passenger | Shadow | | | | |
| ViriCiti Installed | No | Yes | Yes | Yes | No | Yes | No | Yes | Yes | No | | | | |

| Buses accepted by Metro | **10** | **pax svce** | in svce date | in pax date | end pax date |
|---|---|---|---|---|---|
| New Flyer 40' | 2 | **1** | 1/11/2019 | 9/23/2019 | 3/20/2020 |
| New Flyer 60' | 2 | **1** | 1/10/2019 | 9/23/2019 | 3/20/2020 |
| BYD 40' | 2 | **1** | 8/6/2019 | 1/27/2020 | TBD |
| BYD 60' | 2 | **0** | 8/6/2019 | 3/11/2020 | TBD |
| Proterra 40' | 2 | **1** | 12/20/2018 | 9/23/2019 | 3/20/2020 |

## Appendix D: Overview of BEB Technology

**Battery-Electric Bus Technology Description**

This section was prepared by the Center for Transportation and the Environment[20] and reflects industry-wide concepts that are applicable to other transit agencies as well as King County Metro.

Battery-electric buses use energy stored in an on-board battery pack to drive an electric motor (or motors) which turns the drivetrain and propels the bus. In addition to the energy provided for propulsion, the battery system provides energy to drive electric accessories, such as the heating, ventilation, and air conditioning (HVAC) system, air compressor, and power steering pump. Inverters are used to convert current from the battery (direct current, or DC) to a form that is useable by the motor and accessories (alternating current, or AC).
A down converter is used to reduce the DC voltage for delivery to the low voltage batteries, which are used to provide small amounts of electricity required while the bus is not operating or in motion. Components such as the multiplex I/O system, cameras, Wi-Fi and farebox can draw a load even while the vehicle itself is not being powered. Furthermore, a low voltage current is also required to close the contactors to start the bus. This type of current is provided by the low-voltage batteries. A high-level schematic of the vehicle systems is provided in Figure 1.

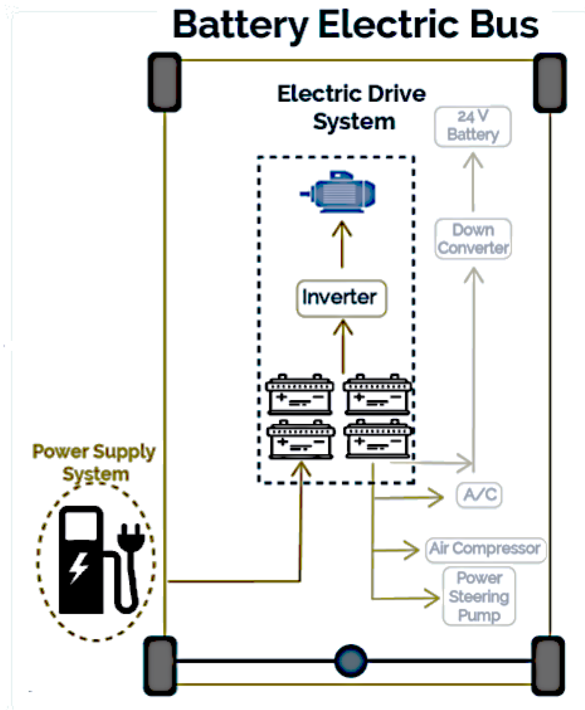


Figure 1. Basic Schematic of a Battery-Electric Bus

Table 1. Energy and Power Comparisons between Diesel and Battery-Electric Buses

| Unit | Describes what? | Conventional Equivalent | Example |
|---|---|---|---|
| **kWh** (kilowatt-hours) | **Energy** | **Gallons** (of diesel) | The bus stores 450 kWh (12 gallons diesel) |
| **kW** (kilowatts) | **Power** | Output for Performance: **Horsepower** | The battery pack can provide 230kW (308hp) |
| | | Input for Fueling: **Gallons/min** | The charger can provide up to 150 kW |

Unlike a conventional diesel engine or a diesel-electric hybrid where the fuel is pumped from an external source into an onboard tank, the "fuel" for a battery-electric bus is provided by the electrical grid and applied to the vehicle by a charging system. Please refer to Table 1 for a summary of the primary concepts relative to battery-electric buses.

[20] Visit https://cte.tv/ for more information on the Center for Transportation and the Environment.

### Energy

In a conventional diesel bus the amount of energy available on the bus is represented by the number of **gallons** of fuel in the tank. In an electric bus the amount of energy stored in the battery is represented in terms of **kilowatt-hours (kWh)**.

