MOVING TO A ZERO-EMISSION BUS FLEET: TRANSITION PLAN

May 2022

Prepared by King County Metro

King County
METRO
Moving forward together

King County Metro Transit

Zero-Emission Bus Fleet

Transition Plan

May 2022

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Executive Summary: A Zero-Emission Vision

Achieving a zero-emission mobility future is essential to King County Metro's core values of safety, equity and sustainability. By protecting our air and water, reducing congestion, and expanding accessibility and opportunity, we will create even more walkable and rollable communities that support health and help everyone achieve their potential.

In 2019, our region's transit network helped take the equivalent of more than 190,000 cars off the road each day and prevented roughly 700,000 tons of greenhouse gas emissions. In the 2020 Strategic Climate Action Plan (SCAP) and the Metro Strategic Plan, Metro pledged to do even more to address the climate crisis countywide and in the fleet Metro operates. Metro committed to:

- Reduce car trips and increase transit ridership to reduce the 6.1 million tons of greenhouse gases emitted annually in King County from passenger vehicles by investing where needs are greatest; providing fast, reliable, and integrated mobility services; and supporting transit-oriented develop countywide.
- Transition to a zero-emission fleet powered by renewable energy by 2035 to eliminate the 100,000 tons of greenhouse gases emitted annually by Metro's bus fleet.

Metro's climate goals promote the agency's vision to deliver a regional, innovative, and integrated mobility network that is safe, equitable and sustainable. Since 2016, King County Executive Dow Constantine has directed Metro to transition to a zero-emission fleet as efficiently as possible. In 2017, Metro committed to transition to a zero-emission fleet by 2040 so long as vehicle and charging technology meets Metro's current and future service needs, charging infrastructure meets our standard operations, renewable energy supplies are secured, safety is maintained, staff are trained, and costs of transitioning are monitored to ensure that incremental costs do not limit Metro's ability to deliver and expand service. The 2019 King County Council "Jump Start" legislation accelerated Metro's initial commitment from 2040 to 2035, with the stated intent to "reduce the overall carbon emissions from transportation as quickly as possible while achieving the goals of Metro Connects." In 2021, to support its policy updates, Metro's analysis found that the agency can achieve the greatest emission reductions from investments in alternative fuels (e.g., renewable diesel), high frequency transit, transit-supporting land use (e.g., RapidRide plus transit-oriented development) and transitioning to a zero-emission bus fleet.

Transitioning to a zero-emission fleet by expanding the battery-electric bus fleet and retaining electric trolley buses, in complement with an integrated mobility system and transit-supportive land use, are the foundations of King County's portfolio strategy to reduce transportation-related greenhouse gas emissions. By investing in transit service where the needs are greatest and prioritizing the scaled-up deployment of zero-emissions buses in south King County where communities have been disproportionately affected by air pollution, Metro is advancing equity.

Getting to a Zero-Emission Fleet

To support a 100 percent zero-emissions fleet by 2035, Metro will use a phased approach to

- Acquire battery-electric buses
- Build the necessary charging infrastructure and supportive information technology
- Convert transit operations
- Train and recruit the workforce

Key milestones are identified in Figure 1 and listed under 'Key Transition Steps' below.

Metro develops a long-term fleet plan to identify bus purchases by year that takes into account planned service, and bus type, age, and size. Metro will transition its fleet to zero-emission by replacing hybrid buses as they are retired with battery-electric buses. All bus purchases from 2024 onward will be zero-emission. Based on the fleet plan, Metro identifies the infrastructure needed to support the fleet. Metro will provide the necessary infrastructure with both new construction and renovation of existing facilities.

Key Transition Steps

- Purchase of 40 extended-range battery-electric buses (BEBs) - 20 40-foot and 20 60-foot – to be put in service by the end of 2022
- Opening of the South Base Test Charging Facility (SBTC) in 2022 that can charge 9 buses simultaneously with chargers from three different vendors to support the first 40 extended-range BEB buses and to test the charging infrastructure (Figure 2)
- Construction and electrification of the Interim Base at South Campus with charge management in 2025 to support 120 new BEBs (Figure 2)
- Deploy charging infrastructure for battery-electric buses in the field at layover (on route) locations

- Completion of the electrify transportation study, to inform on-route charging locations and site electrification planning
- Opening of the South Annex Base by 2028 to accommodate up to 250 battery-electric buses with deployment of standard charge management system (Figure 2)
- Conversion of Metro's seven existing bus bases to support electrified operations
- On-going partnership efforts with local utilities, including planning for grid capacity and rate structures
- Continued development of charging standards, systems, and evolving technology of battery-electric buses
- On-going preparation and training of Metro's workforce for a zero-emission system, from operators and maintenance staff to safety personnel to service planning and scheduling

Figure 2: South Campus Investments

Introduction

King County Metro has established a goal of achieving a zero-emissions bus fleet powered by renewable energy by 2035. The following transition plan identifies the steps Metro will take in the near term as well as its longer-term strategy for achieving a zero-emission bus fleet. This goal will be met through a combination of battery-electric buses (BEBs) and zero-emission trolley buses (trolleys). This plan is intended to satisfy a recent FTA requirement for including a Transition Plan along with any application for funding of zero-emission fleets or supportive infrastructure and to help guide Metro's planning and investment strategies as we move toward our zero-emission goal.

The FTA identified the following requirements to be included in the Transition Plan:

1. Demonstrate a long-term fleet management plan with a strategy for how the applicant intends to use the current request for resources and future acquisitions. (Section 1: Fleet and Procurement)
2. Address the availability of current and future resources to meet costs for the transition and implementation. (Section 8: Financial Resources)
3. Consider policy and legislation impacting relevant technologies.
4. Include an evaluation of existing and future facilities and their relationship to the technology transition. (Section 2: Facilities and Infrastructure)
5. Describe the partnership of the applicant with the utility or alternative fuel provider. (Section 4: Utility Partnerships)
6. Examine the impact of the transition on the applicant's current workforce by identifying skill gaps, training needs, and retraining needs of the existing workers of the applicant to operate and maintain zero-emission vehicles and related infrastructure and avoid displacement of the existing workforce. (Section 7: Workforce)

Background

Department Overview: King County Metro is among the ten largest transit agencies in the United States, with nearly 1,400 buses and 157 routes[1]. Pre-Covid, Metro's system reached more than 1500 buses[2] and 215 routes. Metro operates a diverse service profile, including local bus routes, RapidRide (bus rapid transit), vanpools and rideshare, ADA paratransit (Access) vans, and marine routes. In 2019, before the pandemic, Metro served a daily average of 332,000 bus passengers.[3] Ridership dipped during the pandemic but is on the upswing. The bus fleet includes diesel-hybrids, electric trolleys, and battery-electric buses (BEB). Fifty-five percent of Metro's current buses are 60-foot, articulated buses. The non-bus revenue fleets include more than 1,100 active vanpool and rideshare vehicles and the ADA paratransit program, Access, which includes nearly 400 active vehicles.

Metro has a history of taking steps to reduce greenhouse gas (GHG) emissions. In 2004, Metro became an early adopter of diesel-hybrid buses. 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. Metro was also an early adopter of battery electric buses with the purchase of 11 Proterras in 2016. Metro is continuing this commitment as it looks to add more battery-electric buses and continue its operation of trolleys on its path toward a fully zero-emission bus fleet.

[1] As of May 2022
[2] Metro operated more than 1500 Metro-owned buses pre-Covid, plus 119 additional coaches for Sound Transit
[3] Link to APTA ridership

1. Fleet and Procurement

Metro has been progressing towards a zero-emission fleet since its initial commitment in 2017. Metro's plan to reach zero-emission by 2035 includes both trolley and BEB buses. Our fleet today includes 174 zero-emission trolleys and 21 battery-electric buses (11 Proterra and 10 extended-range New Flyer buses), with the remainder being diesel-electric hybrids. Between now and 2035, Metro will replace diesel-electric hybrids with BEBs as buses are ready for retirement, as shown in Figure 3. By 2035, its fully zero-emission fleet will have just more than 1,400 buses, per Metro's current fleet plan. As described below, Metro develops a fleet plan based on projected service. With the impacts of COVID-19, Metro's current fleet plan forecasts minimal fleet growth in the near term. If service and ridership projections increase more than the current projection, this could also increase the demand for fleet.

Fleet Planning

To guide Metro's fleet management and infrastructure planning, Metro develops a long-term fleet plan. The fleet plan considers planned service and bus type, age and size to identify bus purchases by year. Metro will transition its fleet to zero-emission by replacing hybrid buses as they are retired with battery-electric buses. All bus purchases from 2024 onward will be zero-emission.

Bus purchases based on the latest fleet plan which projects the types and timing of purchase of new vehicles - is represented in Table 1. The fleet plan is regularly evaluated through Metro's Fleet Steering Committee.

