Final Report

Topeka Metro Electric Vehicle Fleet Study

Prepared for Topeka Metro
by Arcadis IBI Group

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Executive Summary

Arcadis IBI Group has been tasked by Topeka Metro to evaluate the feasibility of transitioning to an entirely battery electric fleet for both their fixed route and demand response service. This report summarizes the projected feasibility of conversion based on compatibility with existing schedules, required infrastructure, lifetime cost of ownership, and staff impacts.

Battery electric vehicles use on-board batteries to supply energy for propulsion and other vehicle systems. These batteries typically recharge using power supplied by the local power grid, though on-site power generation and storage is sometimes used in parallel. Modern battery electric buses (BEBs) use lithium-ion batteries. As of January 2023, available BEBs have more constrained operating ranges than diesel powered vehicles, often requiring swap-outs and/or recharging midday to complete service. Depending on the manufacturer and vehicle model, BEB batteries typically have a storage capacity of 250 – 450 kWh, although in recent years some vendors have introduced ultra-long-range buses with battery capacity upwards of 600 kWh.

Topeka Metro is procuring three Proterra battery electric buses and chargers that are expected to enter service in 2023. Though the purchase order is not yet finalized, Topeka Metro has been working with Proterra on the build specifications for three 35’ ZX5 BEBs with 440 kWh batteries and three Industrial Series 120 kW DC fast chargers with 2 dispensers each. This initial equipment order will provide Topeka Metro with 6 available dispensers. These Proterra chargers can support up to 4 dispensers each for sequential charging, resulting in a potential total of 12 dispensers. When charging multiple vehicles, chargers are still limited to 120 kW therefore while charging a single bus takes about 3.5 hours it could take 14 hours or more to fully charge four buses using a single charger. Proterra BEBs come standard with a charging port on the rear passenger side. Topeka Metro’s build spec calls for an additional charging port at the front.

An energy modeling analysis was conducted to gather an in-depth understanding of the impact transitioning to BEBs would have on existing routes. The core of the fixed-route energy modeling analysis is the BEB energy consumption model, which computes the total energy required to operate each block based on several key factors that interact with each other to influence energy consumption. Based on the energy consumption projections, Arcadis IBI Group investigated alternative strategies such as re-blocking and on-route charging to achieve full compatibility between BEBs and an adjusted service plan. Strategies investigated do not affect scheduled trip times for the public, however interlining (which Topeka Metro displays in its public schedules) was examined under the assumption changes may be required to support partial and or full conversion to a BEB fleet. Battery energy demand redistribution efforts were configured to establish theoretical upper bounds of depot infrastructure and vehicle quantities needed to deliver current service. A key finding of the modeling efforts identified that approximately 25% of the fleet (~7 of the 26 buses) could operate using BEB technology under the assumption that all BEBs were dispatched without re-blocking. Under re-blocking strategies, it was determined that approximately 50% of the fleet (13 of the 26 buses) could operate using BEB technology under the assumption that all BEBs were dispatched.

Based on key findings found as part of the energy modeling analysis, Arcadis IBI Group identified existing gaps that prohibit further increase in the electrified fleet and presented potential strategies such as re-blocking and on-route charging that could be used to eliminate existing gaps. These strategies helped Arcadis IBI Group develop 5 mitigation scenarios that would permit 100% fleet electrification. **Figure 1,** describes at a high level, the energy modeling analysis process used for this project and the associated results.

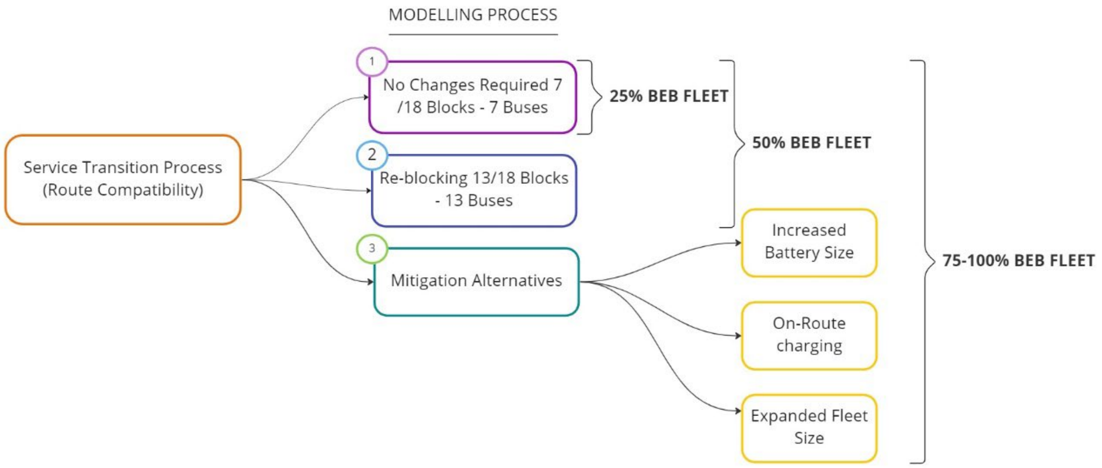

Figure 1. Service Transition Process (Route Compatibility)

The mitigation strategies are described below:

- Scenario 1: Midday charging in depot only
- Scenario 2: Midday charging in depot and at QSS (Short Top-Ups)
- Scenario 3: Midday charging in depot and at QSS (30–min layovers)
- Scenario 4: Midday charging in depot only, Enlarged Battery Size
- Scenario 5: Midday charging in depot and at QSS (30-min layovers), enlarged battery size

Arcadis IBI Group provided fleet, charger, and full-time staff requirements associated with each scenario as well as blocking modifications and high level-capital costs. Based on these findings it was recommended Topeka Metro choose to advance Scenario 3 to the stage of transition planning.

More detailed assessments were then developed for a BEB transition. The transition would also include replacing demand response vehicles to battery electric cutaways. Customized fleet replacement timelines were provided for 25%, 50%, 75% and 100% transition levels over the next 16 years. It is expected battery electric technology will continue to improve over time and may result in further increased battery capacities for buses and cutaways. Therefore, Arcadis IBI Group has developed a fleet replacement plan that follows the needs of existing aging fleet, which will open Topeka Metro up for potential opportunities to procure more advanced battery electric buses and cutaways as these become available, as opposed to procuring vehicles limited to existing capabilities over the next few years.

The infrastructure analysis identified how to support an entirely electric fleet at the Ryan Building by providing eleven 120 kW plug-style chargers to charge fixed-route buses and six Level 2 chargers to charge demand response vans. Dispensers and chargers should be located to the east and west sides of the existing 16” x 16” concrete columns and protected on the exposed side by bollards. This layout would not require major modifications to Topeka Metro’s existing layout and the parking spaces currently used for staff holds could be used for charging cabinets. The maintenance facility would be equipped with two mobile chargers to provide flexible slow charging for maintenance staff using existing wall outlets. Potential on-route charging locations were identified to support the different Scenarios that were investigated.

A financial analysis was conducted to identify potential changes in capital and operating costs related to the transition, and to develop an in-depth understanding of the total cost of ownership for a fully diesel fleet compared to different levels of BEB fleet integration (25,% ,50%, 75%, and 100%). This analysis yielded cost projections which illustrate an estimated $19 million difference between baseline scenarios and 100% BEBs over the span of 16 years.

Based on the route modeling, infrastructure analysis, and financial analysis the recommend approach was to proceed with Scenario 3: Midday charging in depot and at QSS (30–min layovers) though considering the potential for extended batteries and depot charging to reduce or eliminate the need for on-route charging (Scenario 4). The key drivers when converting this into an implementation plan are the vehicles useful life and vehicle age, opportunity for funding, and maturation of the technology. The transition is therefore split into three phases (Proterra Pilot, Phase 1, and Phase 2) as shown in **Figure 2**. In between each of these periods is an evaluation period to evaluate the progress to date and to assess the rate and percentage of the fleet that should be electrified.

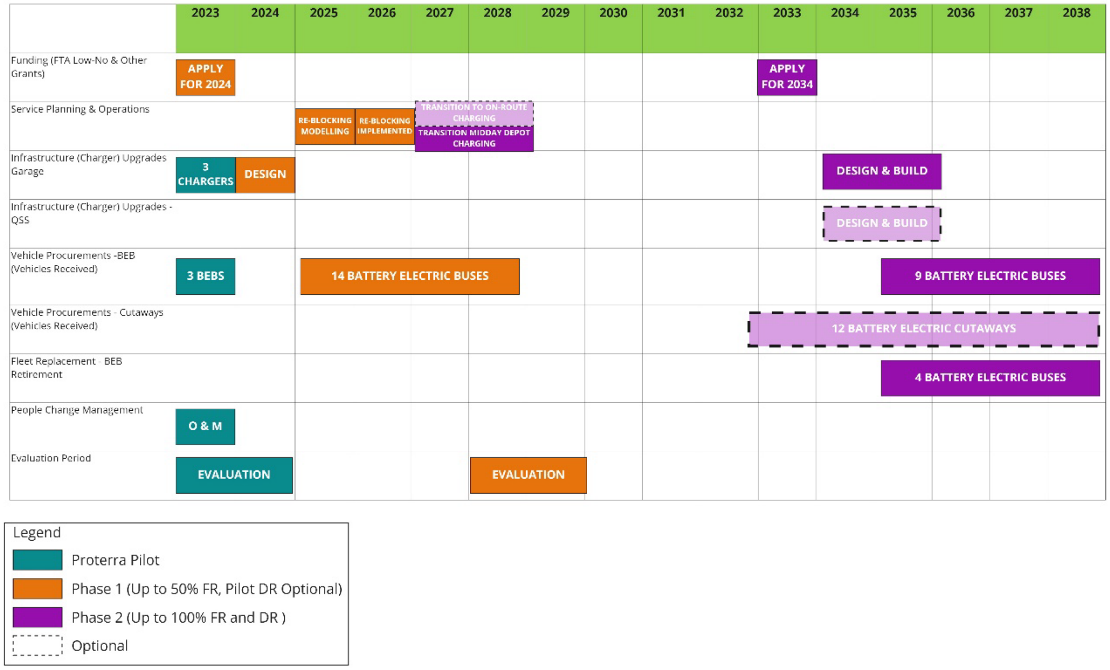

Figure 2. Implementation Plan for 100% BEB Scenario

Lastly, change management implications for the transition were reviewed at the agency level. And also, at the department/work group level for operators, dispatchers, and maintenance staff. Recommendations from this review include:

- Organizing agency-wide concept introductions
- Department-level breakout workshops, training, and re-certification programs for existing staff;
- Updated job descriptions
- Overarching training and implementation of new safety culture and practices to support working with high voltage equipment.

Introduction

Arcadis IBI Group has been tasked by Topeka Metro to investigate and evaluate the feasibility of transitioning to an entirely electric fleet for both their fixed route and demand response service. This Final Report consolidates all stages of the study (previously delivered as draft documents or technical memorandums) and presents a recommended transition plan to achieve full fleet electrification.

This report considers opportunities present within the United States zero-emissions vehicle market as of January 2023, with respect to equipment types and specifications, vehicle and battery performance, and projected costing for fixed and operating elements. Appropriate assumptions are stated where relevant in the report.

Topeka Metro currently relies on diesel powered propulsion technology to support existing services. An electric transition at any level would require modifications including but not limited to existing infrastructure, standard operating procedures (SOPs), and staff training.

Under this study, after a detailed overview of existing conditions, gaps, and opportunities at Topeka Metro, Arcadis IBI Group developed 5 mitigation scenarios that serve as viable options to follow if Topeka Metro were to transition to a battery electric fleet. Scenario 5 was selected collectively by Topeka Metro and Arcadis IBI Group as the preferred approach to follow when transitioning to a battery electric bus fleet. A detailed transition plan was developed for Topeka Metro's preferred option.

The final report is divided into the following sections:

Section 1: Background Provides a high-level summary of Topeka Metro service, battery-electric bus technology, and relevant policies (federal, state, industry, and agency specific). In addition, the results of a facility, electrical, and fleet assessment focused on Topeka Metro's existing and future compatibility to service electric vehicles and related technologies are included.

Section 2: Route Modeling Covers all route modeling aspects including an overview of the methodology used to conduct Route Modeling, step 1 baseline, and:

> ***Section 2.3: Step 2: Battery Energy Demand Redistribution:*** Summarizes the gaps and constraints identified in previous sections and presents an analysis of potential alternative mitigation strategies aimed to addressed identified gaps and constraints.
>
> ***Section 2.4: Modeling Step 3: Mitigation Scenarios:*** Provides an overview of the methodology used to conduct Route Modeling Step 3 and identifies 5 mitigation scenarios that could be used to facilitate an electric fleet transition.

Section 3: Infrastructure Analysis Provides an analysis of charging infrastructure alternatives in parallel with the modeling component and identifies optimized infrastructure installation locations.

Section 4: Financial Analysis: Presents four consolidated fleet replacement plans to support 25%, 50%, 75%, or 100% fleet transition over the next 16 years. Each fleet replacement plan has been developed based on fleet size needs identified through Modeling steps 1 – 3. The plan integrates the fleet retirement horizon with procurement lead times, facility capacity and service operations constraints.

Section 5: Implementation Plan: Presents a detailed procurement financing and investment timeline by year. Provides an updated future state blocking plan and an approach to progressively roll out electric service in conjunction with fleet replacement. Identifies important organizational changes from the perspective of Topeka Metro employees and external stakeholders and presents a proposed high-level approach to organize employee engagement and feedback.

1 Background

1.1 Topeka Metro Background

Topeka Metro is responsible for providing mobility services to the residents of Topeka, Kansas through a mix of fixed-route, on demand, and paratransit services. The agency operates 12 fixed routes, a flex service, and a paratransit service. Topeka Metro's services are described below:

- **Fixed Route**: 12 fixed-routes follow a point-to-point style.
- **The Flex**: A curb-to-curb on demand transit service constrained to servicing the general public within a specified geographical area.
- **The Lift Service**: Origin to destination demand response transportation service that complements regular line-service for qualified customers throughout Topeka Metro's service area.

A map of the fixed-route and flex service is shown in **Figure 3.**

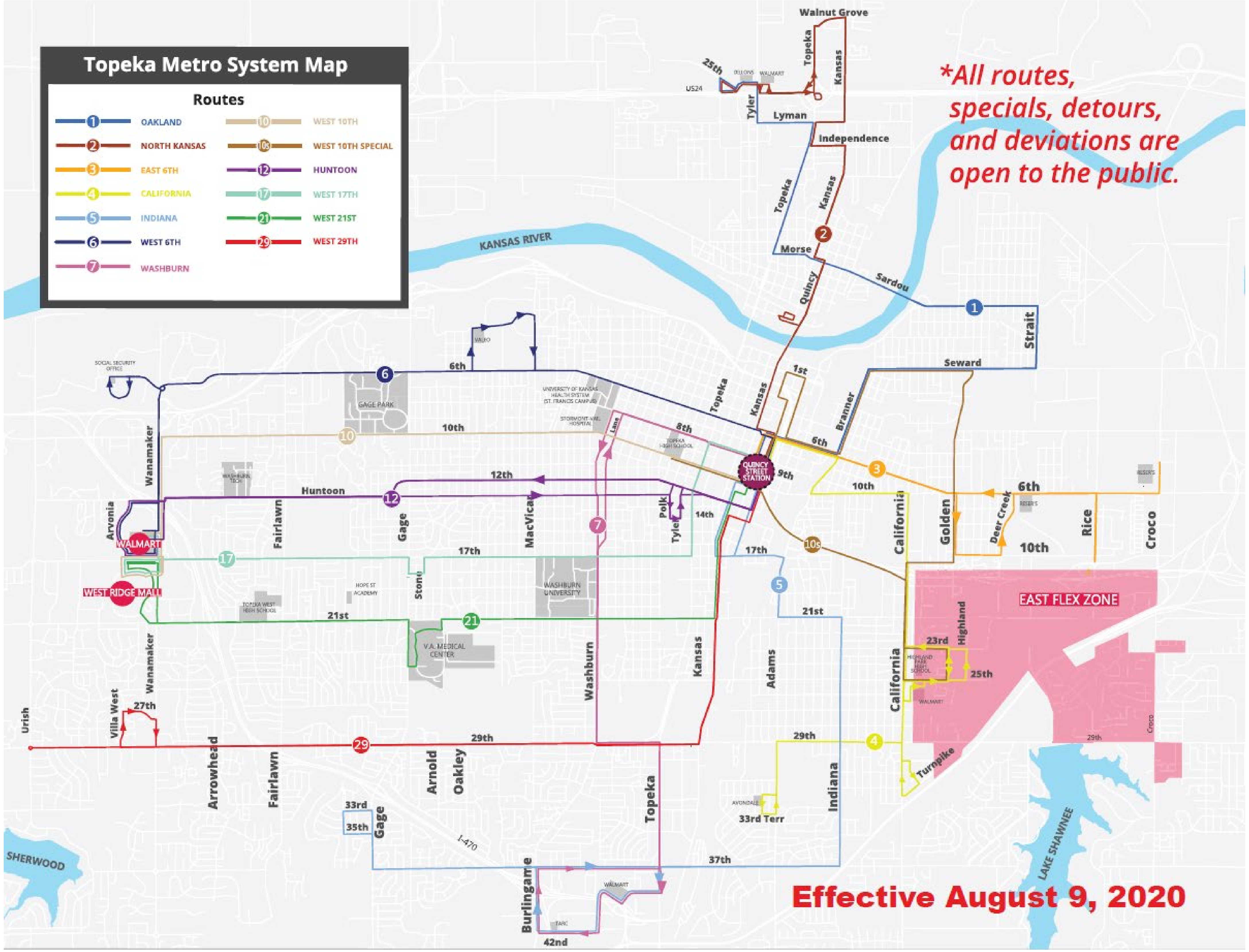

Figure 3. Topeka Metro System Map

1.1.1 Initial Electrification Deployment

Topeka Metro is procuring three Proterra battery electric buses and chargers that are expected to enter service in 2023. Topeka Metro has been working with Proterra on the build specifications for three 35’ ZX5 BEBs with 440 kWh batteries and three Industrial Series 120 kW DC fast chargers with 2 dispensers each. This initial equipment order will provide Topeka Metro with 6 available dispensers. These Proterra chargers can support up to 4 dispensers each for sequential charging, resulting in a potential total of 12 dispensers. When charging multiple vehicles, chargers are still limited to 120 kW therefore while charging a single bus takes about 3.5 hours it could take 14 hours or more to fully charge four buses using a single charger. Proterra BEBs come standard with a charging port on the rear passenger side. Topeka Metro’s build spec calls for an additional charging port at the front.

This study will confirm whether these charger and vehicle build specifications align with Topeka Metro’s long term electrification goals. These specifications may be adjusted to better meet its service needs.

1.1.2 Relevant Projects

In addition to this transition plan Topeka Metro has recently completed or is currently undertaking several other projects. Some ongoing Topeka Metro project and relevant projects within the region include:

- **Topeka Metro System Analysis –** This study, which was completed in April of 2022, evaluated the current and future mobility needs of customers. A specific focus was on identifying ways to increase efficiency and make service changes to accommodate the impacts of COVID-19 including an approximate 30% decrease in ridership.
- **Local Electric Transit Projects** – Neighboring communities including Lawrence, Wichita, and Kansas City are all transitioning from a fully diesel fleet to incorporating electric vehicles with the goal of either a mixed fleet or a fully electric fleet. The local electric transit project poses a potential opportunity for collaboration between Topeka Metro and neighboring communities. In addition, discussions between these nearby transit agencies could also be an opportunity to gain some insight on lessons learned especially with a focus on how Kansas climate conditions have impacted electric vehicle implementation efforts.
- **Private Vehicle Charging Station Projects –** The Kansas Department of Transportation (KDOT) is procuring electric vehicle charging stations for private vehicles on major corridors. A discussion between Topeka Metro and KDOT could potentially provide Topeka Metro with insight on strategic geographic selections for charging stations.
- **I-70 Polk-Quincy Viaduct Project** – In October 2021, a formal partnership agreement was established for the I-70 Polk Quincy Viaduct Project. The I-70 Polk Quincy Viaduct Project will replace the existing viaduct to ease traffic congestion and improve safety. Topeka Metro is cooperating with the project, however progression of the Viaduct Project has the potential to cause redevelopment of the Riverfront area adjacent to Topeka Metro’s Maintenance and Administrative facilities. This would disrupt Topeka Metro transit services.
- **Topeka’s Downtown Plan –** Completed in 2019, discusses districts including Riverfront South where Topeka Metro is located. The continued development of this district could ultimately offer Topeka Metro opportunities for relocation dependent on funding.

1.1.3 Long Range Transition Plan

Topeka Metro Reimagined! serves as the public transit agency's long range transition plan that:

- Documents existing conditions and services at Topeka Metro such as service coverage, land use, traffic impacts on transit
- Identifies and describes service priorities to consider moving forward
- Lists a set of short-, medium-, and long-term recommendations for improving existing conditions at Topeka Metro.

The priorities in the long-range transition were captured via public outreach and internal discussions with Topeka Metro staff and focus on both the priorities of the Topeka community and the Agency. The following priorities are identified and described in *Topeka Metro Reimagined:*

Public Driven Priorities

- Expanding Service Coverage (new routes)
- Expanding Weekend Service (Sunday Service)
- Expanding Weekday Service Hours
- Providing more Frequent/Faster Service

Agency Driven Priorities:

- Promoting Transit Supportive Policies
- Enhancing Customer Facing Service Elements
- Enhancing County and Regional Mobility

Public outreach and internal discussions with Topeka Metro staff were also conducted to identify short term (0-2 years), mid-term (3-5 years), and long-term (5+years) recommendations for improving Topeka Metro service. The following recommendations are included in the long-range transition plan in accordance with their estimated timeframe:

Short Term (0 – 2 years)

- Implement top service enhancements: adding a new route and Sunday service
- Expand Technology to improve efficiency, safety, and rider experience
- Identify preferred relocation site for the administration and maintenance facility if redevelopment of adjacent land use becomes imminent and funding is made available to cover relocation and new construction.

Mid-Term (3 – 5 years)

- Advance second tier improvements: adding South Topeka route, later evening hours, higher frequency service. Revisit regional commuting service
- Invest in fleet renewal, replacing buses due to retire in 2023-potentially with electric vehicles
- Investigate technology improvements to improve efficiency and convenience such as new payment platforms and backend system enhancements
- Work towards build-readiness of the relocated administration and maintenance facility

Long-Term (6 – 10 years)

- Relocate to the new administration and maintenance facility, if redevelopment of adjacent land use becomes imminent and funding is made available to cover relocation and new construction.
- Invest in fleet renewal, replacing buses due to retire in 2026 potentially with electric vehicles
- Identify and support a sustainable funding source
- Pursue visionary improvements to Topeka Metro bus service, such as regional service or autonomous vehicle operations

Throughout this project, Arcadis IBI Group will use the long-range transition plan as a point of guidance. And identify any potential opportunities to focus on specific priorities or achieve specific recommendations as they come up.

1.2 Battery-Electric Technologies

The purpose of this section is to investigate relevant, current, and emerging zero emission vehicle technologies based on an in-depth understanding of Topeka Metro's current operations, stakeholder needs and identified gaps described in this Report. The following information describes key technologies required of zero emission vehicles, existing alternatives, existing vendors, limitations, benefits, and provides information on recent zero emission technology implementations within the geographical context of Topeka, Kansas.

How it works

Battery Electric Buses (BEBs) use onboard batteries to supply energy for propulsion. The batteries also power other vehicle systems such as heating, ventilation, and air conditioning (HVAC), fareboxes, and cameras. Together, electricity used by these systems is called auxiliary load, and can vary quite significantly based on technologies installed onboard as well as the climate in which the agency operates. For example, transit fleets that operate in cities with a milder climate typically have lower auxiliary load due to minimal HVAC usage, compared to those in areas with larger temperature variation.

BEB Battery and Charge Monitoring

Modern BEBs use lithium-ion batteries. Depending on the manufacturer and vehicle model, BEB batteries typically have a storage capacity of 250 – 450 kWh, although in recent years some vendors have introduced ultra-long-range buses with battery capacity upwards of 600 kWh. Refer to Route Modeling tasks in Section 2 for more insights on what battery capacities are most suited for Topeka operations. Battery charge is monitored onboard to ensure assigned blocks can be completed, and this information is also relayed to central dispatch for fleet management. There are many solutions in the market today that perform further analysis on operational data gathered onboard BEBs, introducing key performance indicators (KPIs) such as average mile/kWh, electricity cost/mile, and total electricity usage. These can assist the agency in optimizing operations and reporting.