One limitation of today's battery-electric buses is that they cannot store as much energy as a diesel bus. Using the example in Table 1, the equivalent of 450kWh of energy is approximately 12 gallons of diesel fuel in a conventional bus. At four miles per gallon, a diesel bus that holds 12 gallons of fuel would only be able to travel **48 miles** before needing to refuel. However, battery-electric buses are much more efficient than diesel buses. Therefore, using that same amount of energy capacity, an electric bus may be able to travel **140 miles** or more on average (depending on conditions) before needing to recharge. However, a typical diesel bus may have a 100-gallon tank, giving it a **400-mile range** using the same assumptions. Using today's technology, the only way to match that range (on one charge) in a battery-electric bus is to add heavier and/or more batteries. Due to weight and space considerations, adding more batteries to compensate for the difference is not a viable option. As a result, a battery-electric bus currently has a shorter operating range than its diesel counterpart. Industry research efforts continue to focus on battery density and new chemistries to address the amount of energy batteries can store. Battery density has been improving year-to-year. It is not unreasonable to expect that battery-electric buses will be able to carry more stored energy without increasing weight or limiting passenger loads in the future, further reducing the energy deficit relative to diesel buses.

"Refueling" battery-electric buses takes longer than filling a diesel tank. The time required to charge a battery-electric bus (and provide the energy to operate) will vary based on the charging technology used. Typical base charging (using pedestal mounted chargers, for example) requires the bus to be plugged in for several hours in order to be fully charged. On-route charging, also called layover charging, takes advantage of scheduled stops or layovers to restore the state of charge of the battery and therefore extending the operational range. Using layover charging, range would be governed by the number of layovers and the amount of time available to charge at each opportunity.

It is critical for transit agencies to assess how battery-electric buses will perform in service prior to deployment. Developing a deployment strategy prior to purchasing and placing buses in service allows a transit agency to make decisions about energy storage and charging options, which are two of the distinct operating characteristics of battery-electric buses. It is also important to coordinate with the utility while developing a deployment strategy. Decisions about charging strategies will affect the time of day and amount of electricity consumed, which in turn affects costs. It is important that a transit agency understand all these factors related to providing energy to the buses prior to deployment.

### Power

Power describes the rate of applying or using energy over time. In a conventional diesel vehicle, a common way this is used is to express the output or "performance" of an engine in terms of horsepower. The equivalent unit of measure in electric vehicles is **kilowatts (kW).** Power is what the battery pack can provide as an output to the vehicle for performance, such as speed and acceleration. However, power can also be used to describe the rate of energy being applied by the charger as an input into the battery to replenish it. When power is used to describe the input, the conventional equivalent is how fast a diesel pump can fill a tank (i.e., gallons/minute).

Power as an input is an important consideration during battery-electric bus operational planning because it determines the amount of time it will take to charge the battery. As discussed in relation to **Energy**, it is important to engage with the utility during planning. Depending on the power being applied by each charger and the number and type of chargers operating at the same time, it can also significantly impact the electricity bill.

**What About Amps and Volts**
Because power is an important concept, it is useful to understand what controls the amount of power that can be applied to a battery to charge it. In electrical terms, the basic equation is:

**Power = Voltage × Current**

*or, equivalently, in electrical units:*

**Watts = Volts × Amps**

Amperes, commonly Amps, is a measure of electrical current, and voltage is essentially the amount of electrical "pressure" available to move that current. Using the analogy of a water hose with an adjustable nozzle, one can think of current as the water flow through the hose, and voltage is like the amount of pressure available to spray the water when the nozzle lever is squeezed.

In the context of vehicle charging, the amount of power (rate of energy) applied is determined by both the power rating of the charger as well as the battery system that it is charging. The charger must match the battery pack's voltage, and the current is set according to the battery's ability to accept power. The battery pack and charger are in constant communication during charging and the battery pack will at all times limit the current from the charger based on the battery's capability. For this reason, simply dividing the battery capacity by the charger's power rating will not correctly predict charging times.

## Appendix E: Alternatives Analysis for Charging Infrastructure and Layout

**Alternatives Analysis Factors Overview**

| ***Alternatives Analysis Factors*** | **Layout 1** | **Layout 1A** | **Layout 2** | **Layout 3** |
|---|---|---|---|---|
| **Semi-formal Name** | T-poles | Plug-in | Bridge/Gantry | Ltd. Bridge/Gantry |
| **Site Use and Operational Efficiency** | 3.0 | 3.0 | 4.0 | 2.0 |
| **Power Distribution Complexity** | 2.0 | 2.0 | 4.0 | 3.0 |
| **Construction Risks** | 3.0 | 3.0 | 1.0 | 1.0 |
| **Site Disruption** | 2.0 | 2.0 | 3.3 | 3.7 |
| **Construction Schedule** | 3.0 | 3.0 | 3.0 | 4.0 |
| **Future Proofed** | 3.0 | 3.0 | 4.0 | 1.0 |
| **Decommissioning** | 1.0 | 1.0 | 3.0 | 4.0 |
| **Cost** | 2.5 | 3.0 | 2.5 | 2.5 |
| ***Total Score*** | **19.5** | **20** | ***24.8*** | **21.2** |

Factors were scored from one to four. Four was the highest score.

Notes:

1. Layouts 1 and 1A require more physical space than layouts 2 or 3 either increasing the footprint of the base or reducing the number of buses that can operate from the base. One island is required for each row of buses unless the buses are parked in lanes opposing each other a design that introduces driving methods into the lanes that reduce the safety of drivers.