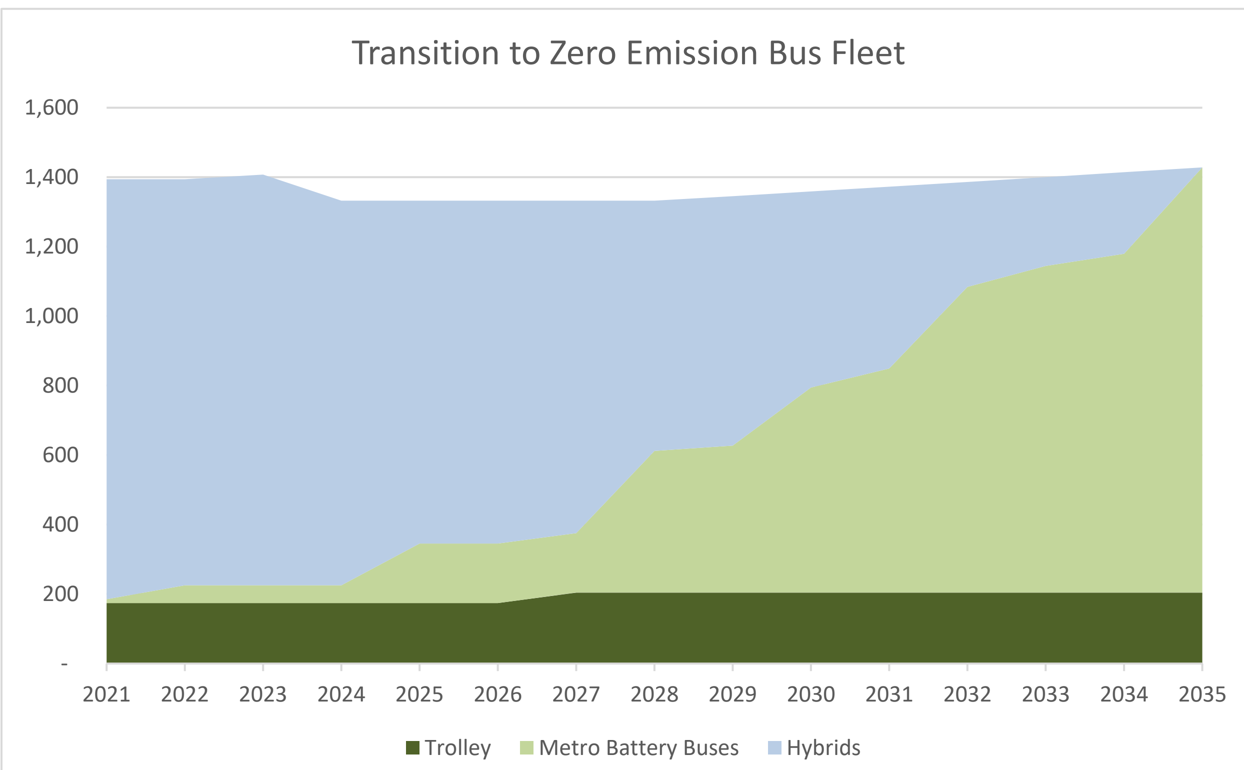

Figure 1: Fleet Transition to Zero-Emission

Table 1: Bus Purchase Plan

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	Total
BEBs		120			240	15	175	55	235	209	35	250	1334
Trolleys				30									30
Total ZE													1364

Near Term Bus Purchases

Metro has recently started taking delivery of an order of 40 extended range New Flyer BEBs (twenty 40-foot and twenty 60-foot). As of the writing of this plan, 10 buses had arrived, with the remainder expected to arrive over the course of the year. All 40 extended-range BEBs are expected to be fully entered into service by the end of 2022. These buses will operate from South Base Test Facility, which was commissioned in spring 2022 (and described more in Section 2). These extended-range buses supplement the initial 11 short-range BEBs launched on the Eastside of King County. The short-range BEBs are supported with proprietary charging infrastructure at the Eastgate park-and-ride and Bellevue Base.

In 2025, Metro will receive 120 BEBs to operate from Interim Base. In 2028, the next 250 BEBs will arrive to operate out of the new South Annex Base. In the following years, Metro will continue to replace its remaining diesel-hybrids with BEBs through 2035, as buses age and charging infrastructure is built both at operating bases and at layover charging facilities.

Trolleys

Metro has successfully operated a zero-emissions trolley program since 1939. Currently, the trolley fleet comprises approximately 12 percent of the total fleet and carries about 15 percent of riders[4]. The trolleys run exclusively in Seattle and continue to be an integral part of Metro's system.

Metro plans to grow its electric trolley fleet in 2027, from 174 to 204 coaches, with the purchase of an additional thirty trolleys. Metro is considering opportunities for strategic expansion and enhancement of the trolley system. In addition, Metro is planning to upgrade the trolley battery systems on the existing fleet as the current batteries reach the end of their useful life. Upgraded batteries will improve off-wire capabilities and provide flexibility to enable the trolleys to navigate construction zones and other blockages. Metro is also planning to replace its existing trolley fleet when it reaches retirement age in about 2033.

Early Short Range Proterra Fleet

In 2016, as Metro was first exploring battery bus technology, we purchased three first-generation, rapid-charge, Proterra buses followed by a purchase of eight second-generation Proterra buses in 2018. These buses have a range of approximately 25 miles.

Metro evaluated competitive vendor proposals and chose to work with Proterra because, at the time, they had deployed the most electric buses in North America. Currently, these buses are in revenue service for two routes, 226 and 241, supported by both layover charging, at Eastgate park-and-ride, and base charging at Metro's Bellevue Base. Eastgate has three chargers on a single gantry with capacity for

[4] Based on 2022 Metro ridership data

five chargers, the first of its kind in North America. These buses provide valuable information regarding electricity use and utility charges and allow Metro operators, mechanics, and riders to experience the technology.

As late as 2018, the electrical dispenser mechanism developed by Proterra, and used by the Eastside routes 226 and 241, known as infrastructure-mounted blade charging ("blade charging"), was being considered as a standard by the Society of Automotive Engineers (SAE)13 J-3105 standards committee (see Section "Procurement Strategy and Standards," following) for more information on SAE standards).However, in the final published standard, blade charging was not included.

The SAE standards adopted in January 2020 have been incorporated in Metro's procurement documents. Metro expects to continue to use the Proterra blade-charging buses in revenue service for the next decade at a minimum because the infrastructure exists and there is no need for replacement until the electrification of Bellevue Base occurs.

Testing Zero-Emission Technology

Bus technology has evolved since Metro's initial investment in the short-range Proterra buses. With the development of extended range BEBs, the newer technology provided options for fleet procurements that could better meet Metro's operational needs. To help inform future purchases and to better understand the technology, Metro completed testing of 10 extended range battery-electric buses, manufactured by BYD, New Flyer, and Proterra. The 10 test buses included 40-ft buses and 60-ft articulated buses, two per length (40-ft or 60-ft), and per OEM[5]. Testing was conducted to verify the 140-mile range and performance specifications with various loads, terrain, and weather conditions. One of each length was operated with passengers. The buses, batteries, and charge facilities were leased. During the summer and fall, the buses performed at or above expectations. More testing is required to gain additional experience with revenue service and operation in cold weather. The testing helped Metro staff learn more about the technology and complete updates and revisions to training requirements and documentation. It also informed purchasing and procurement specifications.

Prior to the bus test, Metro determined that overhead, pantograph down charging was the best option because it provided the most efficient and safest power transfer method available in the industry while keeping the weight of the buses down. (See further discussion in the 'Procurement Strategy and Standards' section). This decision was based on analysis of various charging methods and will provide the basis for base design and conversion moving forward.

Metro also developed a concept of a test charging facility to allow assessment of different charging options, discussed further in Section 2.

Procurement Strategy and Standards

SAE International, also known as the Society of Automotive Engineers, is a global association of engineers and technical experts in the aerospace, automotive, and commercial vehicle industries whose core competencies include standards development through consensus. Establishing technical standards

[5] Proterra does not manufacture 60-ft articulated buses, therefore the test buses consist of two 40-ft BYD buses, two 60-ft BYD buses, two 40-ft New Flyer buses, two 60-ft New Flyer buses and two 40-ft Proterra buses, for a total of 10.

are for the purpose of advancing quality, safety, and innovation in these industries. The organization has established more than 37,000 standards in their history. In a rapidly changing field such as electric vehicle technology, standards serve to establish baseline attributes of various systems (such as charging systems) that enable a level of standardization to facilitate commercial adoption while the industry continues to evolve. The SAE standards denoted in this document were agreed to by all North American bus manufacturers, including Proterra, and will be used for procurement documents to ensure consistency and interoperability exists between chargers, charge dispensers and buses.

When the 2017 Metro feasibility study was released, the North America bus charging standards were not finalized. Charging standards were called out in the 2017 study as a key requirement to support the battery-electric bus industry.