Heating and Cooling Options

Weather can have a significant impact on BEB range due to heating and cooling needs. Currently there are three common methods to heat BEBs in winter: electric heating, diesel space heater, and heat pump. For cooling, buses either use a heat pump or a dedicated air-conditioning system.

Electric heating draws power from the onboard battery and is generally suitable for operations in warmer climates. In colder areas such as Michigan and Wisconsin, studies have shown that energy usage for heating purposes can reach over 50% of total energy consumption[1]. In general, if outside temperatures consistently stay below 0 degrees during winter months, an alternative heat source should be provided to lighten auxiliary load.

A diesel auxiliary heating system is preferred by many agencies that operate under extremely low temperatures, such as Edmonton (Alberta, Canada), Racine (WI), and Boston (MA). As the name suggests, buses are equipped with diesel heaters for winter so as not to draw power from the onboard battery. These systems, however, have higher emissions than electric heating due to this focused use of diesel fuel.

Heat pumps are an emerging technology commonly used in Europe for BEB heating. Heat pumps draw power from the onboard battery, can switch between cooling and heating, and are more efficient than electric heaters. A study conducted in the German city of Darmstadt shows that in winter months (October – March), using a heat pump consumes less than one half of the energy required with electric heaters. In summer, however, heat pumps do not perform particularly better than air conditioners[2].

The most common air conditioners on BEBs are roof-mounted units that draw power from the onboard battery. Unless reversible heat pumps are installed on buses, air conditioners will be required to cool the interior in summer.

1.2.1 Charging

Electric Supply, Generation, & Storage

BEB batteries typically recharge using power supplied by the local power grid, though on-site power generation and storage is sometimes used in parallel. Due to the high energy demand of operating an electric fleet, most electricity needed will be supplied by the grid. This includes supplying the garage for in-depot overnight charging, as well as on-route opportunity charging, if implemented. Electrical infrastructure upgrades are likely required to accommodate increased power demand from existing charging infrastructure.

On-site generation and storage can help manage how much power is needed from the grid, and timing of grid power use to access time-of-day pricing and mitigate peak usage pricing. On-site storage can also provide some energy redundancy in the event of a power outage. For on-site generation, electricity is generated by solar panels and stored in batteries. Buses can then be charged using stored energy when they return to the garage.

Technologies

Section 1.4.3 introduces three key relevant dispenser formats associated with BEB charging, specifically the plug-in dispenser (SAE J1772 Combined Charging System (CCS) Type 1 standard), inverted pantograph (SAE 3105-1 standard), and wireless charging systems (at this point vendor-specific technology not yet standardized). For slower, in-depot charging up to 150 kW, all these dispenser formats are widely available on the market. For fast charging above 150 kW, inverted pantographs and wireless charging are the primary dispenser formats, due to electrical resistance and cooling constraints with plug-style connectors. BEBs are typically manufactured to the customer specified style of charging connection, including selected options for where to position plug-ins connectors relative to the BEBs parking locations (typically near one or more corners of the vehicle). It is common for buses to support both plug-in and

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[1] https://www.sciencedirect.com/science/article/pii/S0959652619346463?via%3Dihub
[2] https://www.eurammon.com/images/eurammon/events/symposium-2020/presentations/Day-3-Sonnekalb-CO2-heat-pumps-applied-to-modern-electric-buses.pdf

pantograph dispenser types, to allow for more charging configurations and opportunities on-route. For inductive charging, buses need a vendor-specific additional under-vehicle receiver connected to the battery for power transmission.

When transitioning to an electric fleet, most transit agencies will procure charging management software to help manage and minimize the cost of vehicle charging. A charging management system monitors charging processes, manages charging time to optimize battery health, and ensures appropriate charge management to avoid expensive peak loads. Charging management is becoming standard practice in BEB charging industry, for it improves operations efficiency and reduces costs.

Limitations

Two limitations associated with charging electric buses are charge level and charge rate, discussed in detail below.

When discussing BEB charge levels, an effective charge of 100% typically refers to 80% of the absolute battery capacity. Also, a battery is considered effectively empty once at 20%. On a scheduled and infrequent basis, BEB batteries are deliberately charged to 100% absolute capacity and then discharged to 0% absolute capacity in a maintenance procedure known as deep cycling. However, regularly charging or discharging the battery outside of the 20% to 80% absolute capacity range would impact battery lifespan.

As an example, a current 40-foot BEB may have high-end nominal battery capacity (i.e., as cited by the manufacturer) of about 660 kWh. These typical thresholds for battery charging and discharging would for this example result in an effective battery capacity of about 400 kWh and a typical practical range of 180 to 240 miles depending on operating conditions.

Charge rate refers to how fast a vehicle can be charged, usually in kW. If a BEB has a maximum charge rate of 150 kW, using a charging method capable of an output of 350 kW will not speed up charging past 150 kW. This is a particularly important specification to look out for in BEBs if on-route fast charging is to be implemented, as the agency will need to ensure that the buses procured can in fact take advantage of these quick top-up points.

Both charge level and charge rate can be managed and optimized by battery and charging management systems to prolong battery life. Users must recognize the limitations of charging as they will impact service design and delivery.

Depot Charging & Configuration

Current state-of-industry charging configurations feature one charger cabinet connected to multiple dispensers (commonly either plug-in connectors or roof-connect inverted pantographs). The charger will direct electricity to each connected bus, usually in sequence, fully charging one bus before moving on to the next. The buses can remain connected and stationary regardless of whether they are actively charging, to reduce labor and costs associated with repositioning buses.

A common BEB deployment model involves exclusively in-depot charging, typically delivered to individual vehicles at 150 kW or less using plug-in chargers and inverted pantographs. This requires equipping the depot with sufficient charging equipment and electricity service to charge all buses overnight to an effective level of 100%, and that each service block be designed based on the available onboard power from the bus battery capacity. For agencies with longer routes that cannot be modified, opportunity charging stations can be installed at terminals and layover points for a quick power up mid-block.

On-Route Charging & Configuration

As previously discussed, plug-in connectors are not suitable for on-route charging with power demand over 150 kW. Inverted pantographs and inductive charging pads can deliver such a level of power and are thus used for on-route charging. These chargers are more expensive than in-depot chargers due to higher power output and should be strategically placed to maximize their value. Best industry practices suggest that on-route charging stations should be located at terminals and layover points, where the infrastructure can serve many buses and to allocate enough dwell time per bus for the top-up.

1.2.2 Benefits

There are many benefits to transitioning the traditional diesel bus fleet to battery electric. Major benefits of BEBs include:

- **No Local Emissions** – BEBs produce no GHG (Greenhouse Gas) emissions from vehicle propulsion at the point of operation; upstream emissions depend on local electricity generation methods. In cold weather climates it is currently common to retain a small diesel-powered interior heater, which would produce a relatively low level of emissions.
- **Improved Air Quality** – BEBs have no exhaust, which improves local air quality by eliminating harmful pollutants such as particulate matter, nitrogen oxides, and carbon monoxide.
- **Reduced O&M Costs** – Pilot projects around the US have shown that BEBs have lower maintenance and fuel costs than their diesel counterparts. Although the capital cost of BEBs is higher than diesel buses, their lifetime cost is usually lower. This does not factor in the cost for purchasing and installing charging infrastructure.
- **Less Noise Pollution** – BEBs are quieter and create a more comfortable urban environment for pedestrians, cyclists and residents along bus routes.

1.2.3 Challenges

Challenges of BEBs compared with internal combustion engine vehicles are primarily related to the charging process, which is significantly more time consuming than refueling with diesel and gasoline. And the resulting coordination for charging multiple buses sequentially from each charger and scheduling charging around other maintenance needs. Specifically, the challenges include:

- **Range Limits** – current BEBs are unable to achieve the same range as a traditional diesel bus. Agencies using BEBs may require a larger fleet or a redesign of the service plan to break up long blocks (with a resulting increase in deadhead time) or include mid-day charging intervals. The most affected blocks will be those that are longer, involve routes with more/steeper grades, or where winter road conditions reduce the opportunities for regenerative braking.
- **Long Charge Times** – Fully charging a BEB can take anywhere from 30 minutes to 4 hours. Multiple variables contribute to the charging time, including onboard battery storage capacity and power ratings of both the battery and charging infrastructure. For a fully electric fleet, the amount of dedicated time required for charging can lead to operational rigidity in service and at the depot, with less downtime to correct for disruptions in scheduled service and routine maintenance. At worst, this increases the

potential for buses not to be sufficiently charged for the start of service. Strategies to mitigate this risk can include:

  - **Spare fleet** – Increasing the spare ratio of the fleet to provide more flexibility for dispatching and maintenance;
  - **Charging Management** – Implementing charging management software and system integrations to monitor power usage and dynamically adjust charging plans;
  - **Providing supplementary on-route charging** – Opportunity charging at strategic network locations can provide quick top-ups. On-route charging must account for the maximum constraint on charge rate imposed by the battery specification. For example, a bus that can charge at 200 kW while at a planned 6-minute layover could achieve only about a 20 kWh top-up;
- **Depot Configuration and Equipment** – Long charging times for each bus mean that most agencies will have to charge many buses in parallel to meet service needs. This typically requires all parking lanes to be outfitted with dispensers, with no more than two or three dispensers supported per charger cabinet. This comes with a significant capital investment cost. Space requirements are another key factor, due to technical limitations on how far the charger cabinets can be placed from the dispensers located at the bus lanes.
- **Range Sensitivity in Cold Weather** – The fuel economy and thus range of BEBs decreases in colder weather, especially if electric heating is also used for interior heating, rather than a diesel space heater or a more efficient heat-pump.

1.2.4 Implementations

Several transit agencies in Kansas and surrounding areas have deployed or are in the process of adding BEBs to their fleets. This section provides an overview of 3 BEB projects in neighboring agencies.

Wichita Transit, KS

Wichita Transit operates the largest electric bus fleet in Kansas, consisting of 4 Proterra Catalyst Electric Buses and 7 ZEPS Buses by Complete Coach Works. These vehicles are powered by 100% renewable energy (via proxy from Renewable Energy Credits) from Kansas wind farms under Evergy's (largest electric company in Kansas) Renewables Direct program. In 2021, City Council approved the purchase of an additional 24 BEBs, funding for which would primarily come from federal money. Wichita Transit plans to continue to partner with Evergy to install the necessary charging infrastructure.

Kansas City Area Transportation Authority (KCATA), MO

KCATA partnered with Evergy in 2021 to unveil two 40-foot electric buses from Gillig. Bus charging is supported by new ChargePoint charging stations installed at the garage. This project is funded by the Federal Transit Administration (FTA) and matching funds from Kansas City's transportation sales tax. The procurement of two BEBs is part of Kansas City's effort to achieve net zero by 2050, in accordance with the City's Climate Action Plan. KCATA plans to roll out more electric buses in the future.

Lawrence Transit, KS

In 2021 and 2022, Lawrence Transit received two separate FTA grants to replace 7 diesel buses in the fleet with BEBs. Five of the seven replacement buses, as well as their charging stations, are set to be in service by the end of 2022. Gillig and ChargePoint have delivered the 5 vehicles and charging infrastructure, respectively. The city has a goal of converting 100% of its fleet of vehicles to clean energy by 2035.

1.2.5 Vendors

A scan of BEB and charging infrastructure vendors with high market share or strong North American presence has been conducted to showcase industry capabilities. This is not an exhaustive list and does not signify preferences for these vendors.

BEB Vendors

Table 1. Battery Electric Bus Vendors

Vendor	Common Bus Models and Configurations*	Example Deployment
BYD	K7M: 30 ft, 215 kWh, 150 kW max charge rate K8M: 35 ft, 391 kWh, 150 kW max charge rate K9M: 40 ft, 313 kWh, 150 kW max charge rate	• Link Transit – Wenatchee, WA • Toronto Transit Commission – Toronto, Canada • Capital Area Transit System – Baton Rouge, FL
Gillig	Flexible configuration, customers may pick and choose: Size: 35 ft, 40 ft Battery Capacity: Current – 444 kWh Upcoming – 490 kWh, 588 kWh, 686 kWh	• MetroLink – Greater St. Louis Metropolitan, IL • Pinellas Suncoast Transit Authority – Pinellas County, FL • Park City Transit – Park City, UT
New Flyer	Flexible configuration, customers may pick and choose: Size: 35 ft, 40 ft, 60 ft Battery Capacity: 160 kWh – 525 kWh	• Massachusetts Bay Area Transportation Authority (MBTA) – Boston, MA • Regional Transit District (RTD) – Denver, CO • Capital District Transportation Authority (CDTA) – Albany, NY
Proterra	ZX5 35-Foot Bus: 35 ft, 225 kWh, 184 kW max charge rate ZX5+ 35-Foot Bus: 35 ft, 450 kWh, 370 kW max charge rate ZX5 40-Foot Bus: 40ft, 225 kWh, 184 kW max charge rate ZX5+ 40-Foot Bus: 40ft, 450 kWh, 370 kW max charge rate ZX5 MAX 40-Foot Bus: 40ft, 675 kWh, 370 kW max charge rate	• Mountain Metropolitan Transit – Colorado Springs, CO • START Bus – Jackson, WY • Edmonton Transit – Edmonton, Canada • GoRaleigh Transit – Raleigh, North Carolina
Nova Bus	Nova LFSe 40-Foot Bus: 40ft, 76 kWh	• Brampton Transit, Brampton, ON • STM, Montréal, QC • Houston Metro, Harris County, TX

Vendor	Common Bus Models and Configurations*	Example Deployment
	Nova LFSe+ 40-Foor Bus: 40ft, 564 kWh	
ElDorado National California (ENC)	Flexible configuration, customers may pick and choose: Vehicle Type: Axess BEB Low-Floor or Standard BEB chassis Size: 32 ft, 35 ft, 40 ft	• Procurement: First Transit – Atlanta GA
Vicinity	Flexible configuration, customers may pick and choose: Vehicle Type: Vicinity Lighting – Medium Duty Low-Floor BEB Size: 32 ft, 35 ft, 40 ft Battery Capacity:168 – 252 kWh Standard level 1-3 charging capabilities,	• Procurement: Billy Bishop Toronto City Airport, Canada
Green Power Motors	EV 250- 30-32 ft, 260kWh, 160 kW max charge rate EV 350- 40.3 ft, 400kWh, 350 kW max charge rate	• City of Vancouver • San Diego Airport Parking Co. • Jacksonville Transportation Authority • University of California San Fransisco
Hometown Coach	View- 17 ft, 226 kWh, 150 kW max charge rate	
Motor Coach Industries (MCI)	J4500 Charge- 45 ft, 544 kWh D45 CRT LE Charge- 45 ft, 389 kWh, 320 kW max charge rate D45 CRT Charge- 45 ft, 520 kWh, 320 kW max charge rate	

*Note that most BEB vendors support manufacturing buses with custom configurations to better meet a transit agency's operational needs.

Table 2. Battery Electric Demand Response Vehicle Vendors

Vendor	Common Bus Models and Configurations*	Example Deployment
GreenPower Motors	EV Star: 25 ft, 118 kWh, 61 kW max charge rate, (range 96 – 153 miles)[3]	
Forest River Bus	Ford E-450 Cutaway: 26 ft, 122 kWh, (range 93 – 119 miles)	
E-Bus Inc	22T: 84 kWh (range 53.4 miles)	
Phoenix Motorcars	Zeus 400: range 100-160 miles, 100 kW/160kW	•
Motiv	EPIC4- 24 ft, 127kWh (range 105 miles), 19.2 kW / 60kW charging rate	• City of Mountain View
Optimal EV	S1-26.6 ft, 113kWh (125 miles range), AC LCL2 charger/ DC fast charge	•
Endera	B6- 26 ft, 150 miles range, AC LCL2 charger/ DC fast charge B8- 28 ft, 150 miles range, AC LCL2 charger/ DC fast charge	• San Diego International Airport • Illumina • Aladdin Airport Parking
Girardin Blue Bird	G5e: 118 kWh, (range 120 miles*)	• STM (Montreal) – Pilot Project
Lightning E-motors	GMC Savana 4500 / Chevrolet Express 4500: 125 kWh Ford E-450:	• Only non-transit applications so far.

* Note grey cells indicate that the bus has not undergone Altoona testing. Altoona Testing is an FTA-funded program that states that all new bus models must be tested at the Bus Research and Testing Center (BRTC) at Altoona, PA before they can be purchased in the nation with federal funds. It was established in response to the requirements of the 1987 Surface Transportation and Uniform Relocation Assistance Act (STURAA) to ensure that transit customers purchase safe vehicles that can withstand the rigors of transit service.

Charging Infrastructure Vendors

BEB vendors often offer charging solutions in parallel. Specialized charging infrastructure vendors also exist in the market, most of which follow the Open Charge Point Protocol (OCPP) Standard and thus compatible with various charging management systems. And also at least the ISO 15118 standard for communications compatibility between chargers and buses.

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[3] Per Altoona Testing for fully loaded Manhattan, Orange County Bus Cycle, and the HD-UDDS https://www.altoonabustest.psu.edu/bus-list.aspx

Table 3. Battery Electric Demand Response Charger Vendors

Vendor	Common Charging Solutions	Example Deployment
ABB	J1772-CCS Type 1 plug-in charging; SAE J3105-1 pantograph charging; Available in a range of power levels from 60 – 180 kW.	• Metro Transit – St. Louis, MO • Laketran – Lak County, OH
Heliox	J1772-CCS Type 1 plug-in charging; Available in a range of power levels from 50 – 600 kW.	• Knoxville Area Transit – Knoxville, TN • King County Metro – Seattle, WA
InductEV (formerly Momentum Dynamics)	On-route inductive charging at 50 to 450 kW; In-depot inductive charging.	• Link Transit – Wenatchee, WA • Chattanooga Area Regional Transportation Authority – Chattanooga, TN
Proterra	J1772-CCS Type 1 plug-in charging; SAE J3105-1 pantograph charging; Available in a range of power levels from 60 – 180 kW.	• Santa Clara Valley Transportation Authority – Santa Clara, CA • Los Angeles Department of Transportation – Los Angeles, CA
Siemens	SICHARGE UC Product Family Power Range: 100 kW – 600 Kw Charging options: Dispenser, contact hood, or inverted pantograph	• GoRaleigh, Raleigh NC • Charlotte Area Transit System (CATS), Charlotte NC
BTC Power	AC, DC, and split systems (DC) charging options SAE J1772 Charging Available power range from 30-360 kW	• Volkswagen • Ford • Electrify Canada
BYD	AC, and DC charging options SAE J1772 CCS-1 plug-in charging Overhead charging (SAE J3105-1) up to 450 kW Wireless Charging Up to 300kW	
ChargePoint	ChargePoint Express 250 125 kW overall power 2 CCS Type 1 dispensers	• San Francisco MTA

Vendor	Common Charging Solutions	Example Deployment
EFACEC	EVORE LMS- CHAdeMO, CCS, and AC Type-2- Simultaneous chargers for 3 vehicles HV 350 G2- Up to 350 kW	
Tritium	Different variants available from 50-350 kW Connector Types- CCS1 or CCS1 and CHAdeMO	• Lynkwell
Wave	Wireless charging, Up to 250 kW	• Twin Transit • Antelope Valley Transit Authority • Metro McAllen • Pinellas Suncoast Transit Authority

1.3 Federal & Local Regulations & Policies

1.3.1 State & Regional

Excavation and Construction Adjacent to Kansas River Levee

The Kansas River Levee, made up of a series of berms, floodwalls, and pump stations along the river, mitigates flood risk in the metropolitan area of Topeka. The Topeka Metro garage is located just south of the South Topeka Floodwall. Construction near the levee is governed by Chapter 17.20 of the Topeka Municipal Code: Construction Adjacent to Flood Control Levees.

The code specifies that permits must be obtained prior to any excavation and construction within 1,000 feet landward or riverward of the centerline of any portion of a flood control works located within the corporate limits of the City. Permits requested of the City are reviewed by the City Engineer to determine if proposed work will impair or endanger the function of any flood protection works. In addition to the special permit, existing zoning bylaws and applicable building codes must be followed for construction.

Kansas National Electric Vehicle Infrastructure (NEVI) Plan

The State of Kansas recently received $39.5 million in National Electric Vehicle Infrastructure (NEVI) Formula Funds to pay for EV (Electric Vehicle) infrastructure. The Kansas Department of Transportation (KDOT) was required to submit an EV Infrastructure Deployment Plan (Plan) to the DOT and U.S. Department of Energy (DOE) Joint Office by August 1, 2022, describing how the state intends to distribute NEVI funds. Plans must be established according to NEVI guidance. NEVI Program funding has now been awarded to Kansas and other States. Topeka Metro should investigate if any funding can be allocated to its BEB infrastructure, though the NEVI program is oriented to DCFC installations for public access at intervals near highway corridors.

KDOT Access, Innovation, and Collaboration (AIC) Program

KDOT’s Access, Innovation, and Collaboration (AIC) Program is a funding opportunity presented by the Kansas Department of Transportation to support a variety of projects for transit agencies operating within the state of Kansas. Eligible projects include but are not limited to bus replacements, bus equipment, bus facilities, and transit-related planning studies.

1.3.2 Federal

Low or No Emission Vehicle Program – Federal Transit Administration (FTA)

The Low or No Emission Vehicle Program (49 U.S.C. § 5339(c)) is a funding opportunity by the FTA for transit agencies to purchase or lease zero-emission/low-emission transit buses and supporting infrastructure. Funding of this program is allocated on a competitive basis. Once granted, Funds remain available for obligation for four fiscal years. Applicants must submit a Zero-Emission Transition Plan to the FTA, as discussed in the following subsection, to be considered for funding. This plan shall function as Topeka Metro's Zero-Emission Transition Plan and will address all related FTA requirements.

Grants for Buses and Bus Facilities Program – FTA

The Grants for Buses and Bus Facilities Competitive Program (49 U.S.C. 5339(b)) makes federal resources available to transit agencies to replace, rehabilitate and purchase buses and related equipment and to construct bus-related facilities, including technological changes or innovations to modify low or no emission vehicles or facilities. Funding is provided through formula allocations and competitive grants. Similar to the Low or No Emission Vehicle Program, applicants must submit a Zero-Emission Transition Plan (see the following subsection) if the fund is to be used towards purchasing BEBs and supporting infrastructure.

Zero-Emission Transition Plan – FTA

To apply for and receive funding from the Grants for Buses and Bus Facilities Competitive Program (49 U.S.C. 5339(b)) and the Low or No Emission Program (49 U.S.C. § 5339(c)), any projects related to zero-emission vehicles must include a Zero-Emission Transition Plan. The plan must cover the following content, as extracted directly from the FTA webpage[4].

- 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.
- Address the availability of current and future resources to meet costs for the transition and implementation.
- Consider policy and legislation impacting relevant technologies.
- Include an evaluation of existing and future facilities and their relationship to the technology transition.
- Describe the partnership of the applicant with the utility or alternative fuel provider.
- 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.

Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Discretionary Grant – U.S. Department of Transportation (DOT)

The U.S. Department of Transportation (DOT) Rebuilding American Infrastructure with Sustainability and Equity (RAISE) grant program provides federal financial assistance to eligible

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[4] https://www.transit.dot.gov/funding/grants/zero-emission-fleet-transition-plan

surface transportation infrastructure projects. Typically projects with high capital costs that have significant local and regional impacts, such as transit corridors, multimodal transportation centers, and rural area access improvement. RAISE project applications are reviewed and selected based on merits, with the criteria being:

- Safety;
- Environmental Sustainability;
- Quality of Life;
- Mobility and Community Connectivity;
- Economic Competitiveness and Opportunity;
- State of Good Repair;
- Partnership and Collaboration; and
- Innovation.

Although the procurement and installation of BEBs and supporting infrastructure alone do not qualify for the RAISE grant, a more comprehensive project with BEB components may be a strong candidate for the program.

1.4 Industry Regulation, Policy, & Standards

An in-depth understanding of regulations, policies, and standards associated with zero emission technologies will be essential to support a smooth transition to a zero emissions fleet. Arcadis IBI Group has extensive experience working in accordance with the following standards and has provided high level summaries of key industry standards to understand throughout any zero-emission vehicle transition project.