2. Layouts 1A has risks to Metro personnel engaged in plugging/unplugging buses to the chargers.

3. Layout 3 requires Metro personnel to move half the buses around at night and replacing them with the other half of buses. The layout intentionally has half the charging spots for the number of buses assigned.

4. Industry designs in North America such as LA, Edmonton-CA, Utah and other large scale charging locations align with layout 2 as most analysis supports this design that as the most easy and safe to operate; The bridge/gantry design option lends itself to future addition of solar-panels or battery energy storage to a level that the other three options do not without constructing a new structural element.

**Further clarification of the Alternatives Analysis Factors**

Site Use and Operational Efficiency – considers if the site will be used in the most operationally efficient manner by analyzing the following questions:

Is additional space provided for parking, maneuverability, and emergency maintenance?

Are the number of coach movements required to meet minimum fleet charge levels minimized?

Power Distribution System Complexity – considers the amount of power required by the utility by analyzing the following questions:

Is the area required for power equipment and conduit runs minimized?

Risks During Construction – considers the risk of construction delays by analyzing the following questions:

Are unusually long lead procurement times required?
And Is subsurface excavation/trenching and dewatering minimized?

Site Disruption and Compatibility with Other Improvements – considers disruptions to the site when converting a diesel-hybrid base to an electric base by analyzing the following questions:

Is there adequate room for shared use of the site?

Are the number of existing utility crossings minimized?

Are existing utilities required to be moved?

Construction Schedule and Phasing – considers meeting the BEB launch date by analyzing the following questions:

Can the phased BEB deployment schedule be met?

Future proof – considers the ability to upgrade technology by analyzing the following question:

Will the system configuration provide operational knowledge and training that is applicable for future BEB bases in other locations?

Future Decommissioning – considers if assets can be removed and repositioned by analyzing the following questions:

Will removing the BEB infrastructure in the future be efficient?

Can the removed infrastructure be more easily reused on another BEB base?

Cost – considers the ten year investment (Interim Base was designed as a life-limited asset) and cost of ownership by analyzing the following questions:

Is this the least total cost alternative?

Are additional costs (compared to other alternatives) justifiable such as for risk mitigation?

### Appendix F: Data Model Memo

## 1. INTRODUCTION AND OVERVIEW

The following documentation includes the financial modeling input sources and calculation assumptions applied in the 2020 vehicle fleet transition evaluation; an update of analysis conducted for King County Metro in 2016-2017.

In addition to updates to the model input assumptions, the structure of the financial model has been refined since the 2016-2017 analysis to include:

- Evaluation of the replacement of Metro's 35-foot buses, previous analysis was limited to 40- and 60-foot vehicles
- Amortization of capital costs over the anticipated life of the vehicle or fueling asset

Values provided are subject to change and represent the assumptions as of July 2020 that were agreed up on by King County Metro in coordination with the consulting team (WSP and CTE).

## 2. GENERAL MODEL ASSUMPTIONS

The following assumptions are specific to the model structure and general fleet replacement schedule.

### FLEET REPLACEMENT SCENARIOS

The financial model evaluates transit bus replacement for vehicles identified in the revised long-range Metro Fleet Plan through 2040. The revised fleet plan includes adjustments for recent revisions in part as a result of COVID-19 as of September 2020. The financial analysis excludes vehicles in the long-range plan, under 35 feet in length, trolley buses, and Sound Transit vehicles.

Three fleet purchase scenarios were evaluated in the model using different vehicle propulsion assumptions, with the first three years remaining constant.

#### ANTICIPATED NEAR-TERM VEHICLE DELIVERIES

The baseline vehicle procurement assumptions through 2023 assume the near-term vehicle purchases are constant for all scenarios and that existing vehicle orders will not be revised based on outcomes from this analysis. Vehicles purchased through 2023 are assumed to be retired during the long-range plan through 2040. Retired vehicles that are assumed to be replaced within the long-range plan through 2040 are included in the analysis.

Near term vehicle purchase assumptions are provided in *Table 1*.

*Table 1: Baseline Vehicle Procurement Assumptions*

| NUMBER OF VEHICLES | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| 40 Foot Diesel Hybrid Buses | 18 | - | - | - |
| 60 Foot Diesel Hybrid Buses | 7 | - | - | 13 |
| 40 Foot Battery Electric Buses | - | - | 20 | - |
| 60 Foot Battery Electric Buses | - | - | 20 | - |

LONG-RANGE VEHICLE REPLACEMENT SCHEDULE

Vehicle procurement assumptions after 2023 are based on full replacement of the existing fleet through the end of 2040, consistent with the fleet plan. Two scenarios evaluate the impacts of procuring (1) all diesel-hybrid electric vehicles and (2) all battery electric bus vehicles. In case two the assumption is the vehicles would operate on a blend of 5 percent biodiesel. The fleet purchase schedule is provided in *Table 2* by vehicle length.