Currently, there are two proposed standards—plug-in charging (SAE J1772 CCS-1), and automated (SAE 3105) which includes pantograph down charging (SAE J3105-1), pantograph up charging (SAE J3105-2), and pin and socket (SAE J3105-3). The last two have not yet been deployed in North America. The former, SAE J3105-1 has a few hundred deployments including Seattle, Los Angeles, New York City and other major transit agencies. After review and approval through the Zero- Emissions Bus Program governance structure, Metro is recommending purchase of buses using the pantograph down charging standard, SAE J3105-1, for multiple reasons. All North American bus manufacturers have experience building to this standard. It lessens the weight on the bus because the bus carries minimal charging hardware; a lower weight bus allows for greater range and longer battery life. This charging system places all responsibility for charger connection on the technology and not on the operator through the standard's hardware, communication, and geo-positioning mechanism. Additionally, fleet maintenance prefers the pantograph down standard because it lessens bus maintenance. Plug- in charging ports (SAE J1772 CCS-1) will be available for maintenance needs and on road recovery if necessary.

Bus Batteries

With the expansion of Metro's electrified fleet, there will be an increasing need to ensure the continued safe and proper handling of the bus batteries once they have reached the end of their service life. Since this usually happens once or twice before the vehicle frame itself reaches end-of-life, there is a need for a process to handle battery packs separate from their on-vehicle housings. Such a process is already in place for the high voltage batteries coming from Metro's fleet of hybrid buses, with some batteries being recycled and others being reused based upon battery chemistry, market conditions, and safety requirements. However, there are indications that disposal of batteries and fire protection storage costs will increase in the upcoming years. To improve this system and accommodate additional battery quantities, chemistries and configurations, Metro is working with partners, such as the Pacific Northwest National Laboratory and the NAATBatt[6] trade association.

Metro is also exploring various other strategies such as OEMs take-back and in-house stationary power applications.

There will be increasing opportunities to partner with utilities around demand response to further lower electrical bills. IT will continue to evolve with the final goal of a fully integrated system that both

[6] NAATBatt International promotes the development and commercialization of electrochemical energy storage technology and the revitalization of advanced battery manufacturing in North America.

manages electrical load between Metro and the utility but also interfaces with vehicle maintenance, asset management and dispatch software.

Battery-electric bus technology is dynamic; the solutions Metro develops today are expected to be scalable, but Metro anticipates there will be changes as the technology matures and Metro better understands how to deploy and manage zero- emissions buses. Metro needs to continually evolve its battery-electric bus program to ensure it is scalable, innovative, and sustainable while still providing service at the highest levels and improving on current practices. The next two decades will be a time of tremendous change and growth for both for Metro and battery-electric technology. Enhancements in energy and power density will improve Metro's operational capability and resiliency.

Additionally, there are trade-offs to consider with battery size and charging strategy. Strategic use of layover charging can help support buses with smaller batteries. These trade-offs are discussed further in Section 3, under 'Layover Charging and Bus Battery Size'.

2. Facilities and Infrastructure

Supporting battery-electric buses will take both electrified base facilities to park, charge and maintain buses and on-route charging infrastructure to provide charging in the field. The base facilities will come from both new facilities and conversions of existing facilities. This section describes the facilities planned to support the fleet plan. Figure 7, later in this section, shows an overlay of the facility planning and the fleet plan.

New Base Construction

Metro has begun building new facilities with large-scale electrical charging infrastructure. Metro is also developing information technology (IT) solutions for charge management and route planning. The first focus is on South Campus as shown in Figure 4. South Campus includes the South Base Test Facility, Interim Base and South Annex Base.

South Base Test Facility. The South Base Test Facility (SBTF) was recently commissioned to support the initial 40 BEBs arriving this year. This facility was designed to enable testing of equipment from multiple vendors in multiple configurations to inform design of future infrastructure and test interoperability. It also provides training opportunities. A diagram and further description of South Base Test Facility is on the following page.

Interim Base. The newly constructed Interim Base at South Campus (Interim Base) will be electrified in 2025. The electrification of Interim Base involves the design and electrification to support 120 battery electric bus. Interim Base is intended as a prototype for future battery-electric bus deployment and base electrification. Metro expects there will be lessons learned and changes that will refine Metro processes and base design as electrification occurs across the bases and fleet.

South Annex Base. South Annex Base at South Campus (South Annex Base) will be in operation as an electrified base in 2028 with capacity for 250 BEBs.

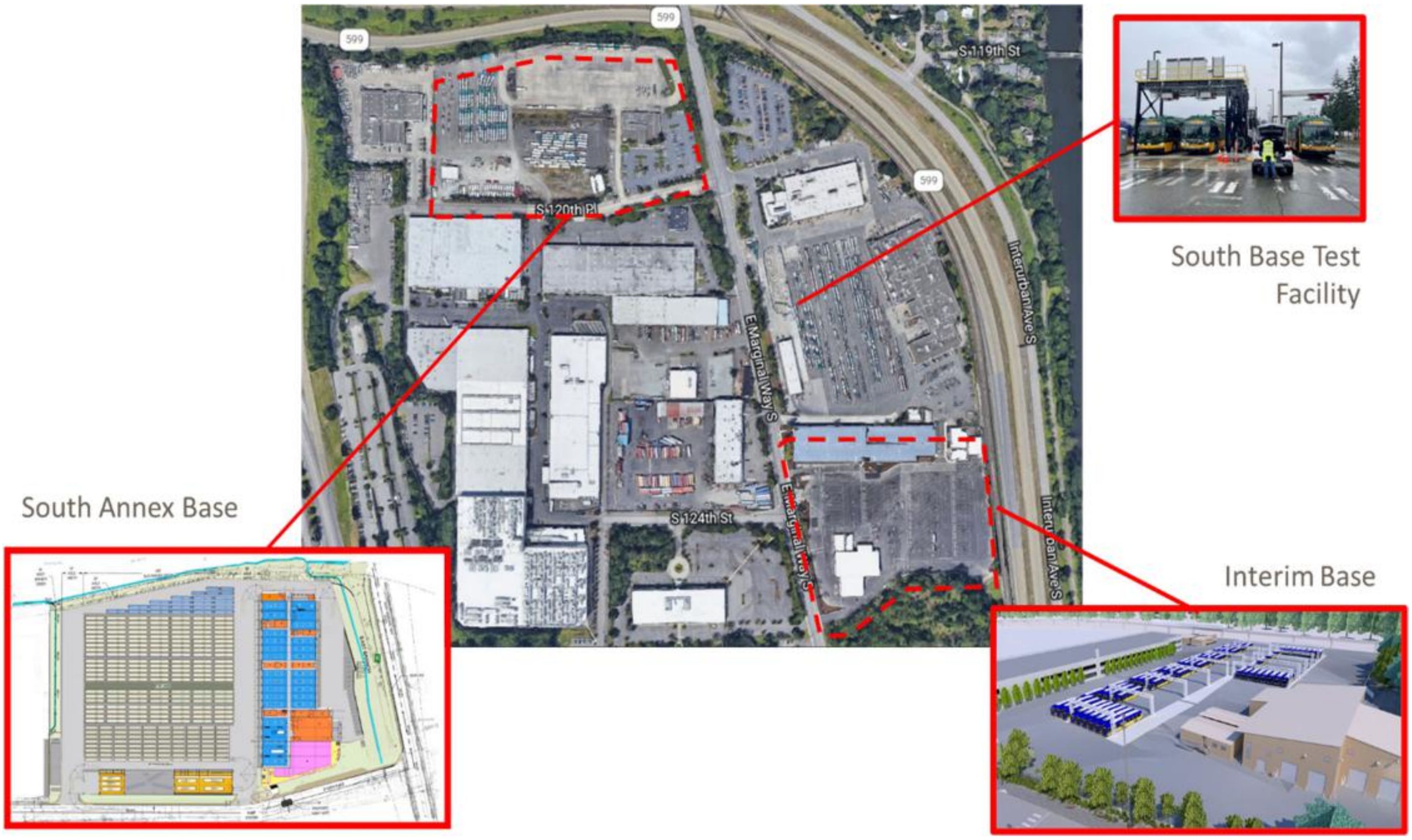

Figure 2: South Campus Electrification Projects

South Base Test Facility (SBTF): A Valuable First Step

The South Base Test Facility is an important step as Metro progresses in deployment of its charging infrastructure:

- SBTF is large enough to provide charging infrastructure for the 40 extended-range BEBs without affecting operational integrity of the base
- Completion of this capital project provided Metro with additional experience using the Energy Savings Performance Contracting (ESPC) alternative contracting method for electrification infrastructure construction for potential time savings and other benefits
- It allows Metro to test compatibility between various charger and bus manufacturers demonstrating interoperability;[7] as well as understanding the equipment reliability
- In the next decade as charger software develops, Metro can deploy new or upgraded charge management software in this controlled environment removed, from base charging infrastructure. Like all software upgrades, adequate testing in an environment localized to a non-essential facility is key to success.
- It serves as a facility for the development of training and maintenance practices and for sharing Metro's learnings with others as a leader in the industry.

What's learned from SBTF will inform the planning for the charging infrastructure at future facilities.