1.4.1 Open Charge Point Protocol

The Open Charge Point Protocol (OCPP, most up-to-date version 2.0.1) is an open-source communication standard for EV charging stations and charging station management systems. The protocol allows any EV charger to work with any charging management software, providing a vendor-neutral standard that unifies communication throughout the industry. Adopters of the OCPP include some of the industry’s largest charging operators and researchers, such as ChargePoint, Siemens, and ABB. Although not mandatory for providers, OCPP compliance enables customers to choose from a variety of solutions rather than be tied to one vendor or supplier. It is an emerging best practice in the charging industry. It will be critical to successful energy management for Topeka Metro to confirm specific OCPP version compliance before purchasing BEB’s, charging equipment, or energy management software.

1.4.2 OpenADR

OpenADR is an open and secure foundation for interoperable information exchange to facilitate automated energy demand response. It is typically used to send information and signals between distribution system operators (DSOs), utilities and energy management and control systems to balance energy demand during peak times. OpenADR is an open, highly secure, and two-way information exchange model, and a Smart Grid standard.

1.4.3 Society of Automotive Engineers (SAE)

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. Three standards related to EVs are discussed in this report.

SAE J1772: Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler

J1772 covers the general physical, electrical, functional and performance requirements to facilitate conductive charging of electric vehicles (EV) and or plug-in hybrid electric vehicles (PHEV) in North America, specifically requirements for the electric vehicle conductive charge system and coupler. This is the most common charging method for EVs where vehicles are plugged in to draw power from the grid through charging stations.

The J1772 standard defines the 5-pin connector **Figure 4** that can support AC charging up to 19.2 kW, as well as the 7-pin combined charging system (CCS 1, **Figure 5)** that supports DC fast charging up to 350 kW. The CCS configuration gives users the flexibility to choose between the slower Level 1/Level 2 charging and Level 3 DCFC fast charging, meeting the diverse needs of EV operators.

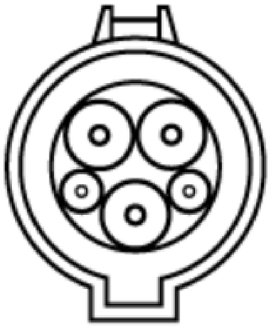

Figure 4. J1772 5-pin Connector[5]

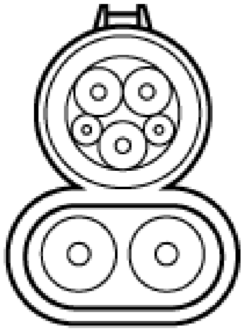

Figure 5.J1772 7-pin Combined Charging System (CCS Type 1) [6]

SAE J3105/1: Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices Infrastructure-Mounted Pantograph (Cross-Rail) Connection

J3105/1 describes the requirements for the Electric Vehicle Power Transfer System Using Conductive Automated Connection Devices Infrastructure-Mounted Pantograph (Cross-Rail) Connection, also known as a bus-down pantograph or inverted pantograph. J3105 encompasses 3 standards for different configurations of pantograph connection, only cross-rail is discussed in this report as it is the most commonly deployed in North America.

Inverted pantograph connection charges buses by extending overhead chargers on a pantograph and connecting to the bus’s roof-mounted rails. Buses must remain stationary while being charged. This type of connection can be used for both in-depot charging and opportunity charging, with opportunity charging typically having higher power output that allows for faster charging. Pantograph charging stations for opportunity charging are typically located at central terminals and layover points, where buses have scheduled stops for a brief period. In-depot pantograph charging power demand usually vary between 50-150 kW, whereas on-street opportunity charging commonly has a power range of 150-600 kW.

Figure 6 showcases an opportunity charging infrastructure-mounted pantograph in action in New York City.

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[5] https://chargehub.com/en/electric-car-charging-guide.html#:~:text=Level%201%20and%202%20Connectors,level%201%20and%202%20charging.

[6] https://chargehub.com/en/electric-car-charging-guide.html#:~:text=Level%201%20and%202%20Connectors,level%201%20and%202%20charging.

Figure 6. J3105/1 Pantograph Connection[7]

SAE J2954/2: Wireless Power Transfer & Alignment for Heavy Duty Applications

J2954/2 establishes a specification guideline that defines acceptable criteria for the interoperability, electromagnetic compatibility, minimum performance, safety, and testing for wireless power transfer for high power wireless charging of BEV (Battery Electric Vehicle) and PHEV vehicles, for heavy-duty, off-road and equipment applications. Wireless charging for BEBs comes in the form of charging pads, see **Figure 7** below for example. Despite this standard, some current inductive charging products are proprietary and not fully compliant.

Figure 7. Wireless Charging Pad[8]

Wireless charging is also known as inductive charging. Typical commercial charging configuration has a power output between 200 kW and 300 kW, though more power can be achieved by adding more pads. Buses must be equipped with a receiving device connected to the batteries to draw power from these charging pads. Inductive charging is more often used for on-route opportunity charging rather than depot charging due to higher cost and implementation complexity[9].

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[7] https://www.nydailynews.com/new-york/ny-mta-electric-bus-purchase-20210525-c7r47mlpnjahjmmuxqmvlivqaa-story.html
[8] https://thedriven.io/2020/06/23/washington-e-buses-get-300kw-wireless-charging-system/
[9] https://www.researchgate.net/project/Life-Cycle-Assessment-of-Wireless-Charging-Technology-for-Electric-Vehicles

1.4.4 International Organization for Standardization (ISO) 11898 – Controller Area Network

Controller area network (CAN) is an electronic communication bus defined by the ISO 11898 standards (11898-1 and 11898-2). These standards enable communication with onboard devices and intelligently control them based off feedback from a component. Collectively, this system is referred to as a CANbus.

CANbus systems can communicate with battery chargers to improve charging efficiency and battery life. As battery technology improves, electric vehicle charging intelligence moves from charger only to a combination of charger and battery. Some lithium-ion batteries can monitor their own status through the battery management system (BMS) and use CAN remote control for a variety of purposes, allowing the battery to control the charge parameters as it deems necessary. For example, if the battery starts to approach 20% battery life, the BMS can send a CAN remote control message to scale down power usage until the vehicle can be plugged in at a charging station.

1.5 Topeka Metro Policies & Practices

The purpose of this section is to identify existing policies and procedures at Topeka Metro that will be important to consider throughout this project to facilitate a smooth transition to a fully electric fleet with minimal disruption. This section will help to identify areas of the labor agreement that might be impacted by or should be considered during a transition to a fully electric fleet. A deep understanding of existing policies and practices at the beginning of the project will help to address potential violations by providing ample time to discuss challenges and develop potential solutions to the transition to electric vehicles with relevant organizations and staff well in advance of any implementation. In addition, understanding daily practices at Topeka Metro such as pull-in and pull-out practices will provide Arcadis IBI Group insight on what works well at Topeka Metro that should remain when implementing BEBs and what could be updated to allow for more efficient workflows and better suit BEBs.

1.5.1 Labor Agreements

Topeka Metro maintenance staff and operators are organized under the Amalgamated Transit Union Division 1360. Based on conversations with Topeka Metro as well as reviewing the labor agreement. Based on this preliminary none of the agreement conflicts with the transition to electrification. Some of the key provisions relevant to electrification though include:

- Topeka Metro has "the right to engage [third parties for maintenance] provided it does not lay off any regular maintenance employees capable of doing such work" (Clause 1.3).
- Layoffs and hiring for new positions are to be completed based on seniority in the same occupational group except for employees who have been on layoff for over 2 years (Clause 1.13)
- Topeka Metro "shall maintain a job description for each job classification. Union officers and stewards will be provided the opportunity to make suggestions or recommendations…" (Clause 1.25).
- Topeka Metro shall pay overtime pay at 1.5 pay for all hours worked over 40 hours per week and workers shall be paid spread time at 1.5 pay for any work performed in excess of a spread of 13.5 hours. In addition, staff will receive 1.5 pay for all work performed in excess of their regular assignment. (Clause 2.4)
- Topeka Metro operators are not provided with lunchbreaks however, operators are given a 5-minute recover time at Quincy Station.

1.5.2 Priority Routes or Services that have Constraints

Topeka Metro has expressed that maintaining and strengthening positive customer experience by minimizing adverse impacts to reliability, travel times, and other factors is a priority for this project. A deep understanding of priority routes and potential modifications to existing services and or routes will allow Arcadis IBI Group to strategically plan and develop optimal service solutions when transitioning to BEBs that will aim to maintain and strengthen a positive customer experience. After detailed discussions with Topeka Metro it was established that all high ridership routes should be considered priority routes. High ridership routes include Routes 6, 10, and 17. In addition, Topeka Metro is interested in adding a micro-transit zone to their service area, a cross-town route, and is considering combining the #1 Oakland and #5 Indiana routes.

1.5.3 Standard Operating Procedures (SOPs)

Topeka Metro has developed several standard operating procedures (SOPs) that promote efficient and mindful movement patterns within and around Topeka Metro Facilities. Existing SOPs have been developed around the existing infrastructure and therefore, have been successful in creating efficient and safe movement throughout the Topeka Metro property. The following SOPs have been developed for key processes that occur daily at Topeka Metro. An in depth understanding of existing SOPs and workflows at Topeka Metro will help support a successful transition from all diesel vehicles to a mixed fleet of diesel and battery electric vehicles, and eventually to a full fleet of battery electric vehicles.

Morning Bus Line Up: The PM dispatcher or afternoon Operations Supervisor is responsible for vehicle assignment. The vehicle assignment process begins after both paratransit and fixed route buses have been fueled, washed, and parked in the garage (in accordance with vehicle lane types). A morning dispatch bus line up sheet is filled out by either the PM dispatcher or afternoon Operations Supervisor by assigning specific vehicle numbers in accordance with morning departure times to facilitate smooth pull-outs. For example, for fixed route vehicles the earliest departure will be assigned to the bus farthest east in lane 3. For demand response, the earliest departure time will be assigned to the vehicle farthest east in Lane 1. The bus line up sheet is completed every day except for Friday (Saturday service requires fewer vehicles and therefore a bus line up sheet does not need to be completed).

To coordinate which buses need maintenance and should not be scheduled for service the following day, Maintenance provides Dispatch and the Operations Supervisor with a list of buses planned to be on hold or used as a tripper for the next day. A tripper is a vehicle that performs service only during the morning and/or afternoon peaks and available for maintenance for part of the day. The list sent by Maintenance is then written on a whiteboard by either the morning Operations Supervisor or Dispatch.

Morning Vehicle Assignment The morning supervisor at around 5:10 am will use the information posted on the whiteboard and the actual line up in the garage to confirm information filled out on the bus line up sheet. Once the bus line up sheet has been made accurate, dispatch will assign operators to vehicles for the first 18 routes of the day on the operators sign-in sheet.

As operators arrive at the garage and clock in, each operator will receive their vehicle assignment via the operator sign in sheet and begin to conduct a pre-trip inspection. A secondary verification of correct vehicle assignment via a radio call will also occur before pull-out. Once operators receive the approval from dispatch via radio, operators begin the pull-out process. The vehicle assignment process is a 10 – 15- minute task that allows the earliest bus to leave around 5:25 am.

Morning Pull Out: Once an operator has confirmed with dispatch via radio their vehicle assignment, buses will begin the morning pull-out process. Both paratransit and fixed route vehicles follow a standard pull-out pattern to facilitate smooth and safe pull-outs. The first paratransit vehicle to exit the garage is always the east most vehicle in Lane 1. Once all vehicles from lane 1 have exited the garage, paratransit vehicles in lane 2 will begin their departure and the vehicles behind will follow except for the west most vehicle in lane 2. The west most vehicle in Lane 2 will exit out of the west side of the garage. During peak hours, approximately 7 paratransit vehicles are to support Lift service at Topeka Metro.

Fixed Route vehicles follow a slightly different pattern, starting with Lane 3 the east most vehicle will exit the garage. Following will be the east most vehicle in Lane 4, this pattern will continue until all east most vehicles in lane 3 -8 have exited the garage. The pattern will restart by going back to lane 3 and continuing the process. **Figure 8** describes the morning pull-out patterns for both Lift vehicles and fixed route.

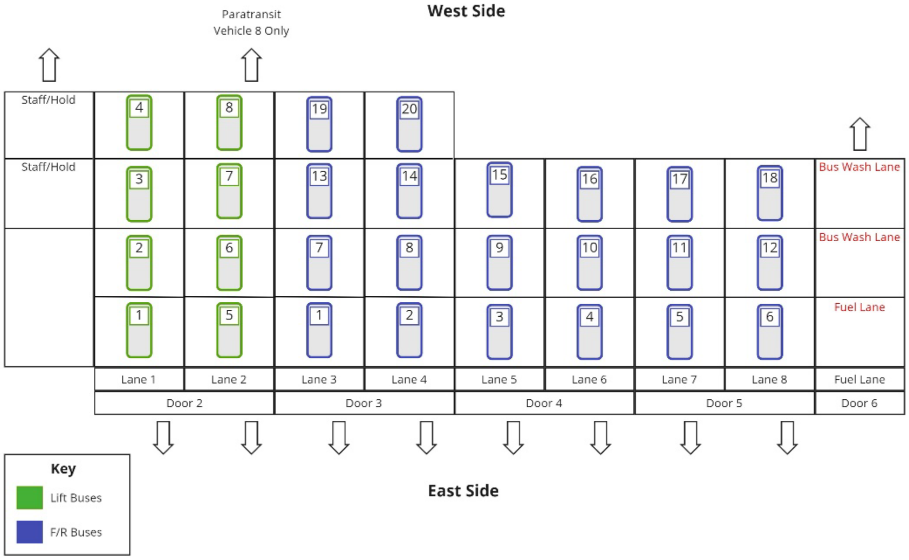

Figure 8. Morning Pull-Out Pattern

Splits and Trippers: Some buses will stay out in service for the entire day while others operate on a split. Operators running split vehicles are relieved at Quincy Station. Trippers have 4 runs in the morning and usually return to the garage 2 hours after their departure time from the garage. Vehicles with mechanical issues that are undergoing maintenance and cannot support a full day of trips make up the tripper vehicles at Topeka Metro. Operators returning to the garage for afternoon splits will enter through the West side. 5 -7 of the returning buses from afternoon splits will depart the garage to support afternoon routes.

Afternoon Line Up and Bus Assignments: Around 12:15 PM dispatch will begin the afternoon line up and bus assignment process in preparation of the arrival of afternoon operators by going to the garage and completing the afternoon bus line up sheet.

Afternoon Pull-Out: As afternoon operators clock-in and receive their vehicle assignment they will approach their assigned vehicle and confirm vehicle assignment with scheduling and dispatch via radio. Once vehicle assignments have been confirmed Lift operators will pull out following the same patterns as morning operators, as shown in **Figure 9**. Fixed route operators following a slightly different pattern required of morning pull-out. In the afternoon, fixed route vehicles will exit the garage by clearing out Lane 3 through Door 3 first and then will continue to Lane 4 Door 3 and so on.

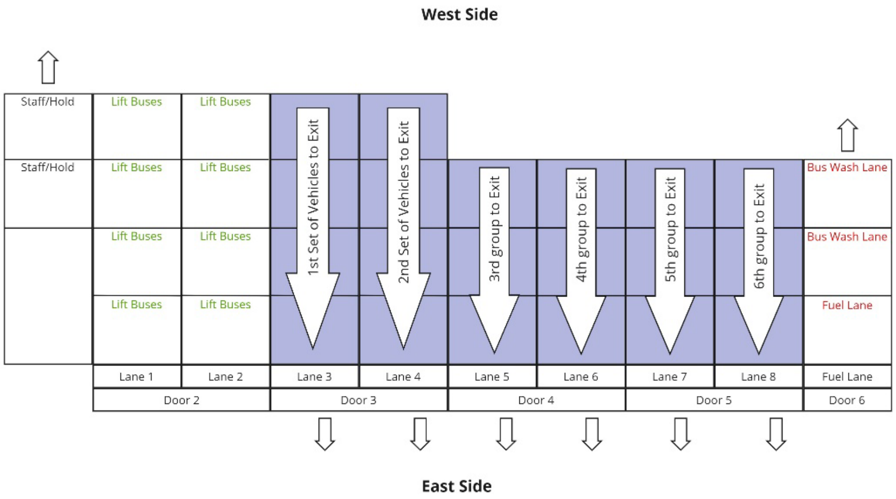

Figure 9. Fixed Route Afternoon Pull-Out Pattern

Evening Pull-in: At the end of each day, a bus line up sheet is filled out to support evening pull-in. Operators drop off the bus outside lane 6, and then maintenance staff will fuel and wash the vehicle with the vehicle entering on the east side of lane 6. Farebox probing and vehicle vacuuming are also conducted in the fuel/wash lane as part of this process. Once the vehicle fueling, washing, probing, and vacuuming is complete, the vehicle will be driven out of the garage on the west Side, make a 180-degree turn to re-enter the garage through the west side and park for the night. The evening pull-in pattern is illustrated in **Figure 10** The last bus to pull-in for the day typically approaches the garage at around 5:30 PM.

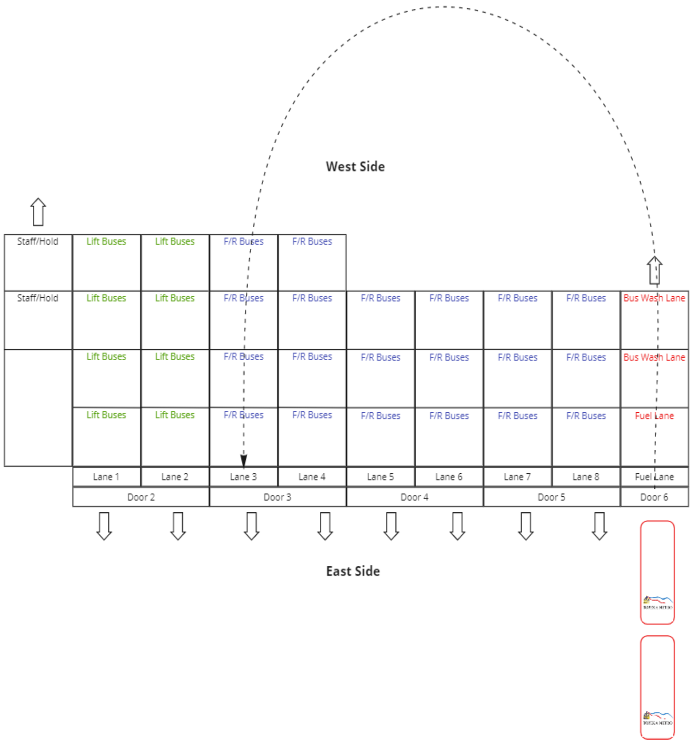

Figure 10. Evening Pull-in Pattern

Having started the morning pull-out at around 5:30 am and completed the evening pull-in around 5:30 pm, nearly twelve hours are available for the overnight charging process.

1.6 Facility Assessment

Topeka Metro operates two primary facilities that have been considered in this report. The first is its Operations/Administration and Maintenance Facilities located at 201 North Kansas Avenue. This site is known as the Ryan Building. The second is Quincy Street Station, the primary transfer point, located at 820 Southeast Quincy Street.

The Ryan Building is depicted on the boundary survey in **Figure 11.** The Maintenance Facility is the red-roofed building located to the west while the Operations & Administration Facility is located to the east. The existing buildings and operations at this site are constrained, allowing little room to construct new facilities or create an outdoor charging yard.

The Ryan Building lies alongside the Kansas River and its levee, which is under the jurisdiction of the Army Corps of Engineers. The levee limits any property expansion to the north. To the east, the property is constrained by N. Kansas Avenue, which can be used to access the site, and the river bridge. Limited staff parking is available under the overpass. The City of Topeka owns the parcel to the west, affording an opportunity for future westward expansion. From an operations standpoint, however, westward expansion would not facilitate the transition to electric vehicles.

Figure 11. Topeka Metro Operations & Administration and Maintenance Facilities Ariel View Facing North[10]

The Operations & Administration Facility is a single-story, mixed-use building, containing both administrative areas and the fleet parking garage. It previously included fleet maintenance operations within the west addition, however that operation was moved out to a new building about 20-years ago. The remaining maintenance space has been converted into parking for relief vehicles, supervisor vehicles and Lift paratransit vehicles. An old service pit in Lane 2 forces the paratransit vehicle to enter and exit to the west.

Although no original construction documents have been found, a visual review of the building indicates it is a concrete structure with masonry walls and metal fascia panels. The roof structure consists of concrete beams and ribbed concrete decking supported by concrete columns. The parking lane bays have a typical height of 11’-10” to the bottom of concrete beams and 14’-6” to the bottom of the concrete ribbed decking. Several gas-fired heater units hang from the roof structure, and these drop to within 10’-11” above the floor. These overhead clearances would allow for running conduit and hose reels within the lanes, but they would likely not allow sufficient clearance for pantograph charging. Approximately 13’-4” feet clear would be needed for pantographs. Given that each pantograph weighs approximately 400 lbs., it is unlikely that the roof structure could support such equipment. A picture of the typical roof structure is shown in **Figure 12**.

The facility has the capacity of 22 fixed-route vehicles and 12 paratransit vehicles as shown in **Figure 13**. Two lanes of vehicles share a single garage door on both the entrance and exit of the building (generally the west and east side, respectively) as shown in **Figure 12**. Parking as well as pull-in and pull-out considerations are described in **Section 1.5**.

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[10] Graphic TMTA Exhibit A, CFS Engineers

Figure 12. Interior Photo of the garage area at the Administration & Operations Facility

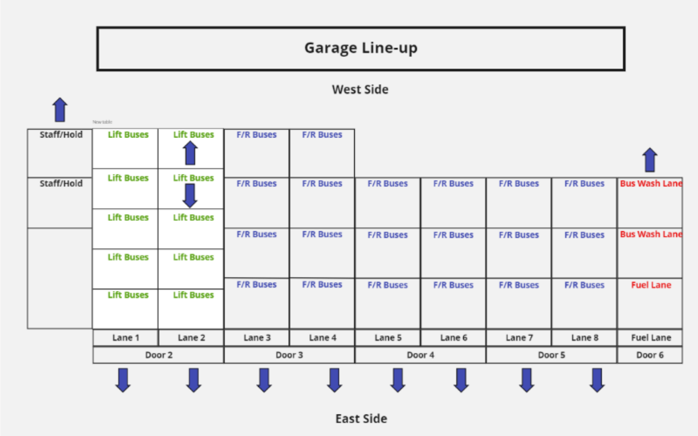
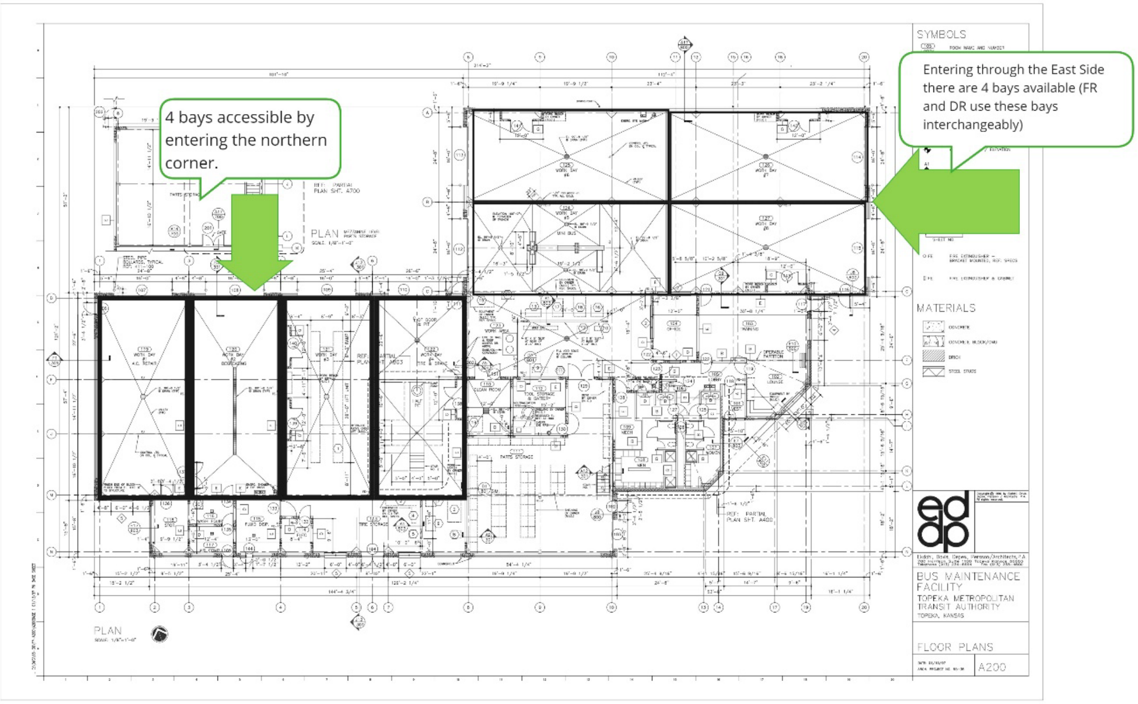


Figure 13. Garage Line Up

The Maintenance Facility is the centralized location for all fleet bus and van servicing and repairs. This building is relatively new, having been constructed around 2000. This is a steel-framed structure with masonry walls and a pitched, standing seam metal roof. Interior overhead clearances are suitable for lifting the fixed route buses for typical undercarriage service. The average clearance within the service bays is 18’-8” to the underside of the steel roof joists. The roof deck height varies with the roof pitch. Suspended HVAC equipment limits overhead clearance in Work Bays 2 and 7 to approximately 14’-6” above the floor. However, the remaining bays have sufficient overhead clearance to service BEB’s.