*Table 2: Forecast Vehicle Purchase Assumptions by Bus Length*

| NUMBER OF VEHICLES | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| 2024 | - | - | - |
| 2025 | - | 40 | 65 |
| 2026 | - | - | - |
| 2027 | - | - | - |
| 2028 | - | 35 | 120 |
| 2029 | - | 20 | 10 |
| 2030 | 30 | 10 | 110 |
| 2031 | 30 | - | 25 |
| 2032 | - | 90 | 80 |
| 2033 | - | 25 | 35 |
| 2034 | - | - | - |
| 2035 | - | 55 | 50 |
| 2036 | - | 10 | - |
| 2037 | - | 5 | 24 |
| 2038 | - | 41 | 2 |
| 2039 | - | 9 | 1 |
| 2040 | - | - | 8 |

**ESCALATION AND DISCOUNT RATES**

All cost values are input into the model in current year (2019) dollars and escalated by different economic growth factors. The analysis is based on projections developed prior to the COVID-19 Pandemic and resulting recessionary pressures, and therefor may overestimate near term escalation rates providing a conservative approach in regard to cost projections.

SEATTLE CONSUMER PRICE INDEX FORECAST

The consumer price index for the Seattle-Tacoma-Bellevue metropolitan area is used as the basis for both escalating costs in pre-2019 dollars to the baseline model input values and for purposes of escalating costs to year of expenditure dollars.

Historical data through 2019 is sourced from the Federal Reserve Economic Data (FRED) CPI-U for all urban consumers in the Seattle-Tacoma-Bellevue metropolitan area. Values are based on annual averages without seasonal adjustments.

The forecast data is based on CPI-U forecast data sourced from King County and the State of Washington.

- Years 2020-2029 are sourced from the August 2020 King County Economic and Revenue Forecast published by the Office of Economic and Financial Analysis and based on the Seattle CPI-U projections.
- Years 2030-2040 are sourced from the June 2020 Washington State Office of Financial Management, Traffic and Revenue Forecast Council (TRFC) and based on HIS-Markit's February 2020 long-term growth forecast.

PRODUCER PRICE INDEX FORECAST

For evaluation of transit vehicle production cost projections, an incremental factor is calculated using the historical variance between the CPI-U for Seattle-Tacoma-Bellevue and the PPI for Bus Chassis Manufacturers as sourced from the Federal Reserve Economics Data (FRED) as published by the Federal Reserve Bank of St. Louis. Based on twenty years of historic differentials from 2000 to 2019 the incremental escalation for PPI has been 1.3 percent over the CPI-U.

### SENSITIVITY TEST EVALUATION

In addition to scenario analysis based on the fleet propulsion assumptions, sensitivity tests were conducted for a moderate or base case and a favorable BEB vehicle case. The sensitivity tests are meant to provide a range of possible replacement cost outcomes based on different assumptions on the outlook on both capital and operating cost projections. In general, for most input variables a plus/minus twenty percent range was applied to the moderate case values to represent the range of potential cost outcomes. In some cases, including fuel and electricity prices, the forecast is based on source data projections for high and low socio-economic and price scenarios.

*Table 3: Primary Sensitivity Test Assumptions – Impact on Results Represents the Percent of Total Cost Variance Between the Sensitivity Tests*

| COST CATEGORY | FAVORABLE BEB | MODERATE CASE | IMPACT ON RESULTS |
|---|---|---|---|
| BEB Purchase Costs | Moderate – 10% | WA and GA State Contracts | **Medium** |
| Vehicle Purchase Cost Escalation | No escalation through 2024 for BEBs | CPI-U with PPI Factor | **Very High** |
| Diesel Price Escalation Rate | USEIA – Table 12._Petroleum and Other Liquids Prices - High Oil Price | USEIA – Table 12._Petroleum and Other Liquids Prices – Reference case | **High** |

| COST CATEGORY | FAVORABLE BEB | MODERATE CASE | IMPACT ON RESULTS |
|---|---|---|---|
| Electricity Price Escalation Rate | USEIA – Table 8. Electricity supply disposition Prices and Emissions - High Oil Prices | USEIA – Table 8. Electricity supply disposition Prices and Emissions – Reference case | **High** |
| BEB Battery Cost | *2019 –*<br>• 35 and 40 foot: $220,000<br>• 60 foot: $233,000 for 60 foot<br>*Beyond 2030 –*<br>• 35 and 40 foot: $64,167<br>• 60 foot: $67,958 | *2019 –*<br>• 35 and 40 foot: $220,000<br>• 60 foot: $233,000 for 60 foot<br>*Beyond 2030 –*<br>• 35 and 40 foot: $146,667<br>• 60 foot: $155,333 | **High** |
| BEB O&M Cost | Equated to diesel operating cost | KC Metro vehicle O&M Cost Curve Analysis- Twenty years of detailed operational data by cost category and by fleet | **Very High** |

**OTHER GENERAL ASSUMPTIONS**

In the 2020 analysis vehicle capital costs are amortized over the vehicle life. A simplified approach was taken in that capital costs in year of expenditure dollars were applied to a straight ratio of cost over the assumed life of the asset. A vehicle assumed to last 15 years would be evaluated using the capital costs for the projected year of operation divided by 15 and either provided in year of expenditure dollars or discounted to 2019 dollars.