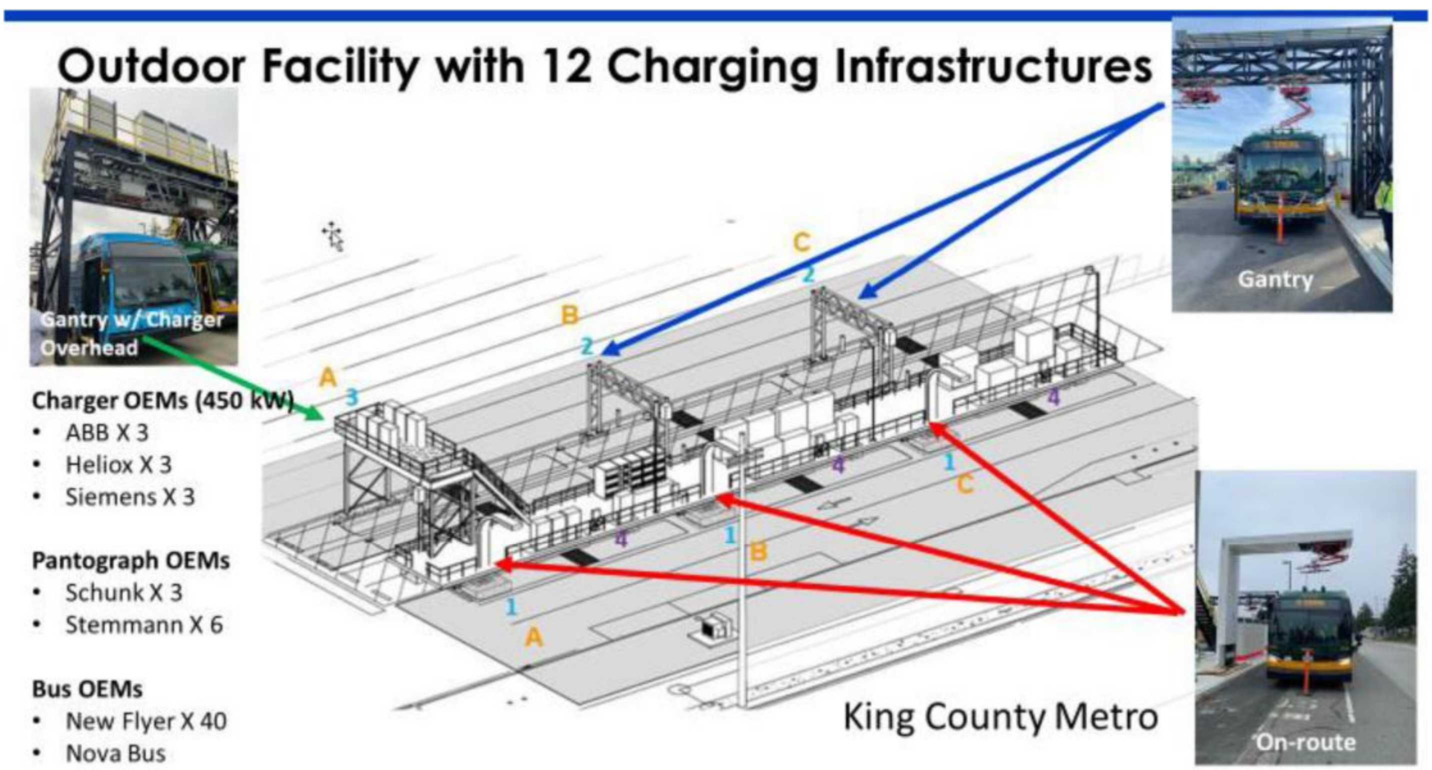

Figure 3: South Base Test Charging Facility

[7] 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. This limits dependence on a single manufacturer and reduces risk of relying on technology that may become obsolete.

Base Conversion

Metro has also begun planning for the conversion of its existing bases to support battery-electric buses which will be a critical part of the transition. Metro owns and operates seven existing bus bases across King County. Metro plans to convert its bases sequentially with each base expected to take between 18 and 24 months for conversion depending on the size and complexity. As bases are closed for conversion, the overall system capacity will be impacted temporarily. Additionally, there will a permanent reduction in capacity of 10-15 percent due to the installation of charging infrastructure within the yards.

The plan to convert bases seeks to balance construction efficiency with the ability to maintain operations. Figure 7 shows the projected conversion schedule, fleet projection and system capacity. Given our current fleet size, once Interim Base and South Annex Base are completed, there should be enough system capacity to enable the shutdown of bases necessary to allow conversion while still supporting operations.

Figure 4: Metro Existing Bus Base Locations

Order of Conversion: Balancing System Capacity and Stable Operations

The order in which Metro plans to convert its bases was determined based on capacity, risk versus benefit, and funding. Metro plans to shut down each facility during the conversion process which will affect between 7 and 17 percent of total system capacity depending on the base that is shut down. Additional concurrent impacts to base operations such as necessary maintenance and potential impact from Sound Transit construction activities and other entities must be considered as well. Timing and extent of power grid capacity work could also impact the final schedule and sequence of the base conversion. There will also be permanent capacity loss post-conversion due to the added infrastructure in the yard which must be considered to avoid dipping into unstable operations.

Each of our bases has independent complexities that factor into how difficult it will be to convert and the perceived benefit from its conversion. Conversion of each base will require companion layover charging sites.

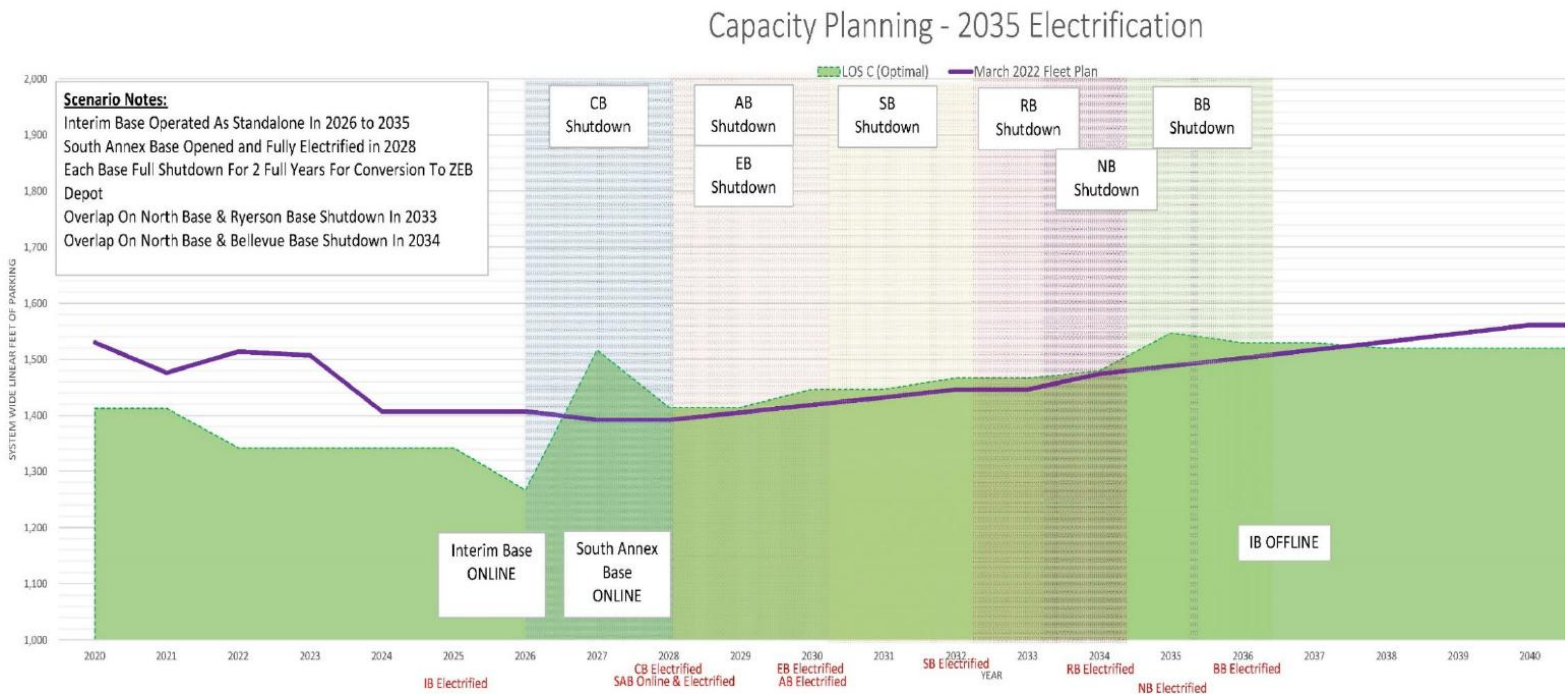

Figure 5: Base Capacity and Electrification Conversion

Metro plans to convert its bases sequentially with each base expected to take between 18 and 24 months for conversion depending on the size and complexity. As bases are closed for conversion, the overall system capacity will be impacted temporarily. Additionally, there will be a permanent reduction in capacity of 10-15 percent due to the installation of charging infrastructure within the yards. The conversion schedule seeks to balance construction efficiency with the ability to maintain operations and takes into consideration characteristics of each base.

3. Charging Strategy

Charging Infrastructure Deployment

Charging infrastructure is comprised of an electrical connection component (plug/socket), communications (antenna), IT (software) and a structural component. For Metro's preferred charging method, the structural component is a concrete base, steel truss gantry that holds the charging heads and the connection to the bus. Metro has chosen to use a pantograph down system.