BEB maintenance is generally similar to diesel fueled buses with regards to wheels, suspensions, and brakes. A typical BEB drivetrain has very few moving parts – only the traction motor (and transmission when present). The reduction in moving parts will eventually reduce parts inventory and storage needs. Changes introduced by BEBs involve the frequency of working around high-voltage components, and for the battery pack the replacements and servicing of their thermal management systems. High-voltage battery repair requires unique tools, equipment, and training, which should be provided by the BEB manufacturer. All hand tools should have a heavy duty insulated barrier, and high-voltage gloves and other PPE (Personal Protective Equipment) should be routinely checked.

The Maintenance Facility has 8 work bays that can support both fixed-route buses and Lift vans, including preventative maintenance bays and a degreasing/wash bay in #2. Work Bay # 3 is equipped with an above ground lift and has +/-18'-8" of overhead clearance. Work Bay # 1 was originally designed for air conditioning repairs and would make a suitable BEB service bay. It is equipped with mobile, wheel-engaging lifts, which would allow for undercarriage battery pack access.



4 bays accessible by entering the northern corner.

Entering through the East Side there are 4 bays available (FR and DR use these bays interchangeably)

Figure 14. Topeka Metro Maintenance Facility

Quincy Street Station is located a little over 1 mile south of Topeka Metro’s Operations and Administration Facility. This station is used as a major customer transfer point, rather than as a destination point. This minimizes deadheads as all routes connect here. The station has designated boarding spots for each route as is shown in **Figure 15** and **Figure 16**.

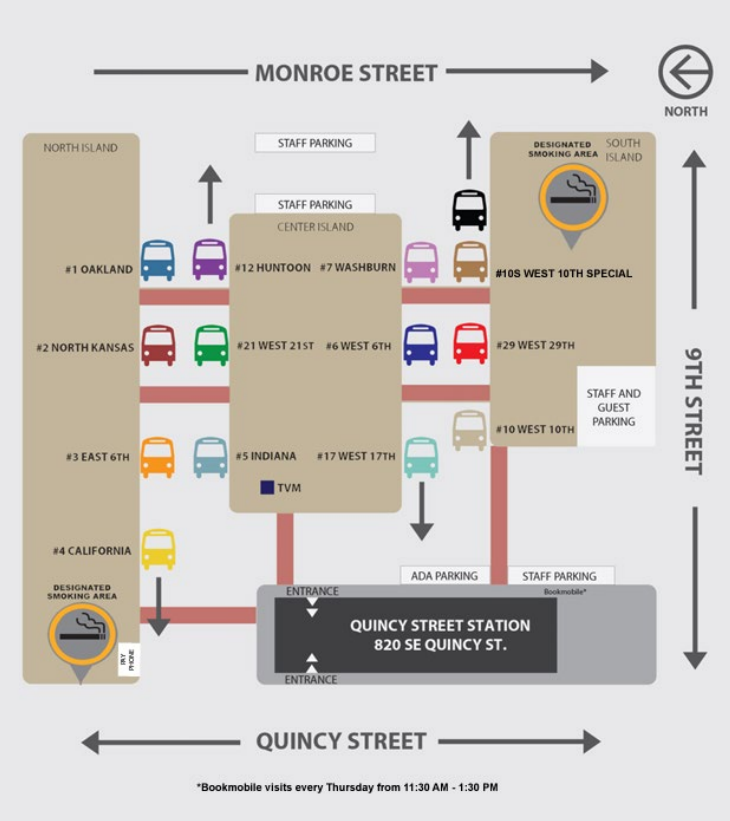


Figure 15. Quincy Street Station Staging Map

Figure 16. Quincy Street Station

1.6.1 Key Takeaways/Summary of Gaps

Based on the facility assessment, some key considerations for Topeka Metro when considering the transition to electric vehicles are:

- The facility was not designed to support pantograph charging and would not be able to without a full structural engineering review[11]. In addition, the existing roof height likely does not support pantographs. This matches discussion with Proterra which has determined plug-in chargers to be preferrable.
- Each route is staged at its own spot at Quincy Street Station which may require modifying the staging approach if on-route charging is found to be necessary.
- Limited space at the Ryan Building to support on-site chargers in an exterior yard, and the site is constrained from expanding on three of its four sides.
- Placement of dispensers and charging cords should be coordinated with the pull-in and pull-out processes and BEB charge port locations.
- Topeka Metro prefers the chargers and dispensers be located within the garage. The area in front of the existing electrical switchgear appears to be a prime location for the new charging cabinets.

Within the garage the narrow aisles between buses will constrain potential dispenser locations, however, the existing concrete columns can offer protection. Alternatively, the charging cords might be mounted from hose reels suspended from the above roof structure.

1.7 Electrical Services Assessment

Topeka Metro's Ryan Building at 201 North Kansas Avenue is provided with utility connections from the southern edge of its property. Each building is fed by its own utility transformer. Electrical service is provided by Evergy. Electrical service is billed separately for each building. From September 2020 to September 2021 the Operations & Administration Facility averaged 14,498 kWh / month and the Maintenance Facility averaged 214 kWh with a peak actual demand of 64 kW and 1 kW respectively. The Operations & Administration Facility is currently equipped with a 3-phase 167 kVA transformer and the Maintenance Facility is equipped with a 3-phase 25 kVA transformer.

Topeka Metro has already begun two projects to improve the capacity and resiliency of its electrical service. The projects are as follows:

- **Evergy Redundant Electrical Connection:** This will provide a new pad-mount three phase 1000 kVA transformer southwest of the Operations and Administration Facility to serve this building plus up to 5 BEB chargers. The transformer would be set on an oversized concrete pad with oversized conduits into the building, to accommodate a future transformer upgrade. The new transformer would originate from the same substation, but on a different feeder circuit. Topeka Metro anticipates that this upgrade will improve the reliability from <95% to >95%. The chargers will be metered separately from the building.
- **Back-up Generator Supply:** This project was recently completed to provide a new 125 kW natural gas, standby-by generator with an Automatic Transfer Switch (ATS) to improve resiliency. This generator is only intended for the administration portion of the load and will not be able to also support the new electric bus chargers.

Topeka Metro operates under a standard tariff called "electric transit services" (ETS) with Evergy. The electric transit services standard tariff is available to any transit provider in the

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[11] Note that no construction drawings have been available for this evaluation.

Evergy Kansas territory. This will provide time of use (TOU) rates with an off-peak rate from 6 PM to 6 AM along with no and low demand rates.

Topeka Metro's existing electrical connection, standby generator and electrical equipment can all be found in the southwest corner of the Operations and Administration Facility. Based on the pull-in and pull-out information discussed in **Section 1.5** it likely makes sense to place charger equipment in this same location inside the garage. Dispensers connected with the charger can be run along the columns throughout the garage. As part of future tasks Arcadis IBI Group will confirm space and operational considerations to identify optimal locations for the placement of chargers for the original three vehicles as well as the potential 25%, 50%, 75% and 100% BEB scenarios.

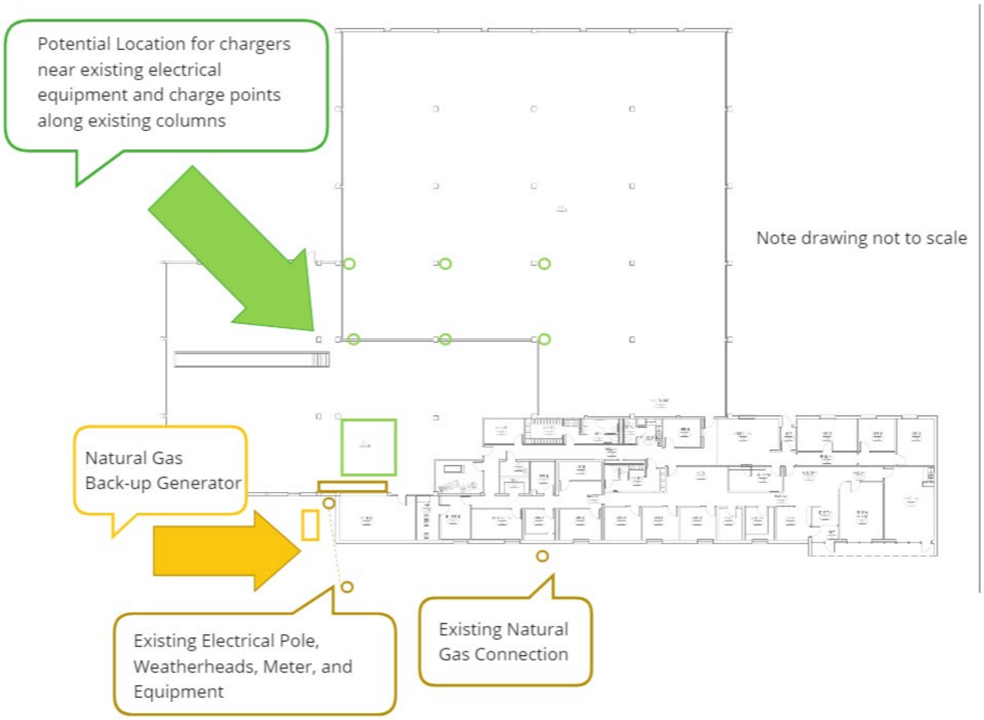


Figure 17. Operations and Administration Facility Utility Summary

1.7.1 Key Takeaways/Summary of Gaps

Based on the electrical services assessment, some key considerations for Topeka Metro when considering the transition to electric vehicles are:

- The standby generator is only designed to provide enough power for the administration building and does not include power for the chargers.
- Due to space constraints the placement of charging equipment will be critical

1.8 Fleet Assessment

A deep understanding of the existing fleet at Topeka Metro will allow Arcadis IBI Group to gain insight on fleet requirements when transitioning to BEBs. Understanding information such as the number of vehicles used during peak demand, planned and upcoming procurements, planned retirement years, and fueling processes will be critical to strategically transition and procure BEBs that minimize disruption. Topeka Metro owns 26 Fixed route vehicles and 13 demand response vehicles.

1.8.1 Fixed Route Vehicles

Topeka Metro owns 26 Fixed route vehicles and is expecting (3) 35-foot Proterra battery electric buses to join the fleet in 2023. Each of these BEBs typically accommodates 50 passengers with approximately 30 seats. The existing fleet contains (16) 2011 Gillig Low Floor Buses that can each support a capacity of 51 passengers. In 2014, the agency received (10) 2014 Gillig low floor buses that can each serve a capacity of 50 passengers.

Figure 18 Topeka Metro Fixed Route Bus

1.8.2 Demand Response Vans

Topeka Metro owns 13 demand response vehicles. Eight of the vehicles are 2013 E450 Glaval Cutaway vans and can each seat 7 passengers with 3 wheelchairs on board or 11 passengers with 0-2 wheelchairs on board. The remaining five are 2021 ARBOC low floor Cutaway vans and can seat 10 passengers or fewer when 2 or 3 wheelchairs are on the van. As of 2021 two of the original E450 Glaval Cutaways have been retired from service

Figure 19 Topeka Metro Demand Response Van

1.9 Key Takeaways/Summary of Gaps

Topeka Metro has an aging fleet with many vehicles expected to be retired in the next few years. For Fixed-route vehicles, 16 of the 26 vehicles have already reached the minimum service life as defined by the FTA (12-year useful life for fixed-route vehicles). The remaining 10 vehicles will reach the end of their minimum service life in the next year. Similarly, 8 of the 13 paratransit vehicles have also reached the end of their minimum service life as defined by the FTA (7-year useful life for paratransit vans). While agencies are allowed to use vehicles past their minimum service life it is likely that in the next 3-5 years much of Topeka Metro's fleet will be upgraded.

2 Route Modeling and Range Compatibility

This section presents the approach and results of energy consumption modeling conducted for all Topeka Metro services. These projections estimate which existing services would be compatible with the pilot BEBs, and which would be more likely to require mitigation if Topeka Metro chooses to proceed with further fleet electrification.

Batteries currently available for BEB applications store less energy per unit of volume and unit of mass than a tank of diesel. As a result, full-size BEBs currently on the market tend to be heavier than equivalently sized diesel buses, and have a lower maximum driving range between charges compared with diesel driving range between fueling.

Projecting energy consumption is important for BEBs because an agency's existing scheduling practices are typically based on the driving range of diesel buses. Schedules are broken into blocks – pieces of work that are pre-planned in the schedule and each filled by one vehicle. Depending on variable energy consumption factors such as hill climbing and interior heating, BEBs often cannot perform a block lasting a full day without being swapped out midday or recharging on-route. This has implications on the overall fleet size required to run service, and the fixed infrastructure requirements to support the fleet.

The goal of energy modeling is to identify instances where the agency's existing schedules are incompatible with BEB range limitations, and then explore alternative strategies to achieve compatibility, such as blocking modifications and (if necessary) on-route charging sessions.

The conventional transit energy consumption modeling conducted for Topeka Metro follows the steps presented in **Table** 4 below. Sections corresponding to the following step are identified below:

Table 4. Energy Consumption and Charging Infrastructure Analysis Steps

DESCRIPTION	SECTION
Modeling Step 1: Baseline State: Building the BEB energy model based on data from Topeka Metro, publicly available weather and terrain profiles, and data from Original Equipment Manufacturers (OEMs).	**Section 2.2**
Modeling Step 2: Battery Energy Demand Redistribution: Applying the model to current Topeka Metro service blocks to identify compatibility gaps where the energy demand for a scheduled block exceeds typical ranges of available BEBs (on the market as of late 2022).	**Section 2.3**
Modeling Step 3: Mitigation Scenarios: Applying mitigation strategies to the current transit schedule to produce new theoretical blocks that achieve compatibility with BEBs, and to identify the fleet size required to run service. Re-validating the adjusted blocks using the energy model already developed.	**Section 2.4**

2.1 Modeling Methodology & Modeling Setup

The core of the fixed-route energy modeling analysis is the BEB energy consumption model, which computes the total energy required to operate each block based on several key factors that interact with each other to influence energy consumption:

- Horizontal propulsion, based on vehicle mass, block service and deadheading distances
- Vertical propulsion, based on terrain elevation
- Passenger loading and stopping patterns for passenger pick-up/drop-off, using data from automatic passenger counters (APCs) onboard Topeka Metro buses
- Heating, ventilation, and air conditioning (HVAC), based on block durations
- Precipitation trends.

Detailed discussion of each factor is found in the subsections below. The model used by Arcadis IBI Group projects total energy consumption based on the interaction of these factors at the trip level, as trips may follow different patterns (turn-by-turn directions) within the same block or route over the course of the day. Some of the available data (notably passenger boarding/drop-off) is further analyzed at the stop level, to provide finer energy consumption values and thus battery State-of-Charge (SOC) projections.

2.1.1 Vehicle Data

Horizontal Propulsion

To calculate the horizontal propulsion energy, we account for the mass of the vehicle including passengers, rolling resistance and air resistance. We also consider the total distance in a trip which allows us to calculate the unit energy consumption per mile traveled. Energy consumption per mile may vary between different BEB models. This analysis assumed the mass of the Proterra ZX5+ 35’ model, which Topeka Metro procured for its upcoming BEB pilot.

Vertical Propulsion

The impact of hill climbing on BEB energy consumption was included in the analysis. While Topeka is not characterized by particularly large hills or steep grades, the cumulative effect of repeatedly climbing smaller rolling grades over the course of service contributes to battery energy consumption.

The calculation of vertical propulsion energy considers the cumulative vertical climb experienced by the vehicle throughout each trip. Energy consumed on vertical ascents is calculated as the cumulative difference in the gravitational potential energy, using the following equation:

$$E_{vert} = m_{BEB} \times g \times h_{climb}$$

m_{BEB} refers to the mass of the bus, g is the acceleration due to gravity (9.81 m/s^2), and h_{climb} is the cumulative positive vertical climb distance.

On descents, the effect of gravity on reducing propulsion energy is similarly subtracted. However, potential energy consumption reduction through regenerative braking is not directly calculated, to produce a more conservative estimate. Instead, driver behavior has been built into the horizontal propulsion component, which is derived from observed field data.

Our methodology takes this approach primarily due to the observed recovery of energy through regenerative braking being highly variable, and therefore unreliable at the feasibility planning stage when projecting future operational and infrastructure needs. To harness the regenerative braking, drivers must adopt a driving technique that is quite different than with a diesel vehicle: drivers must anticipate the need to decelerate early, and then let the regenerative braking slow the vehicle by stepping off the accelerator but not using the brake (sometimes referred to as "one pedal driving"). This is a fundamental adjustment that some drivers find difficult to make. Another factor is that regenerative braking monitors traction and detects when the braking force would exceed the roadway traction (leading to wheel lock). In practice, this means that regenerative braking may often be overridden in slippery conditions due to water, snow, or ice.

The context-dependent nature of these factors emphasizes the benefit of gathering comprehensive data during the upcoming BEB pilot. Empirical data gathered in the local context will enable Topeka Metro to forecast real seasonal energy consumption and identify potential savings opportunities. It also highlights driver re-training as a strategy to maximize BEB range and derive additional operational efficiency.

Heating, Ventilation, and Air Conditioning

Energy consumption by HVAC depends on multiple factors including:

- Temperature gradient (difference between outside and inside temperature) – this is discussed in greater detail in **Section 2.1.3** under ***Precipitation and Climate.***
- Interior volume of the bus
- Air changes per hour (the number of times per hour that all air in the bus is replaced), which is affected by:
  - The baseline airtightness of a given vehicle
  - The cumulative amount of time that doors are open in an hour, and whether multiple set of doors are open (creating higher airflow)

These factors are then multiplied by the length of the block. Depending on the season and day-to-day weather, the resulting total energy consumption can range significantly. Winter and summer represent the periods of highest energy demand due to HVAC, with winter heating creating the highest demand. Importantly for winter heating, BEBs can be designed to either draw all heating energy from the battery, or to also carry a small diesel-powered heater to provide auxiliary heating below a threshold temperature setting.

The analysis for Topeka Metro used specifications corresponding to the Proterra ZX5+ 35' BEBs on order for the upcoming pilot. These buses primarily use heat pumps for heating and air conditioning, to a minimum temperature of approximately 15°F. Below this temperature, the effectiveness of heat pump technology decreases, so the buses are also equipped with auxiliary positive temperature coefficient (PTC) electric heaters. When these heaters are active at very low temperatures, energy consumption is similar to a traditional electric resistance heater. The energy consumption analysis uses this electric heating model to represent a realistic challenging operational scenario that can be anticipated based on Topeka's climate.

Battery Degradation

Battery degradation is not a direct contributor to energy consumption, but rather affects the threshold of compatibility between BEBs and blocks as batteries age. Battery degradation is commonly discussed in terms of State of Health (SoH), the measure of the remaining usable capacity of the battery as a percentage of its original capacity. Degradation is result of unwanted chemical reactions between the component materials in the battery cells that reduce their ability to store and release energy.

The following main external stress factors influence the rate of battery degradation:

- **Temperature of the battery cells**: deviations in either direction from the optimal 77°F (or 25°C, a factor of the cells' chemical composition) can accelerate degradation due to molecular decomposition (at high temperatures) or electroplating (at low temperatures). In general, temperature is the most significant stress factor on battery SoH.
- **State of Charge (SoC):** higher SoC operation results in a larger electric potential between electrodes, which can increase the rate of parasitic side reactions (which effectively put the cell through additional cycles of wear).
- **Load profile:** higher-current operation (either through demanding driving conditions or recharging at high currents) increases the likelihood of failure from mechanical stresses that develop in the battery during cycling.
- **Humidity:** higher humidity increases moisture penetration into the battery, which causes unwanted chemical reactions producing acidic compounds and that lead to corrosion.

With many BEB models having only been on the market for short period of time (often less than one full life cycle), there is a lack of real-world operating data to predict BEB battery degradation in varying climates outside of laboratory simulations and confidential manufacturer testing. Our degradation prediction model uses the average per-bus energy demand from scheduled transit service to project the cumulative number of cycles experienced by the battery over years of use. This is then applied against empirical degradation discharge curves of individual cells developed from academic research to approximate how battery degradation proceeds over time.

2.1.2 Topeka Metro Service Data

Service Schedules

The service schedules used in this analysis, including all routes and block data, were obtained from Topeka Metro's Winter 2022 service plan. The schedule information received was in the form of a GTFS feed, information on blocking from the Doublemap scheduling platform, written turn-by-turn directions for deadheads, and public-facing timetables. These data sets were cleaned, correlated, and processed using route modeling software developed by Arcadis IBI Group:

- Monday to Friday: passenger service from approximately 5:40 AM to 6:40 PM
- Saturday: passenger service from approximately 8:15 AM to 6:45 PM

Graphical visualizations of all existing blocks are provided in **Figure 20** (Monday-Friday) and **Figure 21** (Saturday).

Winter 2022 weekday service consists of 25 blocks, comprising a mix of 13 core service blocks operating for approximately the complete service day, and 12 split/tripper blocks active in either the AM or PM peak. In total, 18 buses are dispatched in the AM peak, and 20 buses are dispatched in the PM peak. Note that two PM school specials (identified as Blocks P and Y) are planned for cancelation and will not be incorporated in later mitigation efforts.

Winter 2022 Saturday service consists of 12 core service blocks operating for the complete service day.

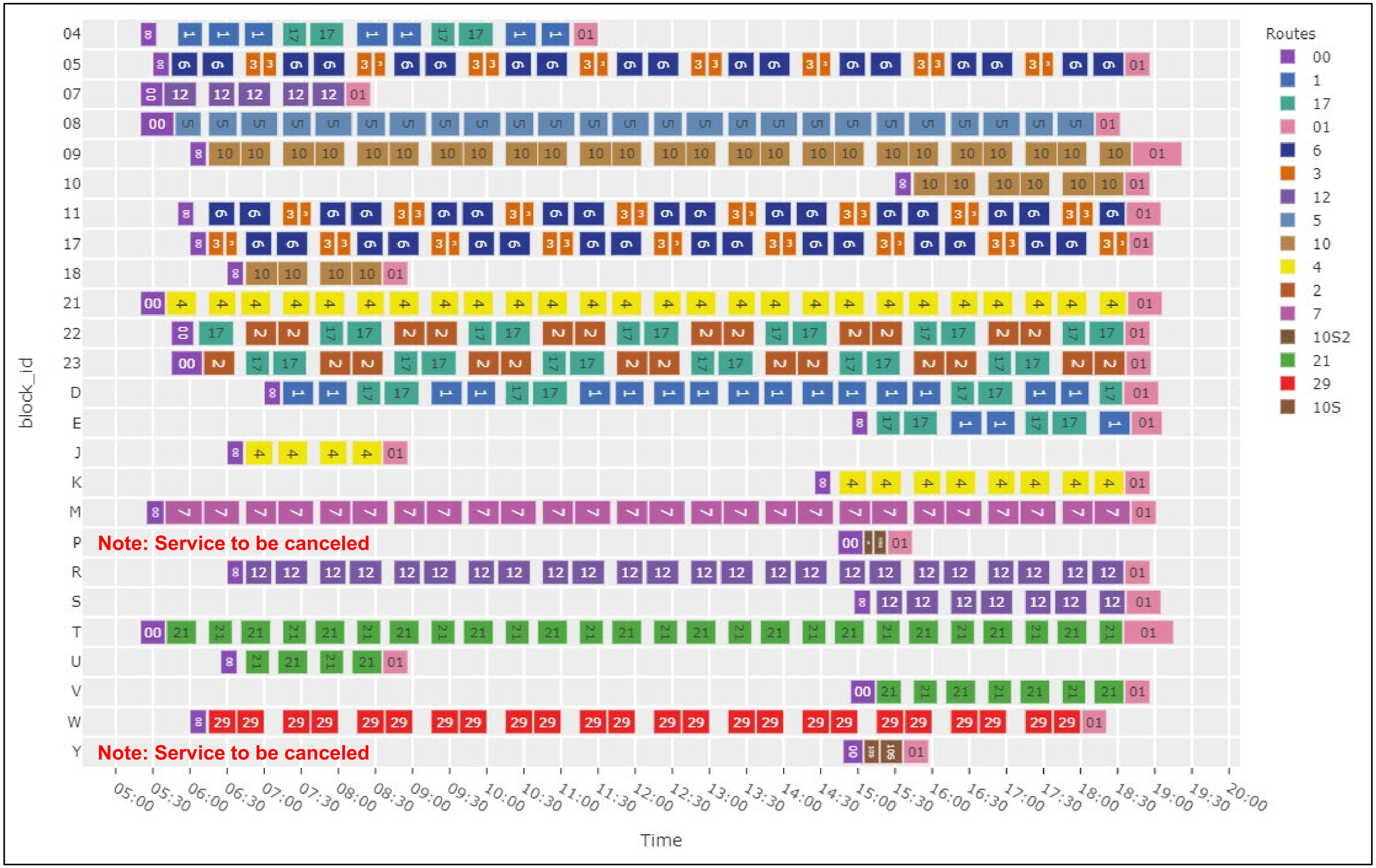


Figure 20. Topeka Metro Block Schedule Visualization (February 2022 Monday - Friday Service)

Figure 21. Topeka Metro Block Schedule Visualization (February 2022 Saturday service)

Passenger Loading

Passenger loading used in this modeling effort was based on the data gathered by automatic passenger counters (APCs) onboard Topeka Metro buses, which includes counts of boardings, alightings, and net passenger load throughout each trip. Data spanning a two-week period in January-February 2022 was sourced from Topeka Metro. This range was selected as the reported trips would correspond with the scheduling datasets, and because Topeka Metro has historically observed relatively high ridership in this period.