The analysis assumes fueling and charging infrastructure are amortized over the life of the infrastructure. Electrical utility infrastructure has an assumed asset life of 40 years, direct vehicle charging infrastructure has an assumed asset life equivalent to the vehicle life of 15 years, and diesel underground storage and pumps have an assumed asset life of 30 years. The initial cost of designing and installing the supporting electrical infrastructure is included in the analysis while conventional fueling infrastructure is excluded from the analysis as storage tanks and pumps have already been installed at each of the bases and only future replacements cycles are assumed. Amortization assumes a set number of vehicles per base that does not change over the life of the asset. As an example, a BEB would incur the total cost of electric infrastructure, divided by the assumed number of vehicles per base, divided by the assumed 40 year life of the asset and applied each year for the 15 years the vehicle is assumed to be operating. Previous analysis assumed a single capital cost for each base divided by the number of vehicles per base in the year the vehicle was purchased.

In addition to vehicle and fueling/charging capital costs, amortization was applied to battery replacements for BEB's, periodic battery disposal costs for BEB's and vehicle disposal costs for all vehicle models. The amortization period for all elements are based on the assumed life of the vehicle or battery respectively.

## 3. CAPITAL COSTS

Capital costs consist of vehicle acquisition, additional options and charges, and supporting charging and fueling infrastructure. Capital costs are one-time costs incurred when the vehicle is acquired.

### VEHICLE PURCHASE PRICE

For vehicles ranging in size between 35 foot to 60 foot, bus purchase price for hybrids range from $623,195 to $1,050,000, battery electric bus purchase price range from $698,000 to $1,400,000 and diesel bus purchase price range from $428,361 to $675,702. Bus acquisition costs are escalated annually by PPI Bus Manufacturing Forecast in moderate case. The escalated prices are used to determine the costs of bus procurement made in that particular year.

Vehicle prices are sourced from the existing Washington Statewide purchase contract terms for all vehicles with the exception of 35 foot BEB's which are sourced from the Georgia Statewide purchase contract as the vehicle specifications are more aligned with Metro's anticipated operating requirements than the vehicle models available through the Washington contract.

*Table 4: Vehicle Purchase Price (in 2019 dollars) per Vehicle Type and Length in Moderate Case*

| VEHICLE TYPE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| Hybrid | 623,195 | 835,609 | 1,050,000 |
| Battery Electric | 698,000 | 956,150 | 1,400,000 |

### ADDITIONAL OPTIONS AND CHARGES

As shown in *Table 5*, there are six categories under Additional Options and Charges. The costs under these six categories are consistent across all vehicle types and lengths. Contingency, however, varies based on the vehicle type and brand. Contingency is determined either at 5% for large firms or 10% for small firms of initial bus purchase price.

Assumed costs for options and charges are based on historical experience at Metro and consistent with the options and charges that are anticipated to be required on any future vehicle procurements to align with Metro's requirements.

For BEBs only an additional $40,000 is assumed to cover the incremental cost quoted by the vehicle manufacturers for an extended 12-year battery warranty. The standard battery warranty assumed under the base cost is 6-years.

*Table 5: Additional Options and Charges (in 2019 dollars) for all Vehicles in Moderate Case*

| | ALL VEHICLES |
|---|---|
| Additional Options and Charges | 9,597 |
| Project Management | 9,717 |
| After Market Equipment | 30,832 |
| Training & Manuals | 8,038 |
| Service Preparation and Inspection | 2.0% |
| Special Tools & Diagnostic Equipment | 0.3% |
| | **BEB Only** |
| Extended 12 year Battery Warranty | $40,000 |

An additional contingency factor is included on all bus models and is based on the potential risk for costs exceeding the baseline capital cost estimates. For existing vehicle technologies and hybrids, the contingency factor is 5 percent while BEB's assume a 10 percent contingency based on both the risk of cost overruns for some of the smaller producers currently in the BEB market, and to align with recent experience on some BEB procurements with manufacturers that are new to the U.S. market and operational conditions and requirements.

*Table 6: Contingency (in % Bus Acquisition Costs) for all Vehicles in Moderate Case*

| VEHICLE TYPE | ALL VEHICLES |
|---|---|
| Hybrid | 5% |
| Battery Electric | 10% |

### CHARGING/FUELING INFRASTRUCTURE

Charging and fueling infrastructure costs for hybrid buses are $109 per vehicle, based on replacement of underground storage tanks, pumps, and associated infrastructure. The current inventory of 24 tanks is assumed to be maintained and replaced over the forecast horizon with similar sized tanks at a replacement cost of $125,000 for each tank and pump based on quoted replacement costs. An additional 20 percent factor is applied to account for potential risk of contaminants and potential future tank enhancements to reduce the potential for leaks. The total cost of tank and pump replacements for the system is divided by the average fleet of 1,100 vehicles to derive a cost per bus of $3,273 in 2019 $s. With amortization over 30 years the amortized cost per year per bus is $109 in 2019 $s.