Attached to the pantograph, through electrical wiring, are contact bars that dispense the electricity. There are various manufacturers building charge heads. Depending on the charger manufacturer chosen, the footprint required for the cabinets and switchgear will vary.

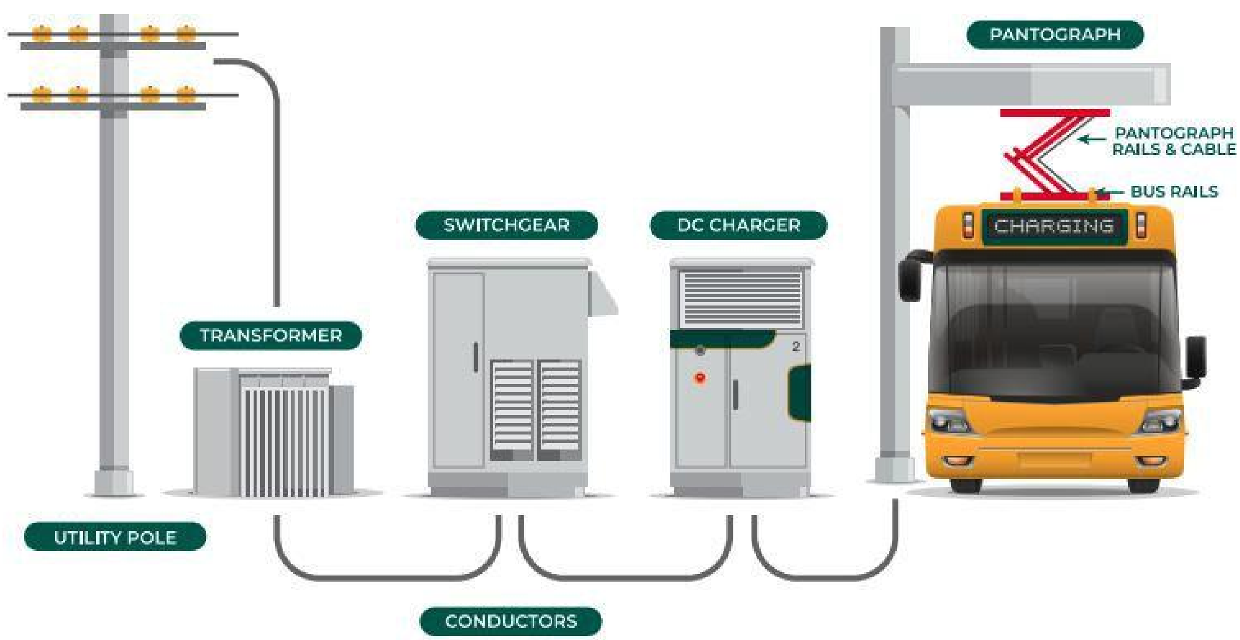

Figure 8. High-level charging infrastructure schematic

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.

[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.

On-Route Charging

Metro's internal testing has shown that the 60-foot extended-range battery-electric buses can reliably support a 140-mile range based on the topography and climate conditions of our region. This 140-mile range supports approximately 70 percent of our routes (blocks of work) under our current system design, leaving 30 percent of our service needing a solution to extend their range. To support more frequent service and longer routes such as many of the RapidRide routes, Metro plans to develop "On-route" or layover charging. Layover charging stations will ideally be located at park-and-rides and other layover locations to take advantage of operator break time to partially recharge the bus without having to return the vehicle to base.

Increasing Resiliency and Flexibility

Layover charging extends the range a bus can go without having to return to a base and adds resiliency and flexibility into the system. Layover chargers will provide options and will be valuable for buses as batteries age and when weather impacts battery performance. Additionally, layover chargers distribute load and electrical infrastructure over a larger area which increases resiliency. They also increase flexibility by supporting the operations of routes from different bases, which will be valuable as routes are shifted between bases during conversion to electrification.

Layover Charging and Bus Battery Size

Incorporating layover charging into the system will influence the size of batteries needed on a bus. 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. Building layover charging infrastructure strategically throughout the County will increase operational efficiency by enabling buses to charge as needed during scheduled layovers. 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. Battery packs must be large enough however to support sufficient range - short-range BEBs such as our first 11 Proterras for example are very limited in where than can be used in our system. An additional benefit to incorporating layover charging is resiliency – if one charging location is unavailable, 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.

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

Locating Charging Sites

Metro is pursuing five initial layover sites in South King County to support Interim and South Annex Base electrification. These initial sites have been selected to leverage work that is underway, primarily as Sound Transit is building new or upgrading existing transit centers related to Link light rail construction and ST BRT investments. The initial sites include South Renton Transit Center, Kent Station, Kent/Des Moines, the Federal Way Transit Center and King County owned Burien Transit Center.

Metro is also in the process of identifying what locations are the best candidates for layover charging across the system. A study currently underway is taking a closer look at Metro's service network as well as layover locations and other potential hubs.

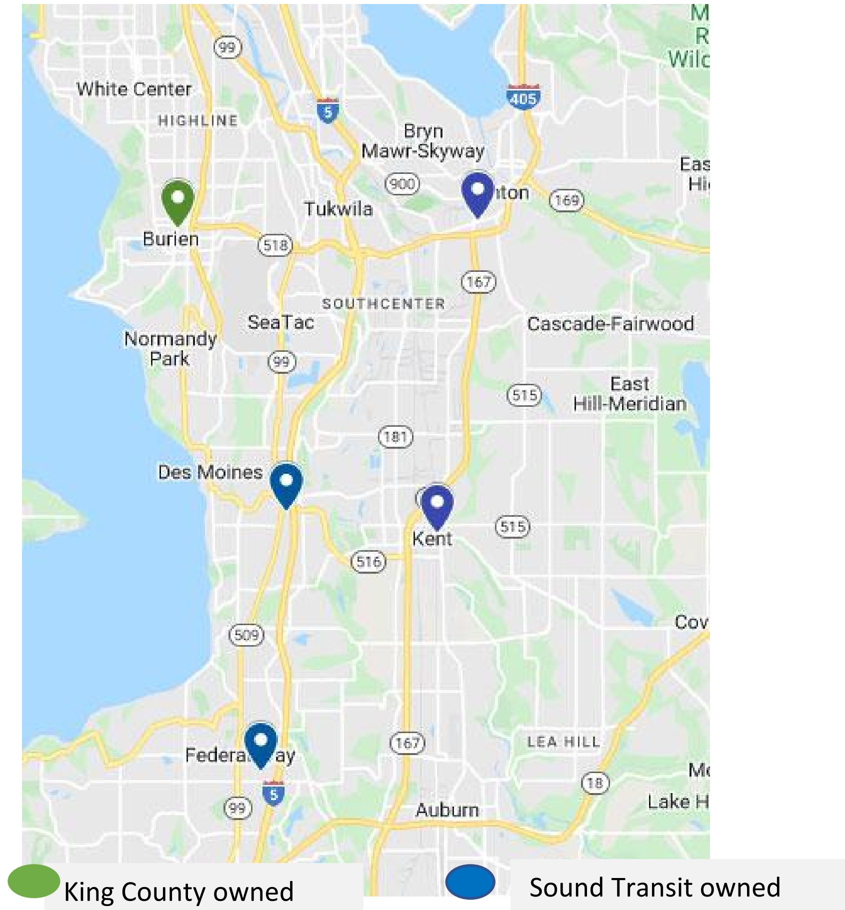


Figure 9. South King County Planned Layover Charging Locations

Working with Others

Layover charging will require coordination and partnerships with others, including jurisdictions, utilities, other transit agencies and the private sector. Layover charging will need significant electrical infrastructure in multiple jurisdictions throughout the County. It will also require physical space, either at off-street locations such as park-and-rides and other transit hubs or possibly within public right of way.

Jurisdiction support and partnership in developing charging infrastructure will be critical. Jurisdictions will play a role in permitting, zoning codes and standards and can facilitate on-route charging development. Additionally, support and guidance for infrastructure development at the state level could also help facilitate. Partnering with other transit agencies such as Sound Transit who also own key terminal locations in King County may create efficiencies through shared charging stations. There could also be opportunities for public-private partnerships with companies such as Microsoft, Amazon or others as the private sector also explores electrification.

Metro is a leader and active participant in activities with other transit agencies and industry organizations such as the Electric Power Research Institute (EPRI) and the Society of Automotive Engineers (SAE) in developing standards and sharing information. We have also cooperated with utilities and the University of Washington on conducting studies, sharing data and supporting grant applications and retired batteries. We are also coordinating with local technical training programs at local colleges to help prepare Metro's future workers to maintain and operate our electric vehicles and charging infrastructure.

4. Utility Partnerships

As Metro moves forward with the battery-electric bus program, one of the keys for success is negotiating an appropriate tariff with the utilities. Metro buses operate inboth Seattle City Light (SCL) and Puget Sound Energy (PSE) territory. Interim Base and South Annex Base are in Seattle City Light territory. Metro is actively engaging with both utilities on tariff rates but is initially focused on Seattle City Light because of the nearer term projects. Figure 10 shows the service areas of Seattle City Light and Puget Sound Energy.