To develop a conservative estimate of energy consumption associated with passenger volumes and weight, the model assumed that the maximum net passenger load recorded throughout each trip would be maintained for the entire trip. For passenger weight, the median weight of American adults (176 lb.) was used, rather than the less strenuous standard value of 150lb. in Altoona testing. Simultaneously, to develop a conservative estimate of acceleration and door openings (associated with higher HVAC use), buses were assumed to stop at all stops reported as having non-zero boardings and alightings in the APC data over the two-week period. The net effect of these overlapping assumptions would be a scenario in which at each stop serviced, an equal number of adult passengers would board and alight, keeping the net load constant.

2.1.3 Environmental Data

Terrain

Our modeling tool queried Google’s Elevation API for the ground elevation of every point in the GTFS shapefile (example data visualization shown in **Figure 22**). Only point-to-point increases in elevation were factored into the vertical energy consumption (shown as h_climb in **Section 2.1.1** under ***Vertical Propulsion***). Decreases in potential energy from downhill grades may be partly recovered with regenerative braking, but this has been excluded for a more conservative energy consumption estimate.

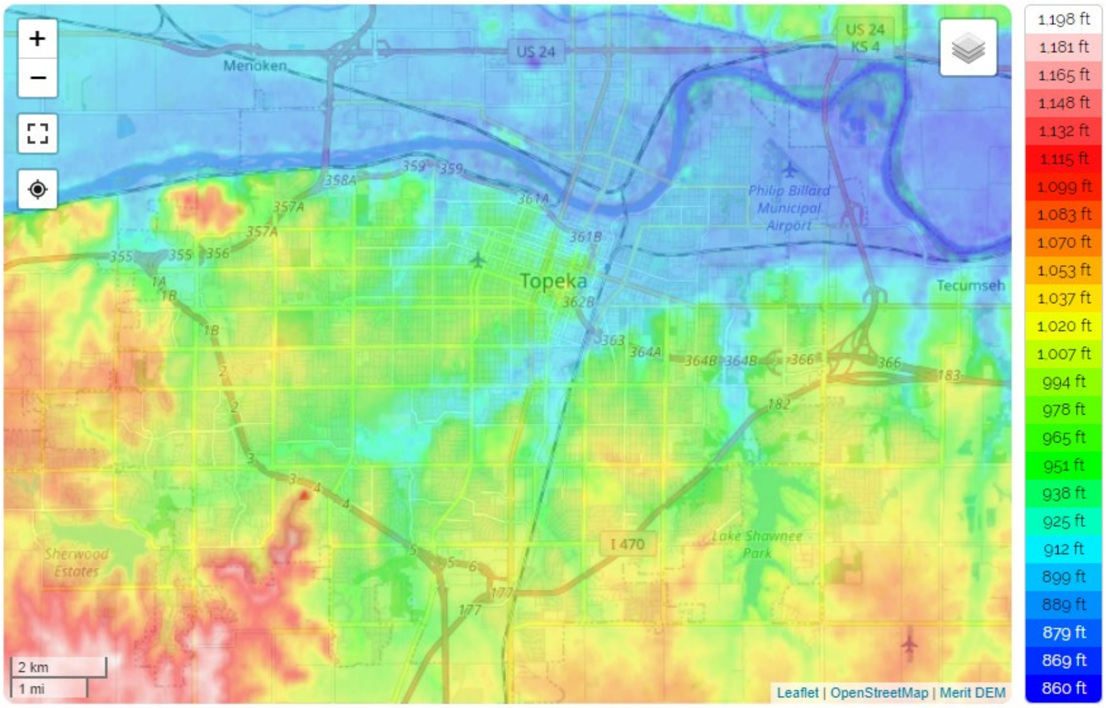


Figure 22. Open-Source Topeka Elevation Data Visualization (Source: topographic-map.com)

Precipitation and Climate

Weather datasets were collected for the Topeka area starting from 1999, to establish historical trends. Temperature data was evaluated primarily to estimate which of summer highs or winter lows would induce higher battery energy consumption from HVAC demands. In the case of winter lows, 15 °F was taken as the temperature at which heating from the heat pump would be replaced by the auxiliary PTC heater. Precipitation data was similarly reviewed to validate average precipitation rates, focusing on road wetness and corresponding reduction in traction. The result of this initial review indicated that a winter scenario would result in a realistic worst-case weather-related energy consumption rate averaging approximately 8.84 kW, though varying across services.

2.1.4 Vehicle Parameter Values Summary

Key parameters were used to represent the characteristics of the BEB vehicle and its onboard systems, as well as other operational factors. These parameters are summarized in **Table** 55 below with their values. Topeka Metro's upcoming BEB pilot will provide an opportunity for empirical data collection for use in further capital procurement and service planning.

Table 5. Energy Modeling Input Parameters

PARAMETER	VALUE	NOTES
Bus Battery Parameters		
Absolute	450 kWh	• Nominal capacity of Proterra ZX5+ 35' model • Extended battery: 492 kWh
Effective (85% of absolute)	383 kWh	• Minimum 15% safety factor to maintain battery SoH • Extended battery: 418 kWh

PARAMETER	VALUE	NOTES
Degraded effective (75% of effective)	287 kWh	• Degradation in effective capacity anticipated by end of service life (15 years) • 87.5% of Extended battery: 365 kWh • 75% of Extended battery: 313 kWh
Battery Efficiency	0.9	
Bus Dimensions		
Curb weight	29,857 lb.	• Proterra ZX5+ 35’ model approximate nominal dimensions
Interior Volume	2472 cu. ft.	
Frontal Area	90.4 sq. ft.	
Door Area	29.1 sq. ft.	
Door Count	2	
HVAC Parameters		
PTC Heater Power	9 kW	• Supplemental power provided by the PTC heater at low temperatures
Ventilation Power	0.5 kW	• Power to circulate air through the bus
Air Change Duration	450 s	• Time for all air in the bus to be exchanged with fresh air
Interior Temperature	64 °F	• The temperature to maintain inside the bus
Other Bus Performance Parameters		
Other Auxiliary Power	0.5 kW	• Power used by lighting, on-board systems, displays, etc.
Drag Coefficient	0.65	
Powertrain Efficiency	0.82	
Other Parameters		
Passenger Weight	176 lb.	• 50th percentile adult weight for American adults (2016)

2.2 Modeling Step 1: Baseline State

After all energy consumption inputs were built into the model, the total energy consumption requirement for each block was projected and compared against the available battery energy storage capacity of the BEB models under consideration. Energy consumption varies by BEB model primarily based on vehicle weight (which the battery itself contributes to) and volume (for HVAC). For this analysis, the Proterra ZX5+ 35’ model was primarily used, to reflect the pilot vehicles expected to enter Topeka Metro’s fleet.

This stage of the analysis considered a minimum acceptable SOC equal to having consumed 80% of the absolute battery capacity. Due to the material properties of the battery cells, habitually taking the SOC beyond this maximum consumption range can impact battery longevity; constraints between 78% and 85% are recommended by various bus OEMs for this reason. A supplemental benefit of this approach is that in an unplanned event where the bus does approach the limit of its range, it will still have enough residual energy to return to the garage.

Among incompatible blocks, those with energy consumption values between the effective and absolute battery capacity values are classified as being “at risk”. BEBs operating those blocks would end with a SOC lower than the effective 20% threshold but higher than 0%. Those with energy consumption fully exceeding the total battery capacity are deemed “infeasible”.

Monday-Friday Service

Weekday modeling results are presented in the tables and figures on the pages below, as follows:

- **Table** 6**:** Table of block key statistics
- **Figure 23:** Graphical SOC profiles of all blocks throughout the day
- **Figure 24:** Histogram of total block energy consumption with new batteries
- **Figure 25:** Histogram of total block energy consumption with degraded batteries

Findings indicate that BEBs with new batteries are compatible with 14 of 25 blocks, including all rush hour trippers. Of these, 2 blocks (P and Y) are school trippers pending cancelation. With degraded batteries, compatibility decreases to 12 of 25 blocks.

Saturday Service

Saturday modeling results are presented in the tablets and figures on the pages below, as follows:

- **Table 7:** Table of block key statistics
- **Figure 26:** Graphical SOC profiles of all blocks throughout the day
- **Figure 27:** Histogram of total block energy consumption with new batteries
- **Figure 28:** Histogram of total block energy consumption with degraded batteries

Findings indicate that BEBs with new batteries are compatible with 7 of 12 blocks, however in a degraded battery scenario this compatibility drops to 2 of 12 blocks. This is due to the duration of Saturday blocks being more uniformly long than the variability observed in weekday blocks.

Table 6. Block Key Statistics and Energy Consumption (Winter Worst Case, 2022 Monday-Friday Service)

BLOCK ID	START TIME	END TIME	DURATION (H)	BLOCK DISTANCE (MI)	MAX PASSENGER LOAD	BLOCK TOTAL ENERGY (KWH)	BLOCK ACTIVE ENERGY (KWH)	BLOCK UNIT ENERGY (KWH/MI)	COMPATIBLE (NEW BATTERY)	COMPATIBLE (DEGRADED BATTERY)
4	05:20	11:30	6.17	212.91	17	183.18	171.39	2.08	Yes	Yes
5	05:30	18:56	13.43	535.72	9	614.70	587.74	2.84	No	No
7	05:20	08:26	3.10	105.60	7	87.58	83.46	2.05	Yes	Yes
8	05:20	18:32	13.20	608.04	18	492.35	479.39	2.04	No	No
9	06:00	19:22	13.37	429.98	15	373.55	355.43	2.14	Yes	No
10	15:30	18:56	3.43	104.35	10	87.51	84.12	2.09	Yes	Yes
11	05:50	19:05	13.25	532.62	9	600.07	572.23	2.78	No	No
17	06:00	18:59	12.98	516.34	9	592.59	565.93	2.84	No	No
18	06:30	08:56	2.43	71.79	5	58.75	56.84	2.05	Yes	Yes
21	05:20	19:06	13.77	532.53	11	552.89	528.29	2.57	No	No
22	05:45	18:56	13.18	452.01	12	431.48	410.42	2.35	No	No
23	05:45	18:57	13.20	446.56	13	438.55	417.63	2.42	No	No
D	07:00	19:03	12.05	471.07	23	399.10	378.77	2.08	No	No
E	14:55	19:06	4.18	140.17	13	129.99	123.07	2.27	Yes	Yes
J	06:30	08:56	2.43	85.17	9	88.78	85.99	2.61	Yes	Yes
K	14:25	18:56	4.52	163.64	7	165.68	158.32	2.51	Yes	Yes
M	05:25	19:01	13.60	480.13	12	454.67	443.62	2.39	No	No
P*	14:44	15:44	1.00	27.00	22	27.47	27.03	2.59	Yes	Yes
R	06:30	18:56	12.43	401.70	8	358.58	336.63	2.17	Yes	No
S	14:57	19:05	4.13	138.99	5	113.27	106.64	1.99	Yes	Yes
T	05:20	19:15	13.92	545.24	11	607.12	577.22	2.74	No	No
U	06:25	08:56	2.52	84.39	4	88.20	83.78	2.57	Yes	Yes
V	14:54	18:56	4.03	157.14	4	159.31	151.94	2.50	Yes	Yes
W	06:00	18:21	12.35	520.48	11	558.12	533.37	2.65	No	No
Y*	14:48	15:57	1.15	32.87	19	34.58	34.28	2.70	Yes	Yes

* Blocks P and Y correspond to Route 10 Special. This route was canceled following the initial route modeling exercise; this service is therefore excluded from later analysis stages.

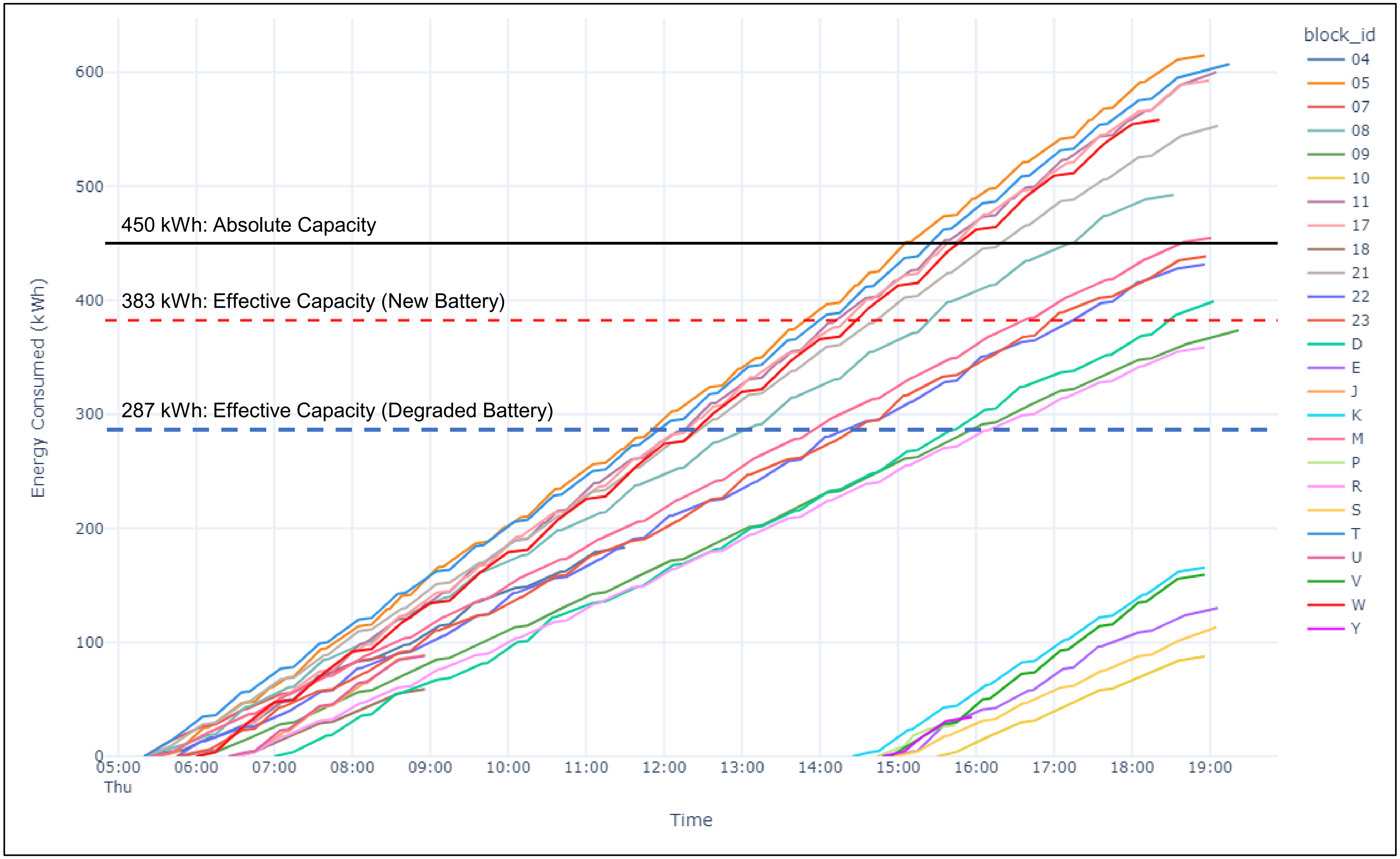


Figure 23. Existing Block Energy Consumption Profiles (Winter Worst Case, 2022 Monday-Friday Service)

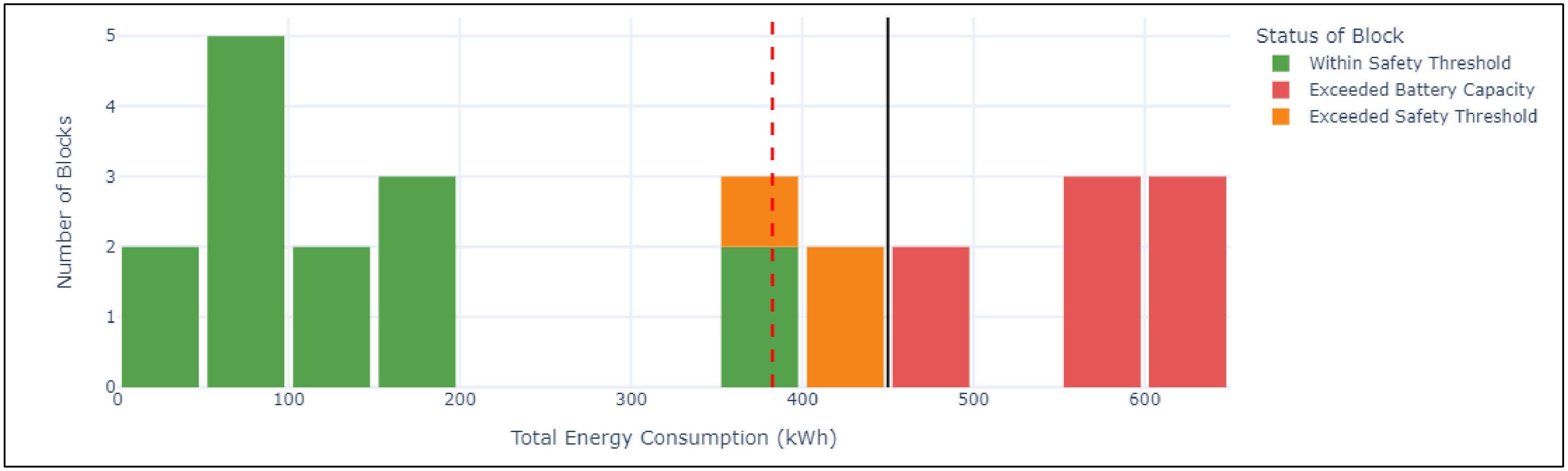


Figure 24. Energy Consumption Histogram (Winter Worst Case, 2022 Monday-Friday Service, New Battery)

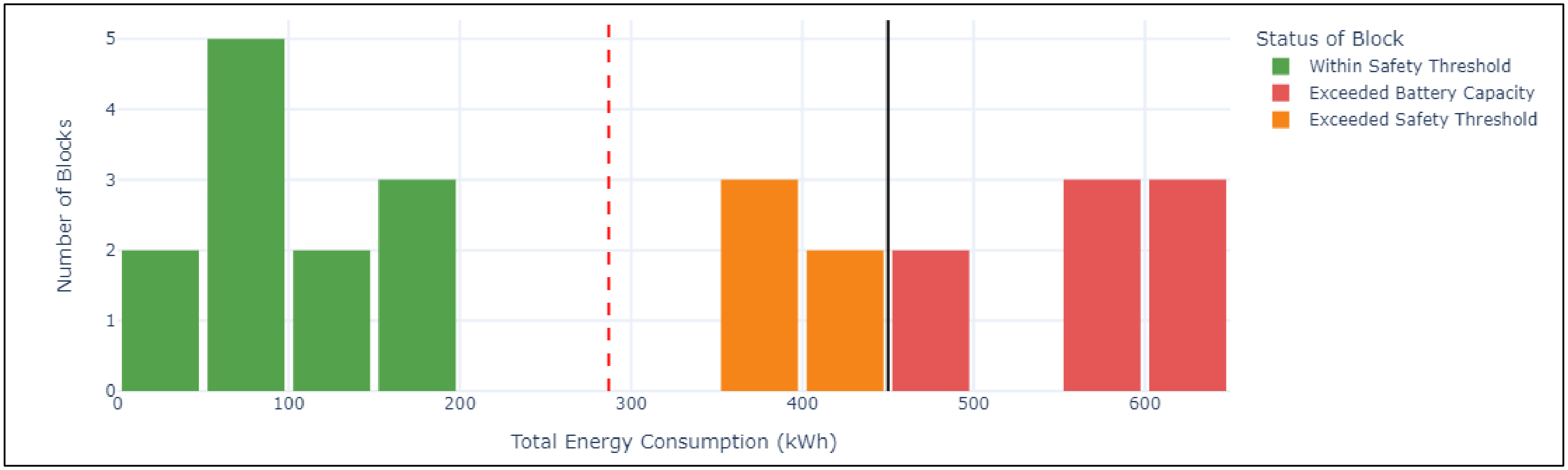


Figure 25. Energy Consumption Histogram (Winter Worst Case, 2022 Monday-Friday Service, Degraded Battery)

Table 7. Block Key Statistics and Energy Consumption (Winter Worst Case, 2022 Saturday Service)

BLOCK ID	START TIME	END TIME	DURATION (H)	BLOCK DISTANCE (MI)	MAX PASSENGER LOAD	BLOCK TOTAL ENERGY (KWH)	BLOCK ACTIVE ENERGY (KWH)	BLOCK UNIT ENERGY (KWH/MI)	COMPATIBLE (NEW BATTERY)	COMPATIBLE (DEGRADED BATTERY)
Sat 1	08:00	18:31	10.52	422.32	3	287.34	278.79	1.71	Yes	Yes
Sat 2	08:30	18:57	10.45	366.33	11	332.06	318.21	2.25	Yes	No
Sat 3	08:00	18:31	10.52	421.69	5	443.77	423.43	2.60	No	No
Sat 4	08:00	18:35	10.58	396.44	9	426.53	423.30	2.77	No	No
Sat 5	08:00	18:35	10.58	489.93	9	417.93	414.69	2.19	No	No
Sat 6	08:00	18:35	10.58	416.75	9	458.21	450.55	2.80	No	No
Sat 7	08:30	19:05	10.58	371.13	0	312.08	308.85	2.16	Yes	No
Sat 10	08:00	18:26	10.43	333.82	10	281.37	266.21	2.07	Yes	Yes
Sat 12	08:30	19:01	10.52	362.42	8	322.79	311.30	2.22	Yes	No
Sat 17	08:30	18:56	10.43	348.71	12	307.10	288.98	2.15	Yes	No
Sat 21	08:00	18:26	10.43	393.57	11	388.08	372.91	2.45	Yes	No
Sat 29	08:00	18:21	10.35	437.66	8	442.73	422.40	2.50	No	No