Supporting utility and charging costs for BEBs are based on recent designs on a facility that assumes charging equipment costs for 9 chargers with 12 heads and assuming two buses per charging station based on the South Base Test Facility. The resulting costs for battery electric buses are assumed to be $354,109 per vehicle based on the estimated costs for the South Base Test Facility. Amortized over 40 years results in a cost of $8,853 in 2019 $s per vehicle per year. An additional charging unit cost of $166,667 per vehicle, also based on the South Base Test Facility, is anticipated to be incurred with each vehicle replacement cycle of 15 years resulting in an amortized annual cost per vehicle of $11,111 in 2019 $s.

*Table 7: Amortized Annual Charging/Fueling Infrastructure (in 2019 dollars) per Vehicle Type in Moderate Case*

| VEHICLE TYPE | FUELING INFRASTRUCTURE | CHARGING UNITS |
|---|---|---|
| Hybrid | $109 | - |
| Battery Electric | $8,853 | $11,111 |

## 4. OPERATING AND MAINTENANCE COSTS

Vehicle operations and maintenance (O&M) costs include general vehicle maintenance costs, tire service costs, fueling infrastructure annual costs, battery replacement costs and its frequency, and bus disposal/retirement costs.

### VEHICLE MAINTENANCE

Vehicle O&M costs vary between the vehicle types and the length of the vehicles. Overall O&M costs are driven by cost per mile of each vehicle and its annual mileage in the financial model.

Operating and maintenance costs are based on analysis of existing Metro fleet operations for hybrid vehicles for 40- and 60-foot models. Costs are based on historical operating experience at Metro. Costs are evaluated using historical annualized cost curves over 15 years that consider the changing operating cost profile over the life of the vehicle. The one exception is Diesel 60-foot vehicles for which there is only nine years of available data using recent bus models..

The BEB 40-foot vehicle costs are based on five years of operating data and verified with limited industry operational experience through the National Renewable Energy Laboratory (NREL) analysis. NREL is a federal laboratory dedicated to research, development, commercialization, and deployment of renewable energy and energy efficient technologies and they test a wide range of operational vehicles to evaluate performance. After five years of operations the cost curve from 6 years to 15 years is based on annual cost increases for Metro's hybrid 40-foot fleet.

There is very limited data available on the operations of BEB 60-foot vehicles in the United States. Therefor an approach was taken to calculate the differentials in costs between existing trolley electric vehicles for 40-foot and 60-foot models and apply the differential to the BEB 40-foot bus cost analysis over the first five years of operations. After five years of operations the cost curve through 15 years is based on annual cost escalation for Metro's hybrid 60-foot fleet.

For 35-foot vehicles, existing operating costs were limited to Metro's current fleet of 60 35-foot hybrid vehicles. Based on the analysis of the 35-foot fleet the differential with the 40-foot fleet did not provide conclusive statistical differences between the 35- and 40-foot fleets and therefore the 40-foot fleet costs were used as the bases for evaluating the costs of the 35-foot vehicle replacements. The 35-foot fleet for BEBs varies slightly from the 40-foot BEBs after five years as the 35-foot BEB vehicle costs after five years are based on the annual percent increase of the 35-foot hybrid vehicles while the 40-foot BEBs are based on ratios with the 60-foot fleet.

Based on recent analysis of BEB conversions by NREL – *Financial Analysis of Battery Electric Transit Buses (June, 2020)* the cost of operating BEB's was assumed to be 27 percent less than conventional diesel vehicles. While this differs from the agencies evaluated as part of this analysis to confirm BEB operating cost data, the impact of keeping costs for BEB's equivalent to diesel vehicles was evaluated through the favorable electric sensitivity tests. Setting the cost equivalent to diesel vehicles is considered to be a best case scenario in this evaluation as operational evidence of lower costs has not been verified or validated.

*Table 8: Vehicle Maintenance Costs (in 2019 dollars per mile) for Hybrid 35', 40' and 60' Buses in Moderate Case*

| UNIT AGE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| 1 | 0.38 | 0.38 | 0.64 |
| 2 | 0.55 | 0.55 | 0.79 |
| 3 | 0.63 | 0.63 | 0.94 |
| 4 | 0.86 | 0.86 | 1.09 |
| 5 | 1.01 | 1.01 | 1.29 |
| 6 | 1.07 | 1.07 | 1.65 |
| 7 | 1.22 | 1.22 | 1.65 |
| 8 | 1.21 | 1.21 | 1.80 |
| 9 | 1.52 | 1.52 | 1.99 |
| 10 | 1.30 | 1.30 | 1.80 |
| 11 | 1.00 | 1.00 | 1.68 |
| 12 | 0.99 | 0.99 | 1.60 |
| 13 | 1.42 | 1.42 | 1.78 |
| 14 | 2.86 | 2.86 | 1.84 |
| 15 | 1.32 | 1.32 | 1.73 |