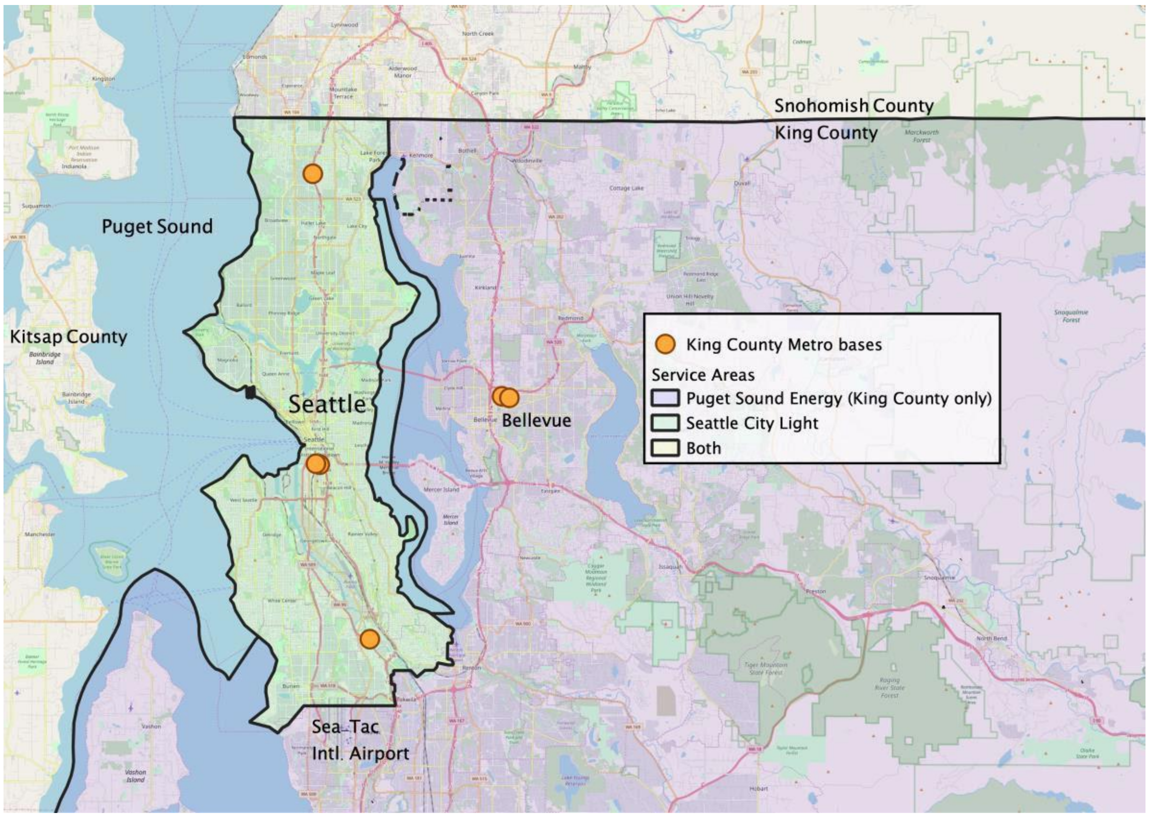


Figure 10. Service areas of Puget Sound Energy and Seattle City Light

In general terms, monthly electricity bills resulting from vehicle charging typically include fixed costs, energy costs, demand costs, and taxes and fees. First, there is a fixed or minimum cost that is applied per meter regardless of the amount of electricity used. Second, there is the actual cost of energy (commonly called "usage") which is calculated by applying a rate per kWh to the total kWh's used by the chargers to replenish the batteries in a given month. Third, utilities typically assess a demand charge, which is applied per kW based on the maximum power drawn by the chargers (also commonly called "load" or "demand") within a given time period each month. Depending on the type of tariff structure, different energy and/or demand rates may apply based on time of day (peak versus off-peak periods). Furthermore, these peak periods may change based on season of the year. Finally, taxes and fees are assessed. There can be several individual fees, some of which are based on usage and others based on demand.

Utility Readiness

Utility readiness is a critical component of Metro's path to electrification. Metro will work with the utilities to assess readiness on a site-by site basis.

Seattle City Light has conducted a system impact study for Interim Base. Seattle City Light has two electrical feeders that are accessible for service. Feeder A runs north/south on the west side of E Marginal Way S and Feeder B runs north/south on the east side of E Marginal Way S. Feeder A can handle the additional load required for Interim Base without any required system modifications. Feeder B is not a viable feeder to support Interim Base. Seattle City Light can support the needs of Interim Base with no significant infrastructure work to the feeders. However, Metro is working with the utility on the best redundancy and resiliency plan. Additionally, Metro will continue to have diesel-hybrid buses running out of the South Base in the near term, which can be used if electrical charging fails or if power outages occur that impact to the ability to provide service.

Power Resiliency

A battery-electric bus operating plan must allow for service delivery when there are power outages that last beyond the battery storage capacity. For Interim Base before our system if fully electrified, diesel-hybrids will replace battery-electric buses until power is restored if there is a power failure. In the longer term, Metro must engage thought leaders and emergency management expertise in designing power resiliency for this new operating model. Resiliency options should extend beyond the local power utility, including on-base solar power, multiples substations or large battery storage banks of reserve energy.

Another challenge is the resilience required for an extended time, such as natural or humanmade disasters that extend power outages for a prolonged period as the local power utility is trying to recover their systems. Public transportation is typically a critical infrastructure in the times of natural disasters, not only for regular or amended service, but also as warming coaches, evacuation and relocation, triage and emergency transport. A discussion has begun with Seattle City Light about power restoration to Metro in cases of catastrophic failure. Over the upcoming months, conversations need to occur with local and county emergency managers to discuss how a potentially electric fleet may change their expectations for major incidents and disaster support to improve recovery services.

5. Information Technology: Charge Management and Other Investments

Metro is working with various internal and external groups on information technology (IT) investments to support electrification. Technology infrastructure is essential to support fleet electrification. The battery charge infrastructure can be used to charge individual coaches, but an overall charge management system is critical to driving efficient fleet charging.

Charge Management

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. This system can prevent unnecessary fees by the utilities, and efficiently manage power to batteries while communicating with the utility to avoid peak demand or grid instability. At its most basic, a charge management system 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 demand fees.

The charge management system needs to take into consideration:

- Minimizing electricity rates that fluctuate throughout the day based on demand
- Requirements for coach charge depending upon vehicle assignment
- The age of the equipment (older batteries are less efficient)

Charge Management and Layover Charging

When Metro first purchased BEBs, the industry standard was short-range, fast-charging buses like the 11 Proterra buses currently serving 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 **Error! Reference source not found.** below). If not properly managed through a CMS, higher-power charging at layover facilities will lead to unnecessarily high electrical bills.[10] 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.

Figure 6: Eastgate park-and-ride 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.

Vehicle Data

Currently, Metro collects vehicle performance, mileage, and fault code data for its buses through a Vehicle Information Box (“VIB”). This data interfaces with the current M5 Asset Management maintenance database (“M5”), updating mileage information and identifying potential repair codes and maintenance needs.

[10] 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.

As battery-electric buses are launched, vehicle performance, mileage and fault code data will interface with M5 and the replacement Enterprise Asset Management system through data loggers that will also provide data elements that are specific to battery-electric bus vehicles, such as State of Charge ("SoC") and evaluation of battery usage. Under the terms of the procurement documents, any data from the buses will belong to King County and will be provided to the County in an unencrypted "raw" format. Per normal Metro processes, this data will be used to support vehicle maintenance. In the future, the vehicle data should be incorporated into the broader IT platform described below.

Scheduling and Dispatch of Electric Fleet

Metro's Scheduling "HASTUS" software is being upgraded to adopt software features that support the requirements of a fully electric fleet. The scheduling process must take into account the charge capacity of the fleet and on-route charging needed to complete assigned work. The scheduling software creates vehicle schedules by chaining together service trips and minimizing deadhead and layover time and distance. With a fully electric fleet, the scheduling system must accommodate on-route charging, and determine how to chain together service trips into vehicle schedules based on requirements for and availability of on-route charging stations.

Dispatch of Metro's current diesel hybrid fleet assumes that each bus is fully fueled at the base before assignment. The main considerations for dispatching buses are the type of vehicle required, and the mileage required to perform the assignment relative to the vehicle's required maintenance. With an electrified fleet, the addition of the electric charge capacity must be considered when assigning a bus, coupled with the accessibility and proximity of layover charging available on route. These criteria must be matched against the charge required to perform the assignment, as well as additional influencing factors such as topography and temperature.

In addition to matching appropriate coach options with assigned work, the base yard management system must plan for the circulation of coaches through charging stations, and position coaches so that adequately-charged buses are accessible to be dispatched as they are needed. The system must track circulation and dispatching to support the frequency of dispatch required to support peak service demands.

The current Vehicle Dispatch system needs to be replaced to accommodate the dispatch requirements of an electrified fleet. A technology Dispatch system replacement project is planned for the 2023-2024 biennium.