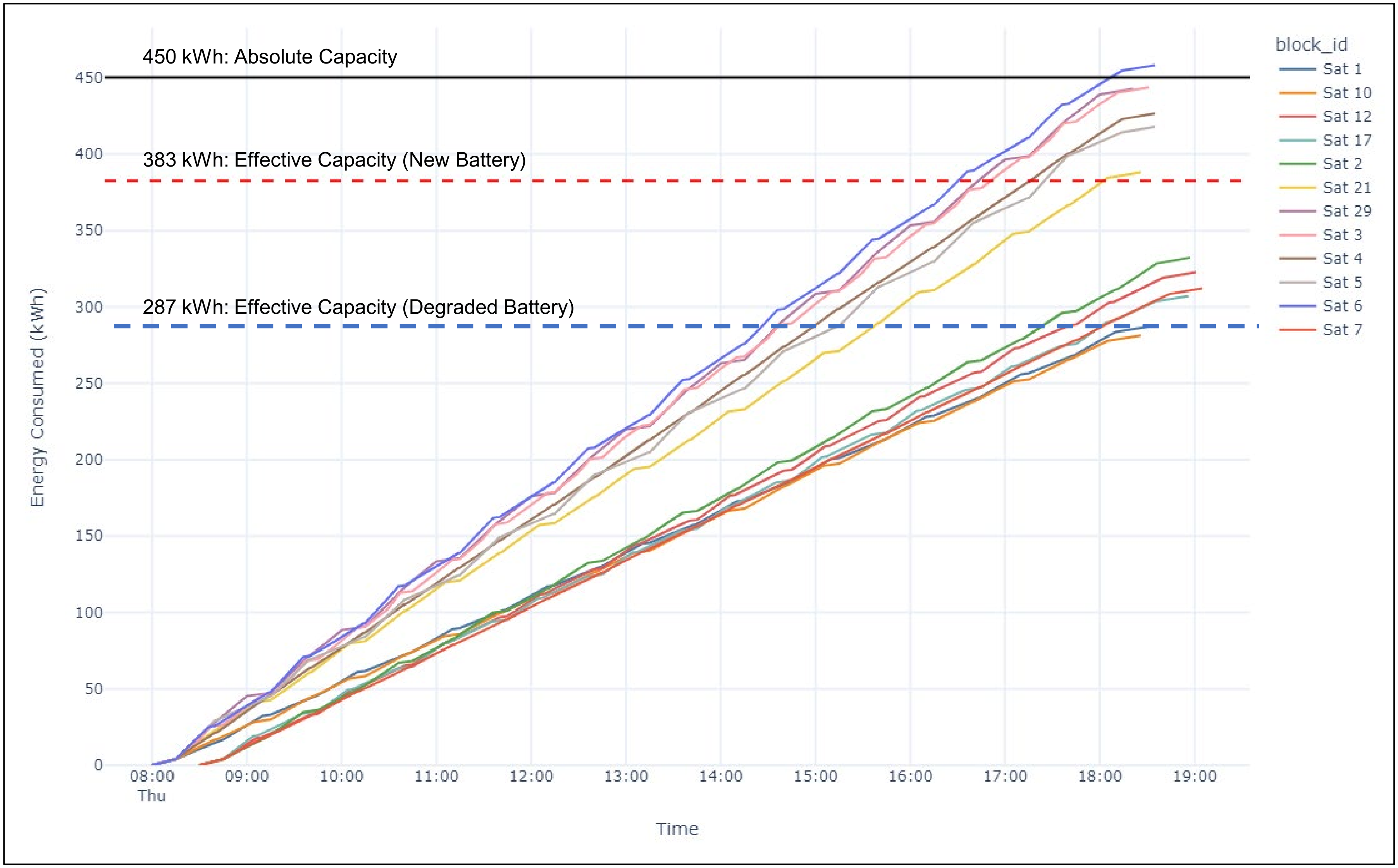


Figure 26. Existing Block Energy Consumption Profiles (Winter Worst Case, 2022 Saturday Service)

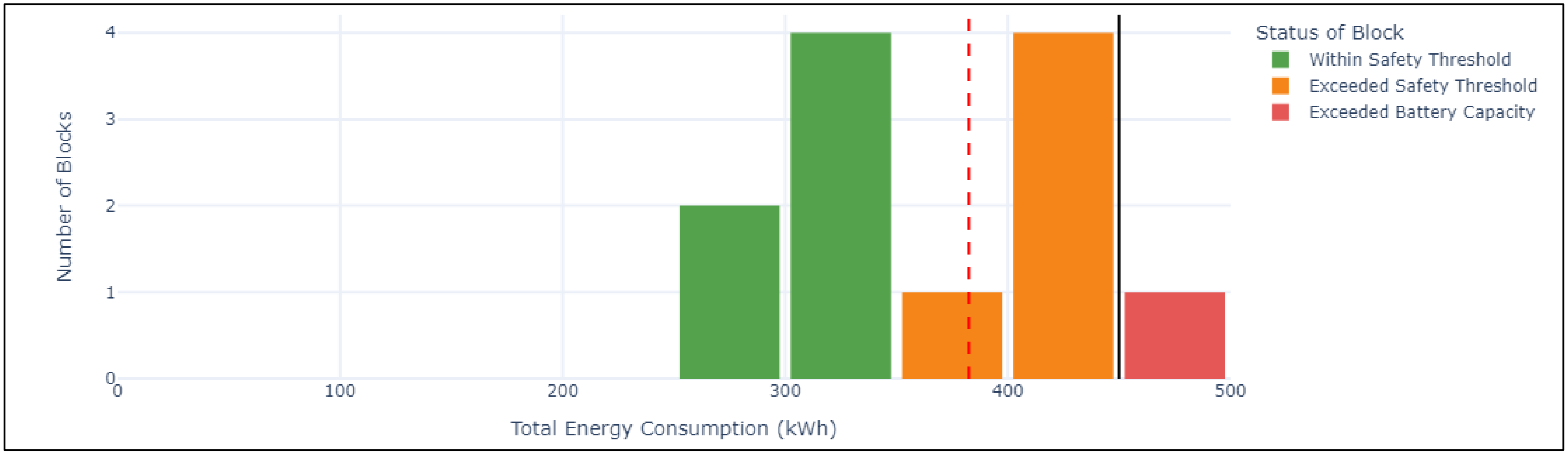


Figure 27. Energy Consumption Histogram (Winter Worst Case, 2022 Saturday Service, New Battery)

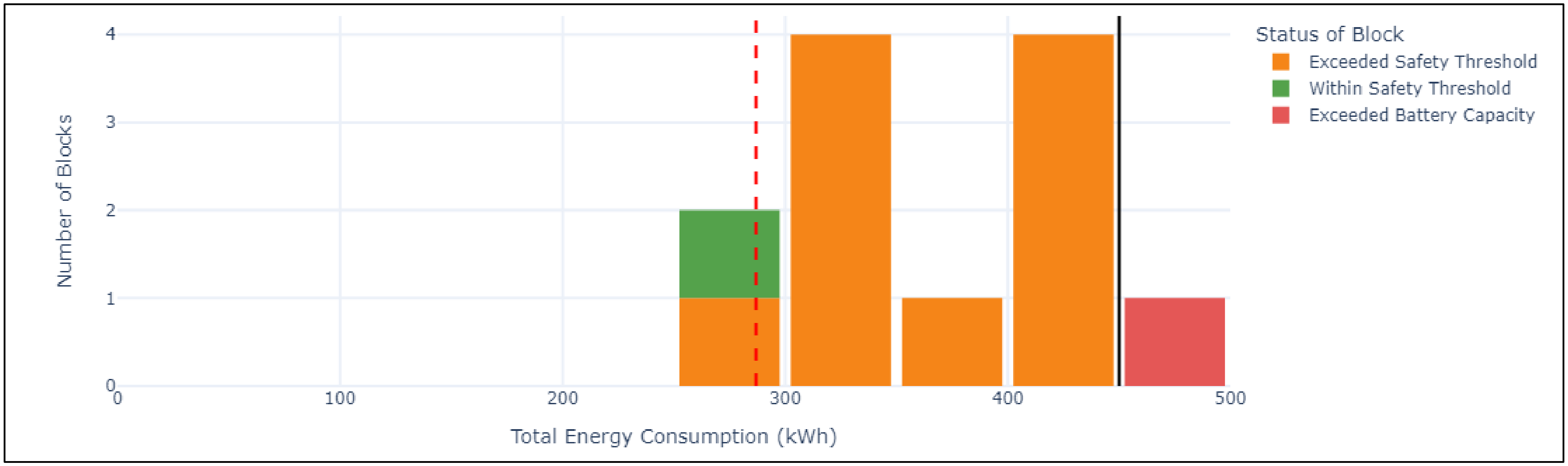


Figure 28. Energy Consumption Histogram (Winter Worst Case, 2022 Saturday Service, Degraded Battery)

2.3 Modeling Step 2: Battery Energy Demand Redistribution

Based on the energy consumption projections identified in **Section 2.2,** Arcadis IBI Group investigated alternative strategies to achieve full compatibility with BEBs using an adjusted service plan. The resulting modeling scenario used the following input constraints:

- 100% BEB conversion (battery capacity specified in each of the modeled scenarios below),
- Fully in-depot charging (assuming the 120-kW charging rate to align with the specifications of the equipment currently on order from Proterra), and
- No alterations to routing or timing of passenger-facing trips.

Based on these constraints, the available redistribution tools consisted of re-blocking and interlining, discussed in subsections below. This would entail the highest increase in vehicle utilization, resulting from increased deadheading and midday in-depot charging layovers. Developing this scenario first established theoretical upper bounds of vehicle quantities needed to deliver current service.

2.3.1 Re-Blocking

Re-blocking involves examining the energy requirements of all trips in each incompatible block and trimming trips from the block to reduce its energy consumption to within BEB range constraints for a single charge. The trips trimmed off are then reallocated to other blocks. In some cases, to achieve compatibility the trips can be appended to other existing blocks with energy consumption headroom, or the trimmed trips from one or more blocks can be formed into new blocks.

Often, re-blocking results in additional buses required to cover the same public-facing service, as blocks that could originally be operated by a single diesel bus are now shortened, and other buses need to cover the removed trips. Re-blocking needs to be conducted strategically such that the degree of fleet expansion required is minimized. An example of an approach to reducing fleet expansion requirements is to build two new blocks in the morning and the evening, and then use the midday time window for recharging in the garage, so that the same BEB can operate both blocks with the recharge between.

The re-blocking conducted as part of this analysis does not represent an exact proposed future schedule for Topeka Metro – there are potentially many alternative re-blocking permutations with equivalent compatibility. Additionally, this re-blocking does not constitute a full revision of the schedule, as it does not include a parallel set of new runs (work assignments) for drivers. It is intended only to estimate fleet size requirements and approximate midday recharging requirements, without changing the public-facing trip times currently advertised by Topeka Metro. Arcadis IBI Group recommends that a full revision of service blocks be performed by Topeka Metro as BEBs are delivered and performance data is gathered under local conditions, in conjunction with other service planning review activities.

Based on Topeka Metro's existing service schedules there are multiple opportunities to re-block weekday service without adding new blocks due to the large number of trippers. While this is not as true of weekend service the number of vehicles dispatched during the weekend is limited to 12 vehicles while currently up to 20 buses are dispatched during weekday services. This means that even if the number of vehicles dispatched during the weekend is increased due to re-blocking it is unlikely to increase the total fleet size.

In the near term as Topeka Metro continues to operate diesel buses for some portion of its fleet re-blocking can also shift work to these for a limited number of blocks that would be unfeasible to complete with BEBs to therefore increase the number of feasible blocks.

2.3.2 Interlining

Interlining, the practice of having buses run alternating trips on two or more routes in the same block, is practiced today by Topeka Metro. More liberal application of interlining was examined as part of re-blocking to support partial and or full conversion to a BEB fleet. As Topeka Metro currently publishes interlining details in its public-facing schedules, changing interlining would be visible to the public.

Interlining can support battery energy demand redistribution by reducing the spread between high and low intensity services: interlining trips on routes with unusually high and low energy consumption together results in an average energy consumption for the block that is closer to the mean of all blocks. This can help reduce fleet expansion requirements.

2.4 Modeling Step 3: Mitigation Scenarios

2.4.1 Available Alternative Mitigations

This section presents an analysis of advantages and disadvantages of potential alternative mitigation strategies that were considered during the development of the final mitigation scenarios. The mitigation scenarios described in the following subsections assumed the following:

- Existing routes and hub-and-spoke network design would remain as currently designed; and
- Facilities including the depot and Quincy Street Station (QSS) would remain in place.

Topeka Metro indicated a desire to develop 25%, 50% ,75% and 100% electrification scenarios as part of the mitigation effort. Throughout this stage of scenario modeling, Arcadis IBI Group assumed a 100% electrification scenario, so that in case Topeka Metro chose partial electrification in the near term and full conversion in the medium-to-long term, the recommended mitigations would support that scaling-up. Transition to BEB operations would then be developed as a phased roadmap working backward from the fully built-out scenario. Choosing which percentage of fleet electrification to ultimately implement can then be thought of in terms of executing certain phases of that roadmap.

2.4.1.1 Re-Blocking

Topeka Metro's existing service schedules present opportunities to re-block weekday service while minimizing the total increase in dispatch size, by leveraging buses on rush hour trippers to assist buses running more demanding services. While this strategy does not apply to Saturday service, the Saturday dispatch consists of 12 vehicles compared with 20 weekday vehicles in 2022. This means that even if the number of vehicles dispatched on Saturday is increased during re-blocking, the weekday dispatch was anticipated to remain the governing factor for fleet size. This was later confirmed through modeling.

In the near term as Topeka Metro continues to operate diesel buses for some portion of its fleet, re-blocking can also shift work to these from a limited number of blocks that would be infeasible to complete with BEBs and therefore increase the number of feasible blocks.

Table 8. Advantages and Disadvantages of Re-blocking

ADVANTAGES	DISADVANTAGES
There is a high possibility that there are several alternative re-blocking permutations with equivalent compatibility which can allow Topeka Metro to select an alternative re-blocking strategy that promotes staff efficiencies, customer satisfaction, and additional needs expressed by Topeka Metro.	May require additional BEBs

2.4.1.2 Increased Fleet Size

Re-blocking often results in the need for additional buses to cover the same public-facing service, as blocks that could originally be operated by a single diesel bus are now shortened, and other buses need to cover the removed trips. The requirement for additional vehicles can be minimized by strategic re-blocking methods. For an example, building two new blocks in the morning and the evening, and using the midday time window for mid-day recharging in the garage, can allow for the same BEB to operate both blocks.

Table 9. Advantages and Disadvantages of Increased Fleet Size

ADVANTAGES	DISADVANTAGES
Potential to minimally disrupt service	Increase fleet size
	Additional costs required of additional vehicles and operational/maintenance needs

2.4.1.3 On-Route Charging

Depending on agency-specific factors (e.g., transit network layout, service frequency, scheduled layovers), on-route charging can sometimes complement or substitute for re-blocking. On a case-by-case basis, on-route chargers can provide benefits in the form of reduced fleet size and potentially staffing requirements, compared with in-garage charging. By charging outside the garage, the need to swap out buses is reduced, along with the staff hours for the extra deadheading. However, trade-offs come in the form of increased fixed infrastructure requirements (capital and maintenance), and reduced flexibility to re-route bus services relative to where the chargers are positioned in the network.

Table 10. Advantages and Disadvantages of On-Route Charging

ADVANTAGES	DISADVANTAGES
Potential to reduce fleet size.	Increased fixed infrastructure requirements (capital and maintenance)
Reduce need for deadheading.	Reduced flexibility to re-route bus services relative to where chargers are positioned in the network.
	Unable to take advantages of energy off-peak charging.

2.4.1.4 Battery Capacities and Charging Systems

Different vehicle battery capacities and charging systems have been identified in the following sections to provide Topeka Metro with information on how specific combinations of battery capacities and charging systems may impact Topeka Metro. **Section 2.4.3** determines the most appropriate combination of battery capacities and charging systems to pursue to support fleet electrification considering the agency's needs and priorities.

Table 11. Advantages and Disadvantages of Battery Capacities and Charging Systems

ADVANTAGES	DISADVANTAGES
Potential to increase vehicle ranges.	Increased energy requirements result in additional energy costs and additional charging infrastructure.
Potential to decrease charging times.	Can increase peak energy requirements.

2.4.1.5 Increased Quantity of Depot Chargers

An increase in the quantity of depot chargers has the potential to increase charging opportunities and flexibility at Topeka Metro by allowing additional vehicles to be charged at the same time. However, the intended transformer upgrade at Topeka Metro is only designed to accommodate up to approximately five 120 kW chargers. A full fleet conversion to BEB's will necessitate a larger transformer in the future regardless of if Topeka Metro pursues the minimal or maximum number of chargers to support services. For this reason, Topeka Metro has worked with Evergy to maximize transformer pads and conduits for potential future expansion.

Increasing the power supplied by chargers can shorten the time it takes to charge vehicles that can be particularly critical for mid-day charging.

Table 12. Advantages and Disadvantages of Increased Number of Depot Chargers

ADVANTAGES	DISADVANTAGES
Potential to reduce operational time	May require additional charging infrastructure
	Can increase peak energy requirements.
	Can require utility upgrades

2.4.2 Gaps & Constraints

Based on the existing conditions assessment at Topeka Metro facilities and a consideration of potential strategies to improve BEB compatibility, gaps and constraints were identified, and are presented in Table 13.

Table 13. Summary of Key Gaps Identified Through Existing Conditions Reviews

KEY GAPS IDENTIFIED IN PREVIOUS TASKS	
KEY GARAGE FACILITY GAPS & CONSTRAINTS	
1.	The facility was not designed to support pantograph charging and would not be able to without a full structural engineering review. In addition, the existing roof height may support pantographs. This matches discussion with Proterra which has determined plug-in chargers to be preferrable.

2.	Limited space at the Riverfront Facility to support on-site chargers in an exterior yard, and the site is constrained from expanding on three of its four sides
3.	Topeka Metro prefers the chargers and dispensers to be located within the garage.
4.	The narrow aisles between buses in the garage will constrain potential dispenser locations.
5.	Vehicle fueling and cleaning will have to consider the impact of having a mixed electric and diesel fleet which requires different amounts of time in the wash and fuel lane.
6.	Vehicle pull-in will have to be staged to ensure electric vehicles are packed in spots equipped with charging dispensers.
7.	The intended transformer upgrade is only designed to accommodate up to approximately five 120 kW chargers.
8.	The standby generator is only designed to provide enough power for the administration building and does not include power for the chargers.
KEY FLEET GAPS & CONSTRAINTS	
9.	For Fixed-route vehicles, 16 of the 26 vehicles have already reached the minimum service life as defined by the FTA (12-year useful life for fixed-route vehicles). The remaining ten vehicles will reach the end of their minimum service life in 2026.
10.	Similarly, 8 of the 13 paratransit vehicles have also reached the end of their minimum service life as defined by the FTA (7-year useful life for paratransit vans).
KEY SERVICE/OPERATIONAL GAPS & CONSTRAINTS	
11.	The dominant candidate location for on-route charging would be the Quincy Street Station (at 820 SE Quincy St.), as all routes pass through this facility and all layovers between trips are currently scheduled at the terminal. However, layovers are not very long (typically 5-10 min), and this time also often serves as a recovery opportunity for a delayed bus to catch up with its schedule, and it is therefore not guaranteed to be available. Charging during short layovers typically involves “fast” charging at high power levels (300-450 kW), however such an interval still only provides a BEB with enough energy to complete one or two trips.
12.	Each route is staged at its own platform at Quincy Street Station which may require modifying the staging approach if on-route charging is found to be necessary.
13.	Placement of dispensers and charging cords should be located to optimize Topeka Metro operational efficiency.
14.	Findings from the route modeling exercise performed in Task 2 indicate that for Monday – Friday service, BEBs with new batteries are compatible with only 14 of 25 blocks, including all rush hour trippers. Of these, 2 blocks (P and Y) are school trippers pending cancelation. With degraded batteries, compatibility decreases to 12 of 25 blocks. For more information on compatibility with BEB batteries for specific Monday – Friday service blocks refer to **Table 6.** Note that a degraded battery is assumed to have 75% of the listed battery capacity and accounting for a 15% safety factor to maintain battery state of health.

15.	Findings from the route modeling exercise performed in Task 2 indicate that for Saturday service, BEBs with new batteries are compatible with 7 of 12 blocks, however in a degraded battery scenario this compatibility drops to 2 of 12 blocks. This is due to the duration of Saturday blocks being more uniformly long than the variability observed in weekday blocks. For more information on compatibility with BEB batteries for specific Saturday service blocks refer to **Table 7.**

2.4.3 Alternatives Selected for Investigation as Mitigation Scenarios

Given the identified constraints on Topeka Metro facilities and operations, the following mitigation strategies were pursued:

- Re-blocking without impacting scheduled trip times that are available to the public, but including more extensive interlining
- Staggered mid-block charging sessions (in-depot and on-route)
- Increased dispatch size
- Increased battery size

The following subsections identify five mitigation scenarios aimed to resolve existing gaps and constraints present at Topeka Metro to support a partial and or full conversion to a BEB fleet. The following four scenarios were developed with an in-depth understanding of the findings identified in Modeling Step 1 (described in **Section 2.2**) and Modeling Step 2 (described in **Section 2.3**). The following subsections describe five scenarios below:

- Scenario 1: Midday charging in depot only
- Scenario 2: Midday charging in depot and at QSS (short top-ups)
- Scenario 3: Midday charging in depot and at QSS (30-min layovers)
- Scenario 4: Midday charging in depot only, enlarged battery size
- Scenario 5: Midday charging in depot and at QSS (30-min layovers), enlarged battery size

2.4.4 Scenario 1: Midday Charging in Depot Only

Scenario 1 examines the operational, fleet size, and high-level fixed infrastructure impact of transitioning to a BEB fleet using depot charging only. Battery capacity was assumed to remain at 450 kWh, aligning with the specifications of the vehicles currently on order from Proterra.

2.4.4.1 Re-Blocking and Midday Charging Simulation Results

Key findings for Scenario 1 are presented in **Table 14** below.