*Table 9: Vehicle Maintenance Costs (in 2019 dollars per mile) for Battery Electric 35', 40' and 60' Buses in Moderate Case*

| UNIT AGE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| 1 | 1.12 | 1.12 | 1.06 |
| 2 | 1.21 | 1.21 | 1.17 |
| 3 | 1.39 | 1.39 | 1.41 |
| 4 | 1.36 | 1.36 | 1.86 |
| 5 | 1.74 | 1.74 | 2.47 |
| 6 | 1.84 | 2.22 | 3.17 |
| 7 | 2.10 | 2.22 | 3.16 |
| 8 | 2.07 | 2.42 | 3.45 |

| UNIT AGE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| 9 | 2.60 | 2.68 | 3.82 |
| 10 | 2.22 | 2.43 | 3.46 |
| 11 | 1.72 | 2.26 | 3.22 |
| 12 | 1.69 | 2.16 | 3.07 |
| 13 | 2.43 | 2.39 | 3.41 |
| 14 | 4.90 | 2.48 | 3.54 |
| 15 | 2.26 | 2.33 | 3.32 |

**VEHICLE TIRES**

Vehicle tire service costs per mile are consistent across all vehicle types and vary only by vehicle's length. The financial model applies the tire cost per mile with the annual mileage to determine the overall tire costs incurred in a bus lifetime.

Tire maintenance and replacement costs are based on historical Metro experience and assumed to be the same for all vehicle propulsion types.

*Table 10: Vehicle Tires Cost (in 2019 dollars) per Vehicle Type andin Moderate Case*

| | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| All vehicle types | 0.065 | 0.065 | 0.065 |

**VEHICLE FUEL COSTS**

Battery electric buses utility costs are based on PSE / Seattle City Light (2019 – 2020) prices which includes demand charges. The utility costs are escalated using the United States Energy Information Administration (EIA) growth rates beyond year 2020. Diesel fuel costs are based on the wholesale values from the August OEFA forecast and exclude state and federal fuel taxes.

Total vehicle fuel costs are determined using the fuel efficiency for each vehicle type, fuel consumption per year and vehicle annual mileage.

*Table 11: Vehicle Fuel Costs per Vehicle Type in Moderate Case*

| FUEL TYPE | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| Battery Electric - Utility Costs (YOE $/kwh) | 0.10 | Transition based on EIA growth rates | | |
| Diesel - B5 (YOE$/gallon) | 1.44 | 1.78 | 1.96 | 2.05 |

#### CHARGING AND FUELING INFRASTRUCTURE

Hybrid buses are assumed to have no charging and fueling infrastructure costs. Maintenance of battery electric buses charging and fueling infrastructure costs are based on limited experience to date and assumed at $218 per vehicle share of charging unit in 2019 dollars per year and escalated by Seattle CPI-U Index annually. The analysis applies the charging and fueling unit cost per bus and the annual bus count to determine the total charging and fueling infrastructure costs.

#### BATTERY REPLACEMENT

Hybrid vehicles do not incur battery replacement costs as they are embedded in the O&M costs. Battery electric buses assume $213,889 for 35 foot and 40-foot buses and $226,528 for 60-foot buses. Costs are based on current contracted disposal cost rates of $2.50 per pound. The analysis then assumes that battery electric buses will incur battery replacement costs every 12 years, primarily based on the anticipated battery life provided by the vehicle manufacturers under an extended battery warranty of 12 years.

*Table 12: Battery Replacement Weight (in 2019 dollars.) per Vehicle Type in Moderate Case*

| VEHICLE TYPE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| Battery Electric | 213,889 | 213,889 | 226,528 |

### 5. DISPOSAL

Battery and bus disposal costs are assumed to occur on a periodic basis and at the end of the assumed vehicle life respectively and are amortized annually over the assumed life of the vehicle.

#### BATTERY DISPOSAL

Hybrid buses do not assume battery disposal costs. Battery electric buses incur battery disposal costs based on the battery's weight. The analysis applies the battery disposal costs at $2.50 per lb. with the battery weight to determine the overall battery disposal costs.

*Table 13: Battery Disposal Costs (in lbs.) per Vehicle Type and Length in Moderate Case*

| VEHICLE TYPE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| Hybrid | Battery replacement costs are included in O&M | | |
| Battery Electric | 8,703 | 8,703 | 11,077 |

#### BUS DISPOSAL

Bus disposal costs are determined as a percentage of initial bus acquisition costs. When retiring buses, hybrid vehicles assume to recoup 4 percent of the initial bus purchase cost. Battery electric buses assume to recoup 5 percent of the initial bus purchase cost at the time of bus retirement. The slightly higher assumption for BEB's is to account for the higher cost of disposal for some of the lighter weight materials used in the body of the vehicle that may not have the same opportunity and value in regards to potential for salvaging parts or components.

*Table 14: Bus Disposal Costs (% of Bus Acquisition Costs) per Vehicle Type in Moderate Case*

| VEHICLE TYPE | ALL BUSES |
|---|---|
| Hybrid | 4% |
| Battery Electric | 5% |

## 6. ENVIRONMENTAL

Environmental costs consist of tailpipe emissions, upstream emissions, and noise. The analysis converts these non-monetized values to cash costs. The environmental costs are measured in dollars per mile and the total cost calculations are driven by vehicle annual mileage.