6. Operations

Metro is planning to first deploy the battery electric buses on routes in South King County. The first 40 buses will be operating from South Campus, using the new South Base Test Facility to charge. The service profile design began by analyzing all routes from South Base. From these routes, Metro's scheduling group identified vehicle assignments of less than 140 miles, a range current testing supports, and the range required in the procurement documents to determine which routes would be supported from the initial deployment.

The next large orders of battery buses will also operate from Metro's South Campus as Interim Base opens in 2025 and South Annex Base in 2028. For these next deployments, Metro is planning to develop several layover chargers. With layover charging in place, battery-electric buses can be assigned to vehicle assignments that are longer than 140 miles. To help identify optimal locations for on-route chargers, Metro is conducting a Transit System Electrification Study that will include an analysis of energy needs of service routes, factoring in topography, varying weather, and passenger loading. This will help inform service planning as well as suggest locations such as park-and-rides, mobility hubs and transit-oriented development sites that could offer potential charging locations.

7. Workforce

Metro has developed and is expanding upon training and educational programs for vehicle maintenance, operators and other employees working with battery-electric buses. Metro has a strong foundation in electrified transportation. Metro operates and maintains the electric trolley system which has been in operation since 1939 and Metro's hybrid diesel-electric buses include batteries.

Training is required for battery maintenance, electrical infrastructure maintenance, bus cleaning and maintenance, safety and dispatching, operator training, transit control center and service quality. The development of these training programs spans groups from across the organization including Safety and Security, Vehicle Maintenance, Fleet Engineering, Capital Planning and Power and Facilities.

Metro is working both to support existing employees through training and to recruit new employees with appropriate skills. Metro's Vehicle Maintenance group works with local Community Colleges to hire graduates for the mechanic rank. Our in-house educational programs support workers to stay current on technology and high voltage safety. Our work force is equitable and our union very supportive to employees. We work to recruit and retain employees with a competitive pay scale and create a respectful and diverse work environment. Furthermore, we ensure employees have the training necessary to safely perform their jobs.

Additionally, fleet procurement includes training for vehicle maintenance for our fleet needs with each contract.

Collaborating with Labor Management

King County Metro Vehicle Maintenance has a long history collaborating with our Local 587 partners. In the case of the Battery Electric Training our Labor Management were very supportive and pleased that we are taking a proactive approach to educate their members on the emerging technology that will be our future.

Apprenticeships

King County Metro Vehicle Maintenance has an established State Registered Apprenticeship program. The program will be expanding to support the Battery Electric bus efforts and education. As King County Metro Transit is a leader in Equity and Social Justice, we will be drawing from our current diverse workforce to fill the new apprenticeship positions. We are always searching and reaching out to our local school and colleges for new talent and individuals who are interested in joining the transit world.

BEB Training Academy

To develop a workforce with the skills required to maintain a zero-emission bus fleet, Metro has developed the BEB Training Academy. This involves training current Vehicle Maintenance Employees and expanding the Vehicle Maintenance staff. Since procuring diesel-hybrids in 2004, electric trolleys in 2014 and Proterra's in 2015, Fleet Engineering has developed curriculum for training Vehicle Maintenance employees providing them with the skills needed to repair and maintain electric and battery-electric technology. While some training classes for all-electric buses will need to be developed, many of the curriculum used for the diesel-hybrid and electric trolleys can be applied for all-electric buses. This section outlines the curriculum developed to ensure a successful transition toward all zero-emission, all-electric bus fleet and to prepare a well-trained Vehicle Maintenance department.

Curriculums are divided is three categories: Primarily Curriculums, Secondary Curriculums and Classes for First Responder, TCC, and District Supervisors

- Primarily Curriculums
  These classes are developed to train Vehicle Maintenance personal on how to maintain, trouble shoot and repair the BEB coaches. The Primary classes will be held before the opening of the South Interim Base.
- Secondary Curriculums
  The Secondary classes are classes that are developed to train Lead Mechanics and Mechanics on how to maintain, trouble shoot and repair the BEB coaches. These classes will be held after the South Interim Base is opened. Some systems are utilized current KCM coaches and are deemed Secondary classes.
- Classes for First Responder, TCC, and District Supervisors
  Class designed to aid First Responders when responding to accidents involving all electric coaches. The class is familiarization with the coach. Each agency will be giving the Emergency Response Guides. The class is also designed to train District Supervisors and TCC.

Charger Maintenance

Metro's Transit Facilities Division has been successfully maintaining bus chargers for over five years. As projects are constructed, charger maintenance training is included in project contracts - charger maintenance training was included as part of the contracts for both South Base Test Facility (SBTF) and Interim Base, for example. These training packages include a combination of classroom training and on-the-job training.

Operator Training

Metro has developed training to prepare operators to drive BEBs. The training takes approximately 30 minutes, added on to the traditional training. The focus of the BEB training is to familiarize the operator with the power gages and controls and provide an opportunity to go on a drive so drivers can get a feel of the extra torque and acceleration on turns and inclines. The main considerations in driving a BEB instead of a hybrid coach are:

1. Monitoring the charge level in the BEB
2. The difference in the operating noise level of the buses – for example, since BEBs are quieter, its especially important to notice for pedestrians in the area.
3. Differences in the drivers compartment of gages and knobs
4. The extra power and acceleration of the BEBs
5. Docking into the charging stations

IT

Metro IT and King County IT procure their own training and security needs as well as data-protection needs.

7. Policy Environment

King County Metro Transit's commitment to transition to an all zero-emission fleet by 2035 is codified in agency policies adopted by the King County Council and King County Regional Transit Authority. These policies formalize the strategic direction for reducing emissions from our fleet and are an extension of a legacy of sustainability commitments. In 2013, King County Metro Transit was a founding signatory to the APTA Sustainability Commitment. Metro Transit's commitment in the 2015 King County Strategic Climate Action Plan was furthered by the 2017 commitment to transition to a zero-emission fleet powered by renewable energy. In 2021, the 2020 King County Strategic Climate Action Plan[11], Metro Transit Strategic Plan for Public Transportation 2021 – 2031[12], and Metro Connects long-range plan were adopted. These policies established targets to reduce Metro Transit fleet GHG emissions by 45 percent by 2025 and 70 percent by 2030, compared to a 2017 baseline. These policies adopted an accelerated target for Metro's bus fleet zero-emission transition goal to 2035.

Metro Transit submitted these adopted climate action plans to FTA, as part of the FTA's Climate Challenge initiative. On Earth Day, April 22, the Federal Transit Administration recognized Metro and nine other transit agencies for exemplary efforts to combat climate change as part of the FTA's Climate Challenge initiative. The FTA's Climate Challenge was created in 2021 to help advance President Biden's greenhouse gas reduction goals. A total of 171 transit agencies have signed on to participate. Awardees were honored across eight different categories. Metro was named the "Most Equitable" in recognition the ways that the SCAP and Metro's Strategic Plan to address climate change impacts and transportation access in underserved communities.

Climate policies adopted by Washington State in 2021, including the Climate Commitment Act and the Clean Fuels Standard. Both policies are expected to help support Metro Transit and statewide efforts to electrify transit vehicles. The Climate Commitment Act (SB 5126) will establish a statewide cap and invest program that will for the first time put a price on GHG pollution (implementation date of 1/1/23), with the overall target to reduce statewide GHG emissions 95 percent by 2050 while providing billions of dollars of new investments in Washington climate action. The Climate Commitment Act is projected to generate several new revenue sources earmarked for reducing transportation emissions. Most of the transportation funding will go to transit, bike and pedestrian infrastructure, and electrification projects. The Clean Fuels Standard (HB 1091) establishes regulation (implementation date of 1/1/23) for reducing GHGs of transportation fuels (i.e. gasoline and diesel) by 10 percent by 2028 and 20 percent by 2035, as compared to 2017 levels. Under the Clean Fuels Standard, Metro Transit can generate credits for electrification of public transit vehicles. Utilities in Washington state will generate revenues from residential EV charging and be required to re-invest a portion of revenues to support electrification efforts in communities overburdened by air pollution. This state policy will provide a revenue source for Metro Transit and facilitate electrification efforts by increasing utility partnership capacity and create a more favorable market for electrification in the region.

[11] King County 2020 Strategic Climate Action Plan. Available at: https://your.kingcounty.gov/dnrp/climate/documents/scap-2020-approved/2020-king-county-strategic-climate-action-plan.pdf

[12] King County Metro Transit Strategic Plan for Public Transportation 2021 – 2031. Available at: https://kingcounty.gov/~/media/depts/metro/about/planning/pdf/2021-31/2021/metro-strategic-plan-111721.ashx

8. Financial Resources

King County Biennial Budget

Metro's current budget includes funding to build and electrify Metro's Interim Base at South Campus and the new South Annex Base – Interim Base will support 120 BEBs and South Annex Base will support 250 BEBs. Funding is also included for additional battery electric buses. The 2023-2024 Biennial budget that will include the planned expenditures for the period 2023 to 2032 is currently under development. The intent is to develop a Capital Budget that will fully fund the necessary vehicle and infrastructure investments to achieve a zero-emission fleet by 2035. The requested budget becomes public record at the end of September 2022 as it is transmitted to our elected county council for consideration, with adoption at the end of November. As part of our funding approach, Metro seeks state and federal grant funding wherever possible for our BEB fleet. Financing models are further described below.