Table 14. Scenario 1: Midday Charging in Depot Only– Key Findings

MAJOR FINDING OF MODELED SCENARIO	PROJECTED OUTPUT VALUE	COMPARISON TO BASELINE	
		(2022)	(2023)
Peak daily dispatch size	21 buses (weekday)	20 buses	18 buses
Peak mid-block depot charging	5 buses × 120 kW = 600 kW	N/A	N/A
Peak overnight depot charging	4 buses × 120 kW = 480 kW	N/A	N/A
Operational changes	• 86 weekday deadheads • 48 Saturday deadheads • Buses deadheading between QSS and the depot for charging, at a rate of approx. 2 every 30 minutes • Staffing increase of 2 full-time equivalents (FTE) to shuttle buses • Drivers in passenger service would conduct service changeovers at QSS.	• 50 weekday deadheads • 24 Saturday deadheads	• 46 weekday deadheads • 24 Saturday deadheads

The re-blocked schedule and associated midday charging requirements for Scenario 1 are presented in the figures on the pages below, as follows:

- **Figure 29** & **Figure 30:** Re-Blocked Schedule (Weekday and Saturday)
- **Figure 31** & **Figure 32:** Net Energy Consumption (Weekday and Saturday)
- **Figure 33** & **Figure 34:** Mid-Block Charging Demand (Weekday and Saturday)
- **Figure 35:** Overnight Charging Schedule (Most Constrained Case)
- **Figure 36:** Overnight Charging Demand (Most Constrained Case)

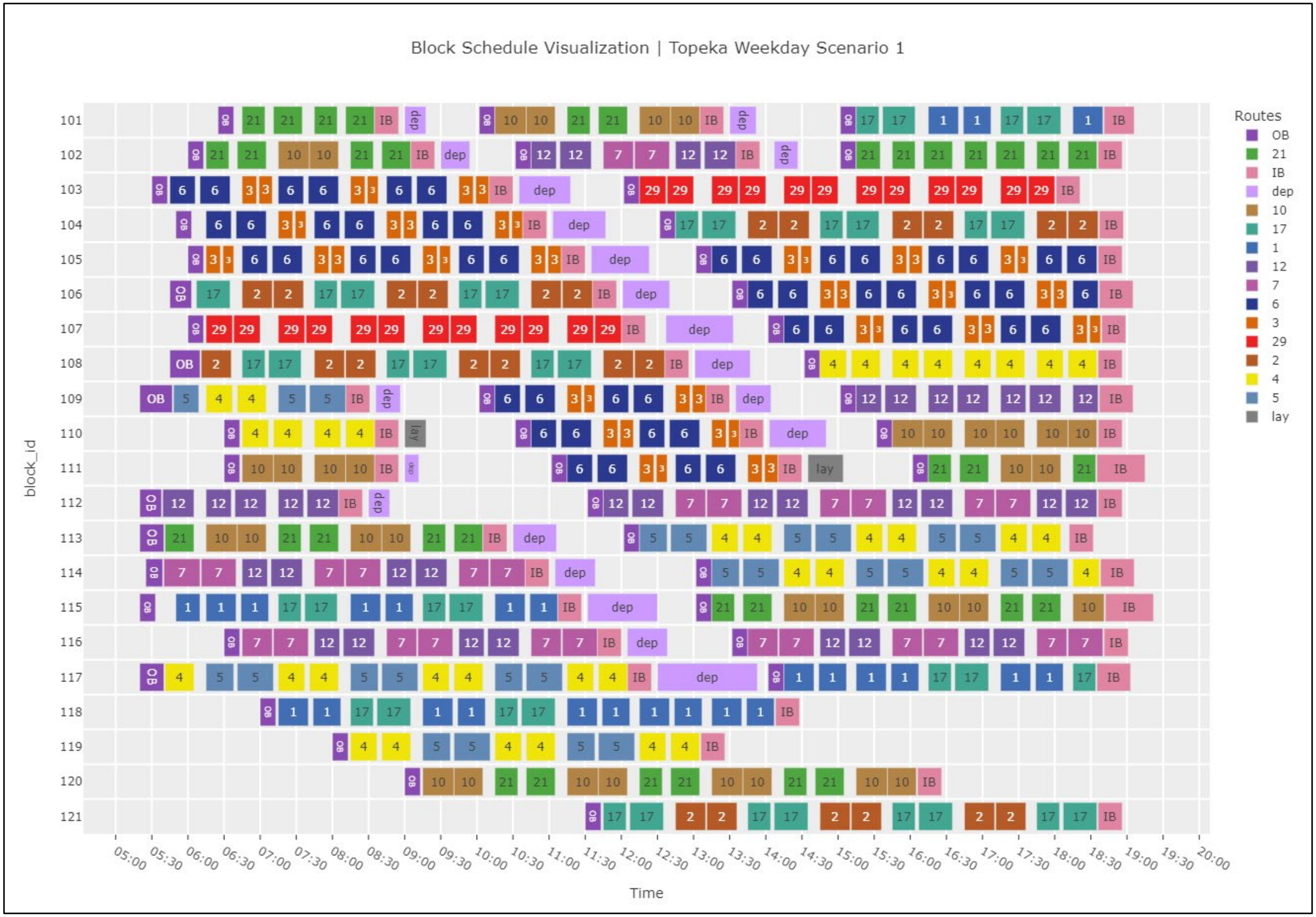


Figure 29. Scenario 1: Midday Charging in Depot Only – Re-Blocked Weekday Schedule

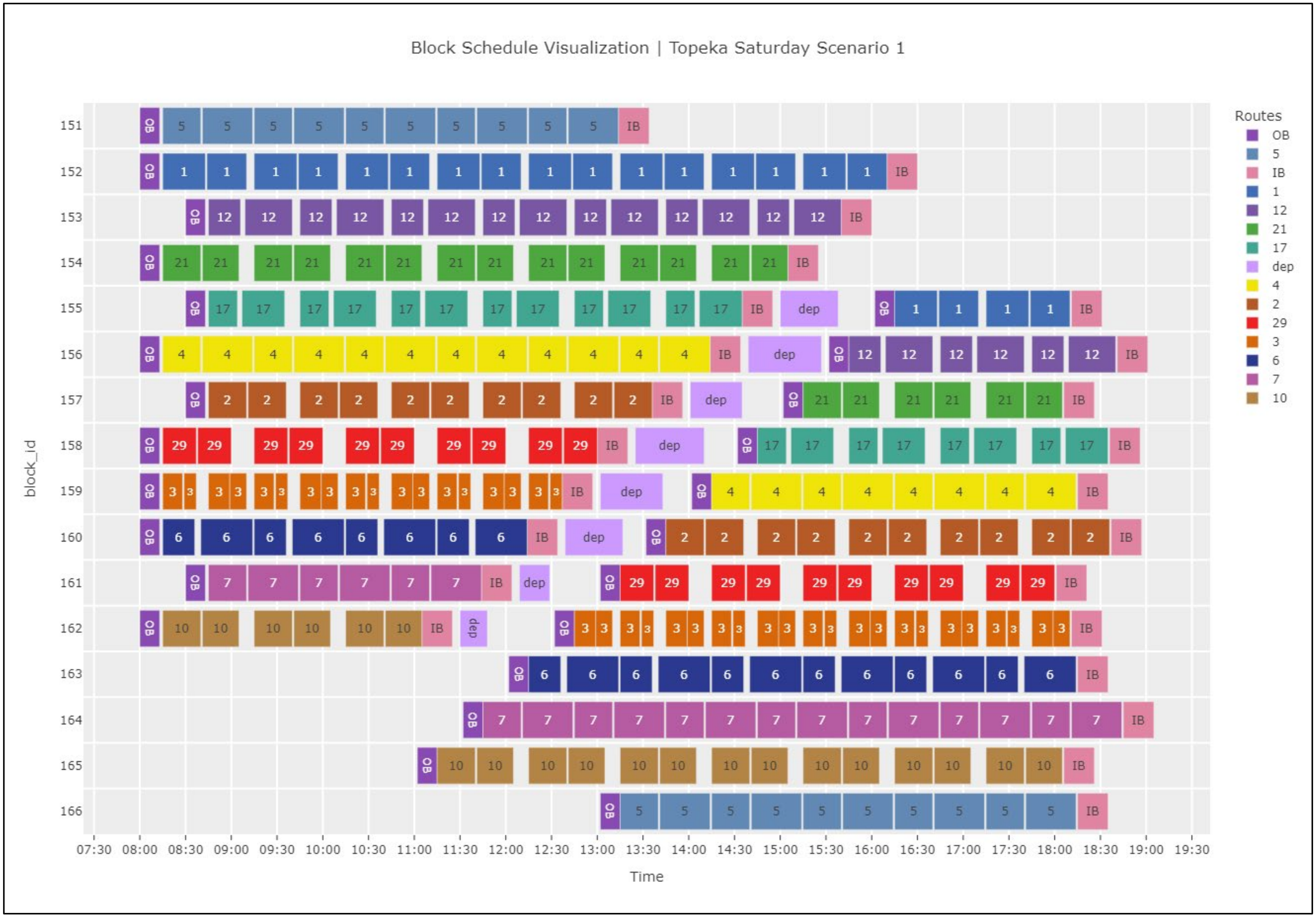


Figure 30. Scenario 1: Midday Charging in Depot Only – Re-Blocked Saturday Schedule

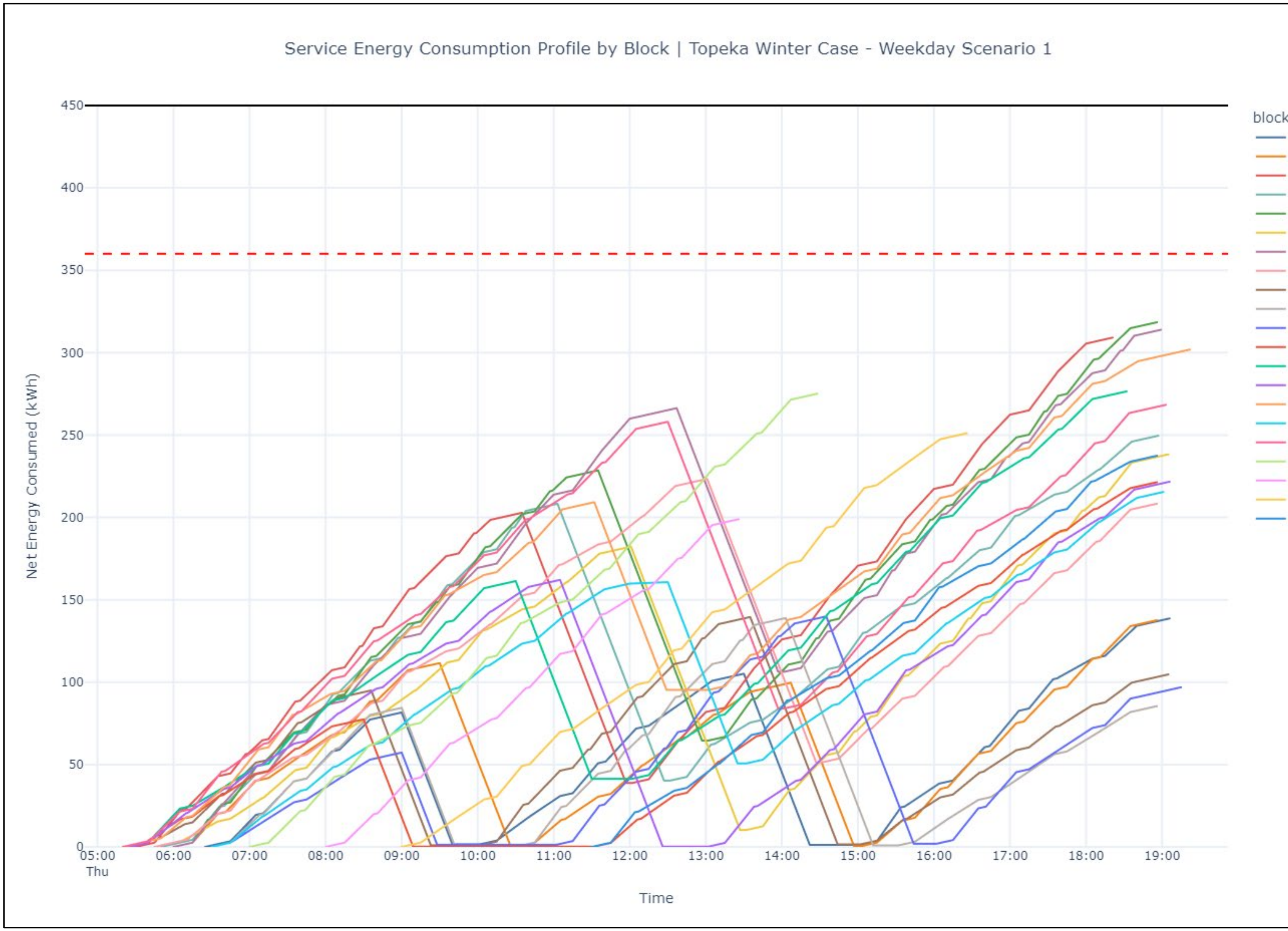


Figure 31. Scenario 1: Midday Charging in Depot Only – Weekday Net Energy Consumption Projections

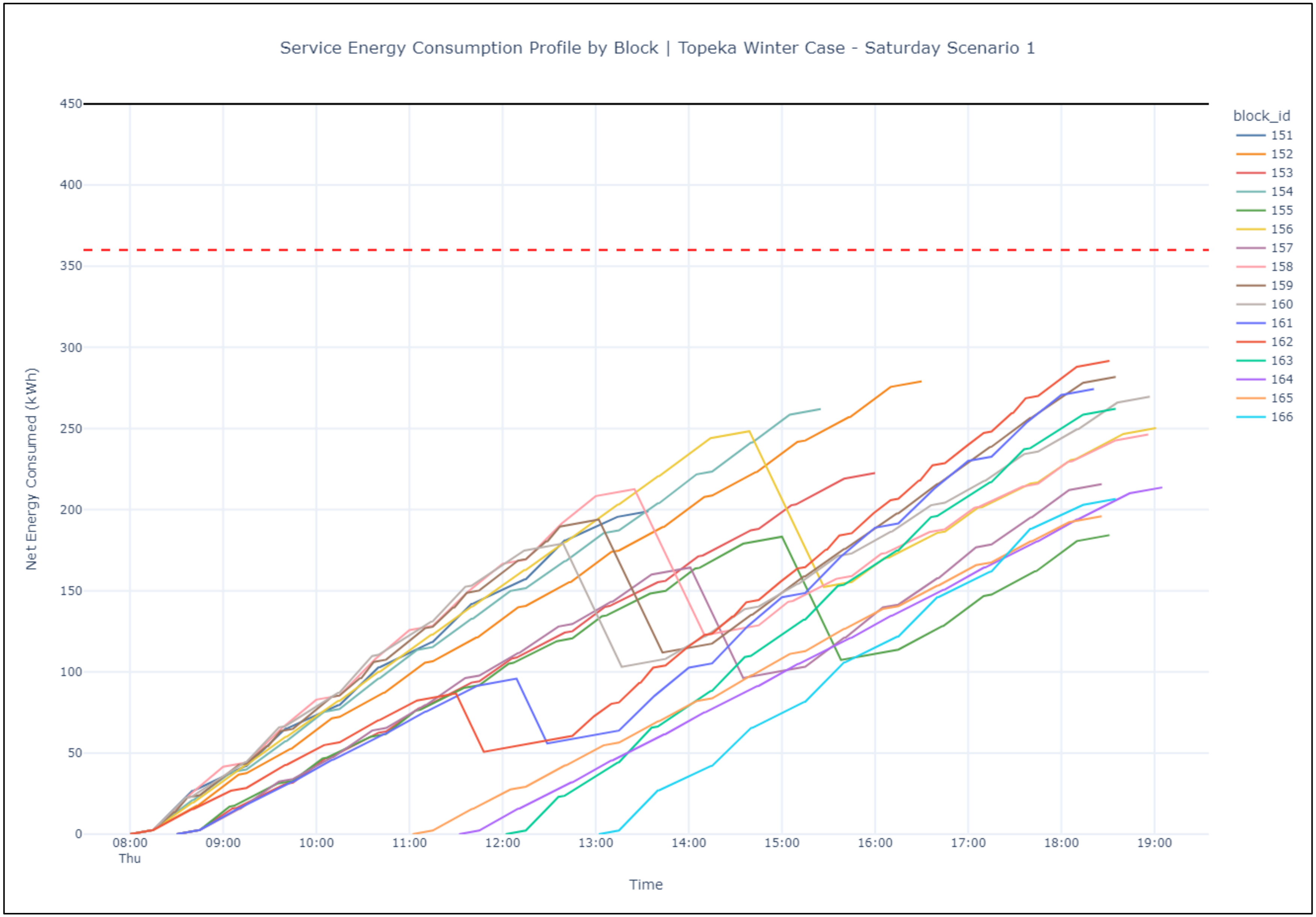


Figure 32. Scenario 1: Midday Charging in Depot Only – Saturday Net Energy Consumption Projections

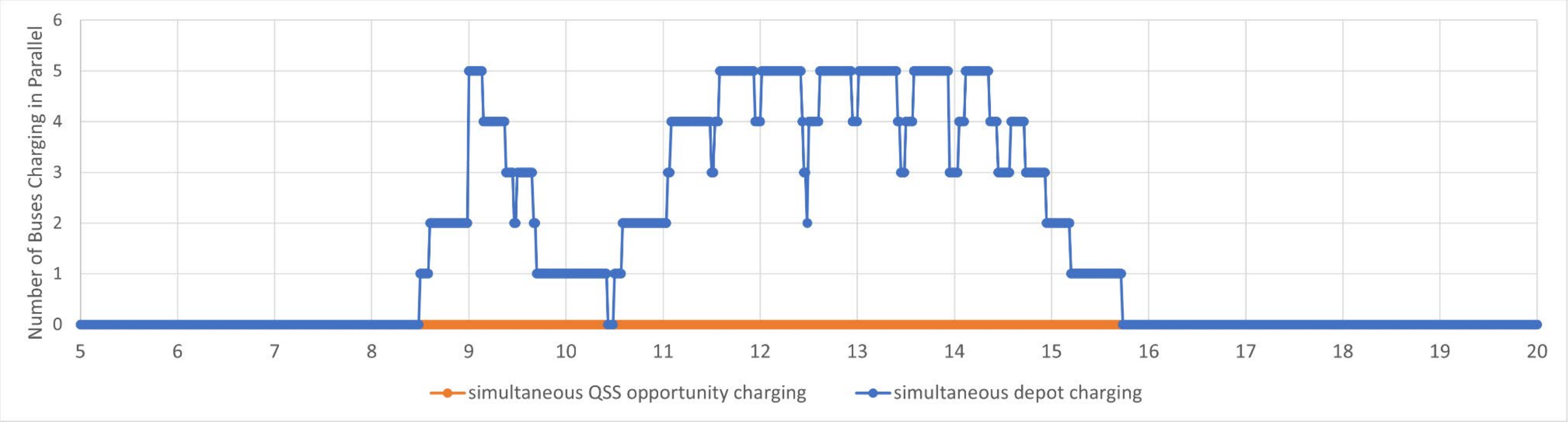


Figure 33. Scenario 1: Midday Charging in Depot Only – Weekday Mid-Block Charging

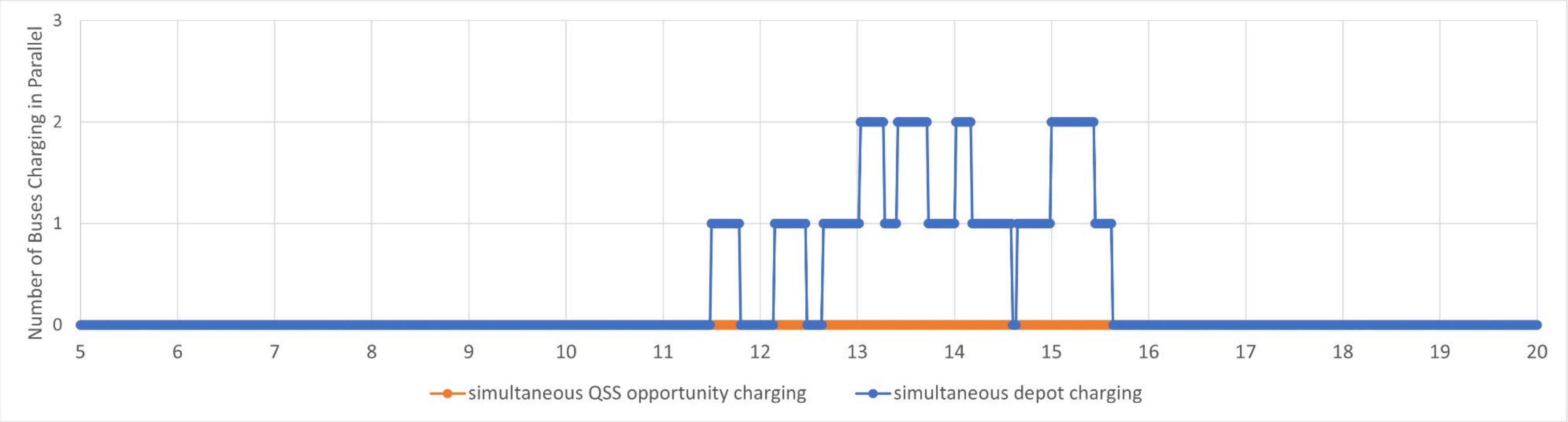
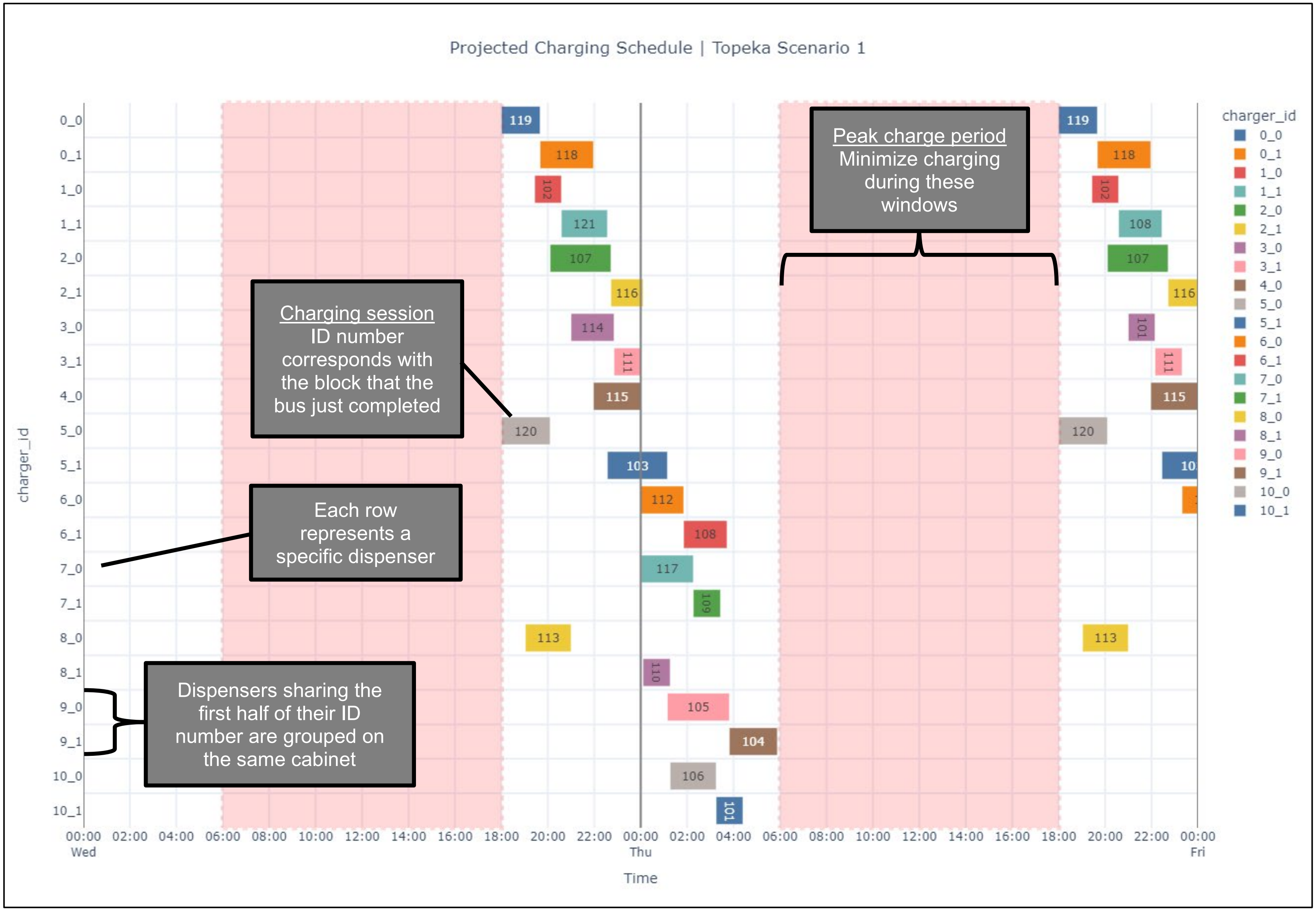


Figure 34. Scenario 1: Charging in Depot Only – Saturday Mid-Block Charging



Peak charge period
Minimize charging during these windows

Charging session
ID number corresponds with the block that the bus just completed

Each row represents a specific dispenser

Dispensers sharing the first half of their ID number are grouped on the same cabinet

Figure 35. Scenario 1: Midday Charging in Depot Only – Overnight Charging Schedule (Wednesday-Thursday Shown)

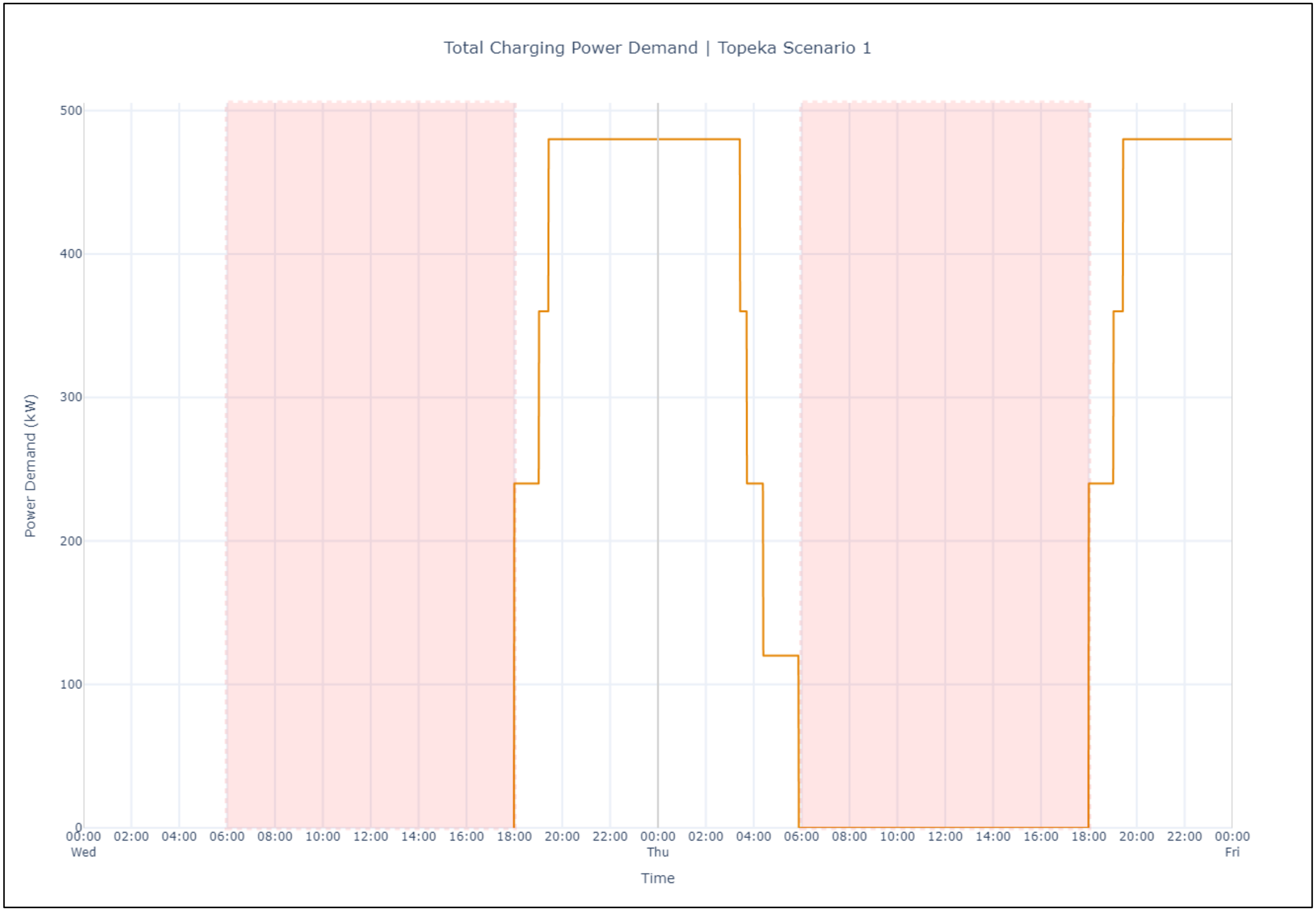


Figure 36. Scenario 1: Midday Charging in Depot Only – Overnight Charging Power Demand (Wednesday-Thursday Shown)

2.4.4.2 Associated Costs

Table 15 provides a high-level 12-year mitigation cost estimate for a 100% BEB fleet under Scenario 1. Note that these costs do not reflect inflation nor implementation schedules; for additional details and more specific costs see the Financial Analysis section.