### EMISSIONS – TAILPIPE AND BRAKES

Tailpipe emissions consist of $CO_2$, NOx, SOx, $PM_{10}$, VOC, and $PM_{2.5}$. The analysis assumes different levels of tailpipe emissions in g/vehicle mile traveled (VMT) for hybrid and battery electric buses. Battery electric buses are assumed to only incur $PM_{10}$ and $PM_{2.5}$ tailpipe emissions.

The source for emissions data is AFLEET emission factors, based on data from EPA's MOVES2014b emission factor model and Cal Trains BCA Model Assumptions for monetized values of PM10.

The analysis first converts the tailpipe emission in grams per mile to tons per mile, using the .000001 gram/ton conversion rate. The tons per mile is applied to the annual mileage to determine the overall tailpipe emission amounts. The analysis then applies the tailpipe emission amounts to dollars per tons to determine the total tailpipe emission costs as provided in Table 17.

*Table 15: Tailpipe and Brake Emissions (in g/VMT) for Hybrid Vehicles in Moderate Case*

| EMISSION TYPE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| $CO_2$ | 2,057 | 2,057 | 2,851 |
| NOx | 1.13 | 1.13 | 1.57 |
| SOx | 0.01 | 0.01 | 0.02 |
| $PM_{10}$– Tailpipe | 0.02 | 0.02 | 0.03 |
| VOC | 0.1 | 0.1 | 0.1 |
| $PM_{2.5}$– Tailpipe | 0.02 | 0.02 | 0.03 |
| $PM_{10}$ – Brakes | .11 | .11 | .11 |
| $PM_{2.5}$ – Brakes | .01 | .01 | .01 |

*Table 16: Tailpipe and Brake Emissions (in g/VMT) for Battery Electric Vehicles in Moderate Case*

| EMISSION TYPE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| $CO_2$ | - | - | - |
| NOx | - | - | - |
| SOx | - | - | - |
| $PM_{10}$– Tailpipe | - | - | - |
| VOC | - | - | - |
| $PM_{2.5}$– Tailpipe | - | - | - |
| $PM_{10}$ – Brakes | .11 | .11 | .11 |
| $PM_{2.5}$ – Brakes | .01 | .01 | .01 |

*Table 17: Tailpipe and Brake Emissions (in 2019 dollars/ton)*

| EMISSION TYPE | EMISSIONS IN DOLLARS PER TONS |
|---|---|
| $CO_2$[21] | 74 |
| NOx | 8600 |
| SOx | 50,100 |
| $PM_{10}$ (Tailpipe and brakes) | 160,952 |
| VOC | 2,100 |
| $PM_{2.5}$ (Tailpipe and brakes) | 387,300 |

**EMISSIONS – UPSTREAM**

Upstream emissions consist of $CO_2$ and $CH_4$. The analysis assumes different levels of upstream emissions in g/VMT for hybrid buses. Battery electric buses are assumed to not incur upstream emissions.

The source for upstream emissions is AFLEET emission factors based on data from EPA's MOVES2014b emission factor model. No upstream emissions are assumed for BEBs as electricity is assumed to either be sourced from hydroelectric, or electricity from fossil fuel sources is assumed to include a carbon offset cost.

The analysis first converts the upstream emission in grams per mile to tons per mile, using the .000001 gram/ton conversion rate. The tons per mile is applied to the annual mileage to determine the overall upstream emission amounts. The analysis then applies the upstream emission amounts to dollars per tons to determine the total upstream emission costs as provided in Table 18.

[21] $CO_2$ emission values is in Year of Expenditures dollars per ton and was converted to 2019 dollars using a discount factor in the analysis

*Table 18: Upstream emissions (in g/VMT) for Hybrid Vehicles in Moderate Case*

| EMISSION TYPE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| $CO_2$ | 291.4 | 291.4 | 404 |
| $CH_4$ | 2.4 | 2.4 | 3.3 |

*Table 19: Upstream Emissions (in Year of Expenditures Dollars/Tons)*

| EMISSION TYPE | EMISSIONS IN DOLLARS PER TONS |
|---|---|
| $CO_2$[22] | 74 |
| $CH_4$[22] | 2,224 |

**NOISE**

Noise values and costs are derived from a study conducted by MTA in 2007 on noise differentials between various types of buses and FHWA Policy and Governmental Affairs guidance on Cost Occasioned Approach. No distinction was made in either study on the noise attributed to buses of different lengths. Noise costs are 0.067 dollars per mile for hybrid vehicles. Battery electric bus noise costs are at 0.05 dollars per mile. The analysis applies the noise costs per mile to the vehicle's annual mileage to determine the total noise costs.

*Table 20: Noise Costs (in 2019 dollars/VMT) per Vehicle Type and Length in Moderate Case*

| VEHICLE TYPE | 35 FOOT BUSES | 40 FOOT BUSES | 60 FOOT BUSES |
|---|---|---|---|
| Hybrid | 0.067 | | |
| Battery Electric | 0.05 | | |

[22] $CO_2$ and $CH_4$ emission values is in Year of Expenditures dollars per ton and was converted to 2019 dollars using a discount factor in the analysis