Financing Models

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. Generally Metro uses cash financing and some grant funding for bus procurement and capital projects. Per current practice, Metro 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. The exact mix of cash funding, reserve use and debt financing will be developed based on Metro's financial condition and other economic considerations.

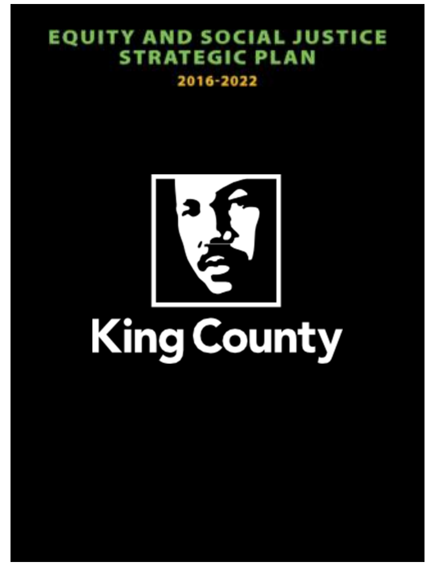
Funding Opportunities

A combination of cash, grants and debt financing would be used to fund electrification.

- **Cash/Fund Balance**
  - Metro will prioritize existing fund balance and projected revenues from sales tax, fares and other sources to support spending on electrification infrastructure and fleet.
- **Competitive Grants**
  - Metro will seek grants through established and new sources of funding that electrification projects and fleet replacement would be competitive for.
- **Debt Funding**
  - Despite the recent increase in projections for financing rates, it will still be beneficial for Metro to use debt to finance some of the cost of electrification.
  - Electrification and South Annex Base projects could be good options for the FTA Transportation Infrastructure Finance and Innovation Act (TIFIA) Credit Program
- **Additional future revenue sources**
  - Legislated increases of sales tax, property tax or other sources, including revenues from credit generation via the Washington State Clean Fuels Standard, could help to fund the cost of electrification infrastructure.

9. Equity and Social Justice

Long range battery-electric bus service will be launched in South King County where historically underserved communities live. Battery-electric buses benefit communities living in the areas of the bases by reducing ambient noise and eliminating local pollution. Metro may also choose to sponsor educational events/outreach to the community about the new technology and its role in reducing carbon emissions and improving air quality.



In addition, the location of the bases in proximity to areas with a high percentage of priority populations (people of color, low-income individuals, and people with limited English proficiency) will make it easier for Metro partnerships for recruiting and job skills development with local community colleges to reach priority populations. Many of the projects that will be undertaken to implement battery-electric buses will be subject to King County "priority hire" requirements, mandating that contractors advertise and prioritize hiring within zip codes that have lower income and employment levels than the King County Average. In addition, in procurement for projects associated with the battery-electric bus program, Metro will use the "Equity and Social Justice innovation plan," criteria, offering consultants the opportunity to propose equitable innovations aligned with the county's Equity and Social Justice Strategic Plan as part of their delivery of projects.

There will be benefits to the operator and maintenance workforce, beyond the potential for advancement opportunities through job skills training. Compared to existing technology, driving a battery-electric bus reduces fatigue because of reduced noise, vibration and there is less exposure to the operator and maintenance staff to criteria air pollutants and toxins.

Appendix A: Metro's Zero-Emission History

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.[13]

In **Error! Reference source not found.** 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.[14] In the 2017 Study, the Executive and Metro recommended – and 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.

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

[14] Metro, "2017 Study," 16.

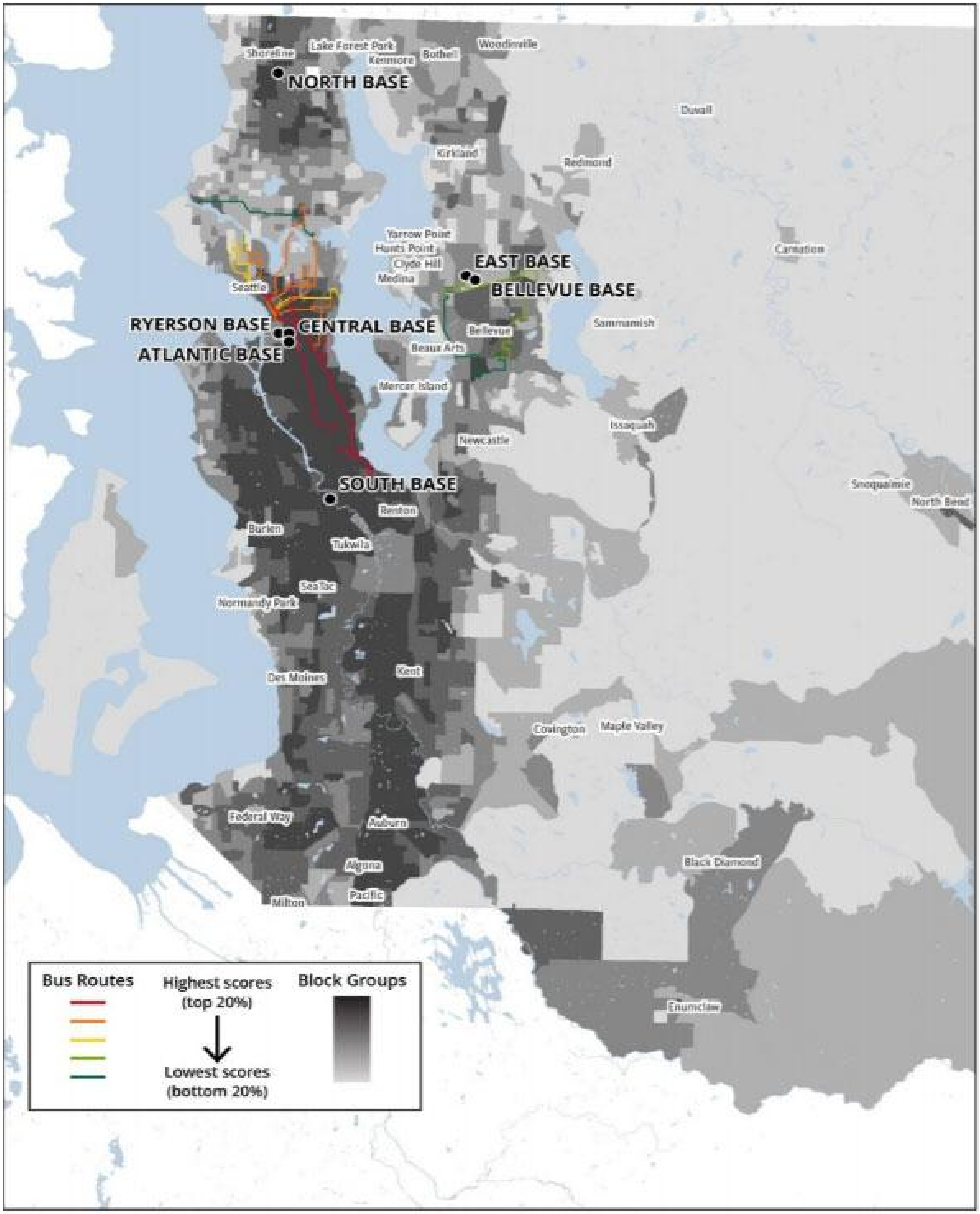

Figure 7: Map of air pollution vulnerability and bus routes in King Count

Appendix B: Battery-Electric Bus Technology Description

This section was prepared by the Center for Transportation and the Environment1 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 10.

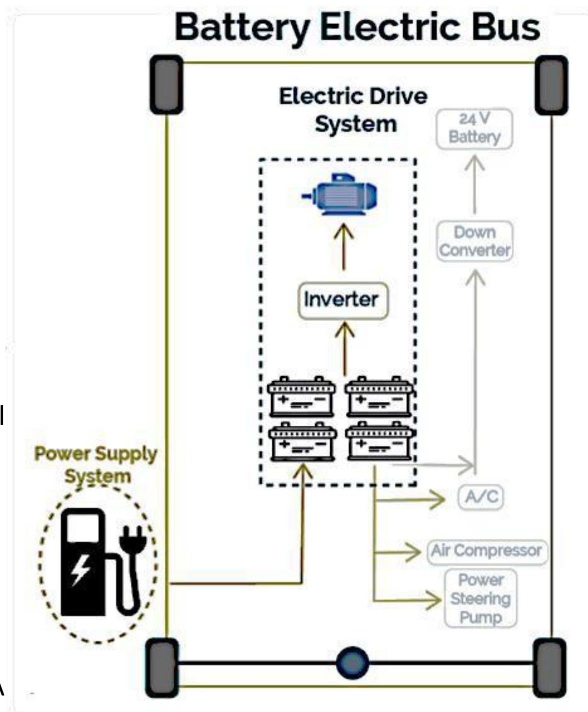

Figure 8: Basic Schematic of a Battery-Electric Bus

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.

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 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 (e.g. 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 (load or demand charges, see Section "Utility Rates", page 19 for additional discussion).

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 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.