Table 15. Scenario 1: Midday Charging in Depot Only– Associated Costs

ITEM	UNITS	UNIT COST	TOTAL
Extra Buses (capital only based on current quote)	3 Buses	$1,100,000	$3,300,000
On-route Chargers (high-level device and engineering)	0 Chargers	$500,000	$0
Demand Charge QSS	0 kW	$3.90 / kW / month	$0
Additional Staff	2 FTE	$64,687	$1,552,476
TOTAL			**$4,852,476**

2.4.5 Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups)

Scenario 2 examines the operational, fleet size, and high-level fixed infrastructure impact of transitioning to a BEB fleet using mid-block charging at the depot and at QSS for short top-ups at high power rates (300 kW). Top-up charging would take place only between existing trips, with no layovers. Battery capacity was assumed to remain at 450 kWh, aligning with the specifications of the vehicles currently on order from Proterra.

2.4.5.1 Re-Blocking and Charging Simulation Results

Key findings for Scenario 2 are presented in **Table 16** below.

Table 16. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Key Findings

MAJOR FINDING OF MODELED SCENARIO	PROJECTED OUTPUT VALUE	COMPARISON TO BASELINE	
		(2022)	(2023)
Peak daily dispatch size	20 buses (weekday)	20 buses	18 buses
Peak mid-block depot charging	5 buses × 120 kW = 600 kW	N/A	N/A
Peak mid-block QSS charging	3 buses × 300 kW = 900 kW	N/A	N/A
Peak overnight depot charging	4 buses × 120 kW = 480 kW	N/A	N/A
Operational changes	• 64 weekday deadheads • 32 Saturday deadheads • Drivers in revenue service would charge between trips and circle to departure points • Limited number of buses deadheading between QSS and the depot for charging • Potentially addressed with existing staffing	• 50 weekday deadheads • 24 Saturday deadheads	• 46 weekday deadheads • 24 Saturday deadheads

The re-blocked schedule and associated midday charging requirements for Scenario 2 are presented in the figures on the pages below, as follows:

- **Figure** 37 & **Figure** 38**:** Scenario 2 Re-Blocked Schedule (Weekday and Saturday)
- **Figure** 39 & **Figure** 40**:** Scenario 2 Net Energy Consumption (Weekday and Saturday)
- **Figure** 41 & **Figure** 42**:** Scenario 2 Mid-Block Charging (Weekday and Saturday)
- **Figure 43:** Overnight Charging Schedule (Most Constrained Case)
- **Figure 44:** Overnight Charging Demand (Most Constrained Case)

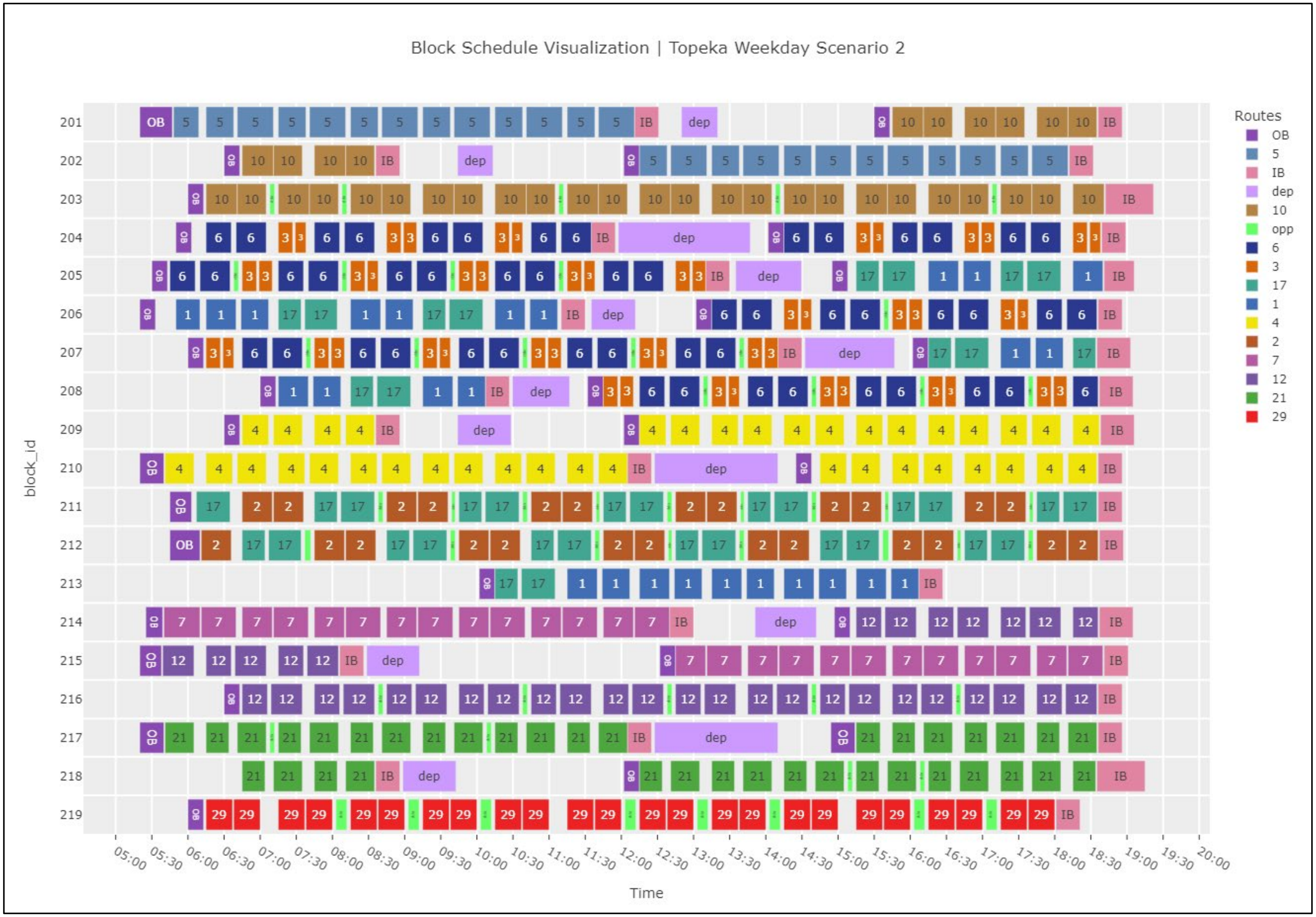


Figure 37. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Re-Blocked Weekday Schedule

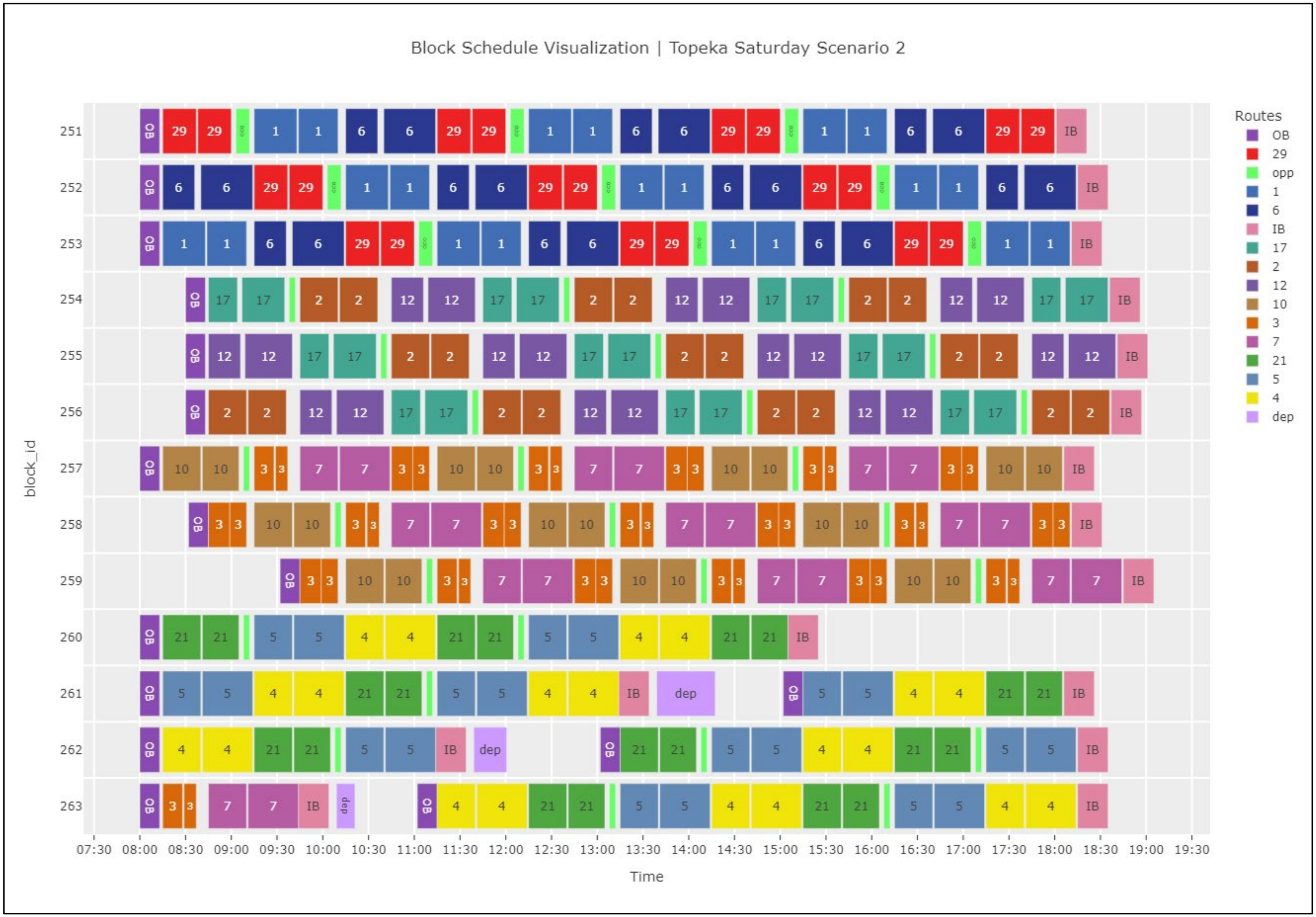


Figure 38. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Re-Blocked Saturday Schedule

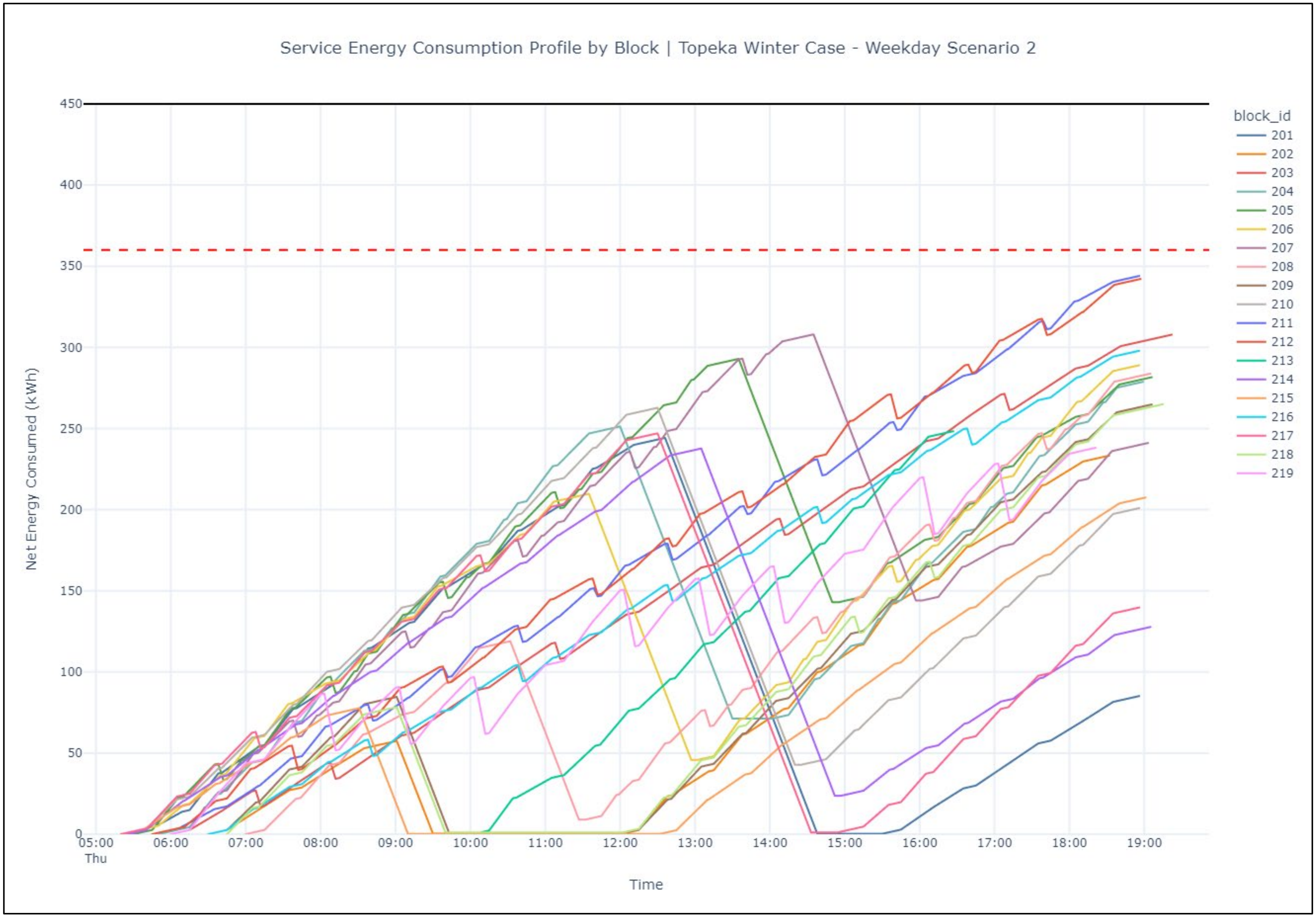


Figure 39. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Weekday Net Energy Consumption Projections

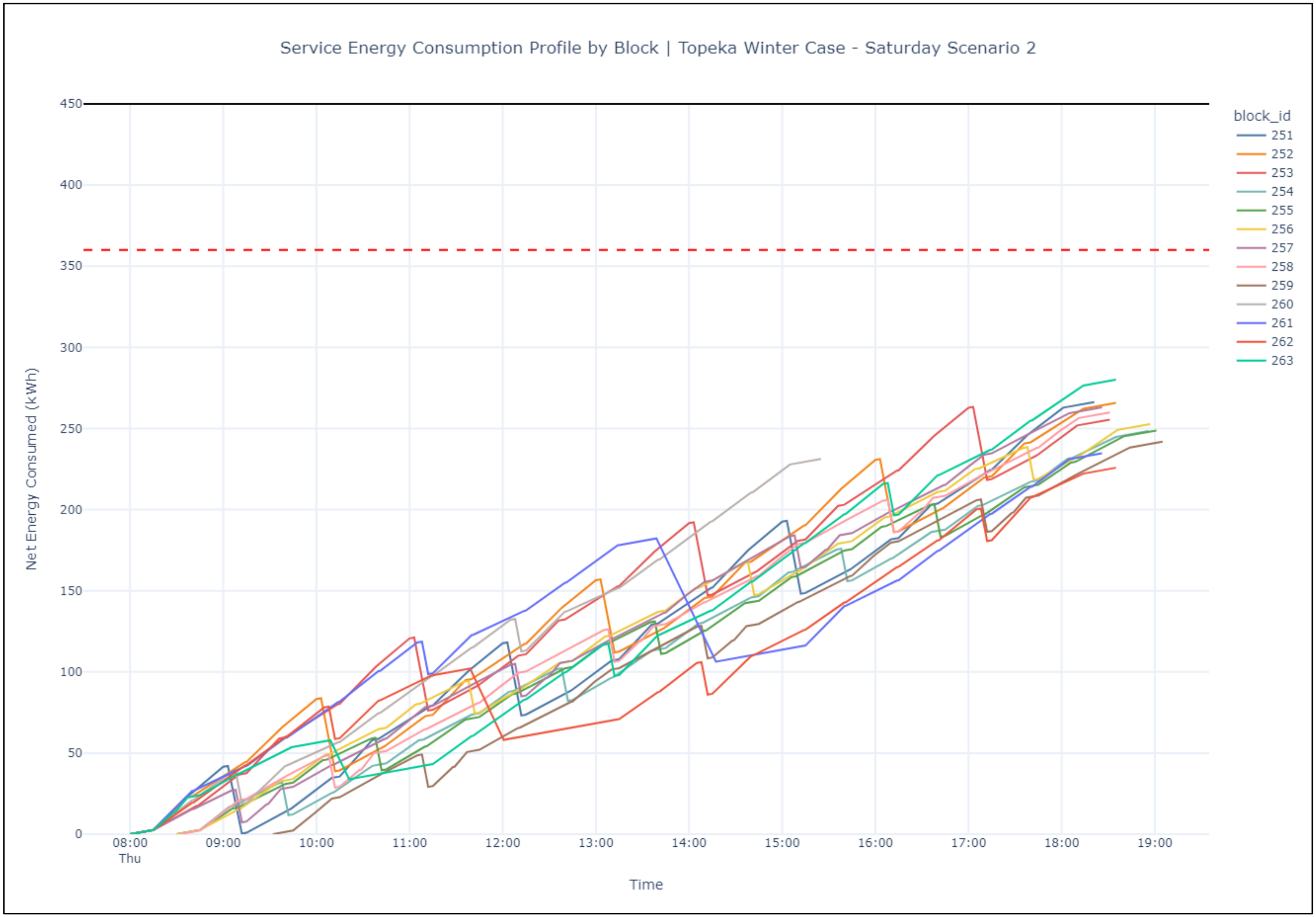


Figure 40. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Saturday Net Energy Consumption Projections

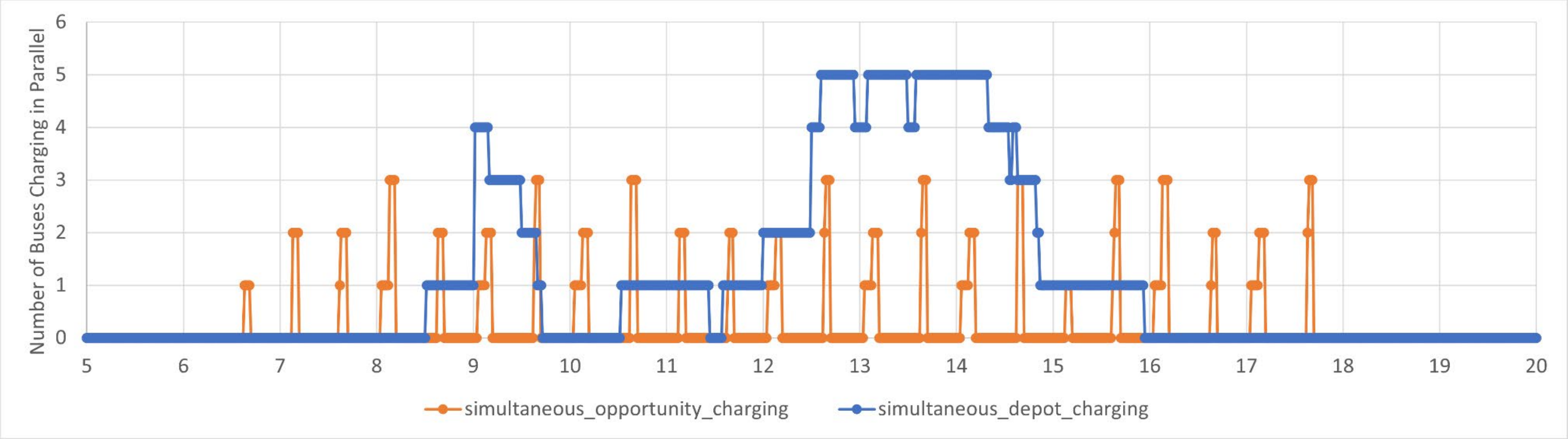


Figure 41. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Weekday Mid-Block Charging

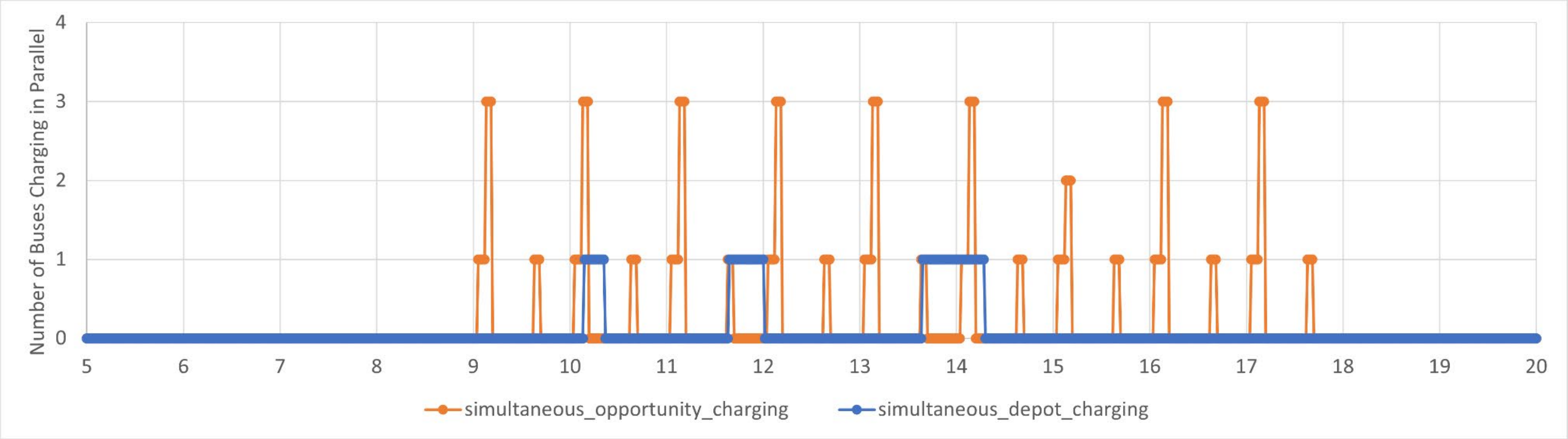


Figure 42. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Saturday Mid-Block Charging

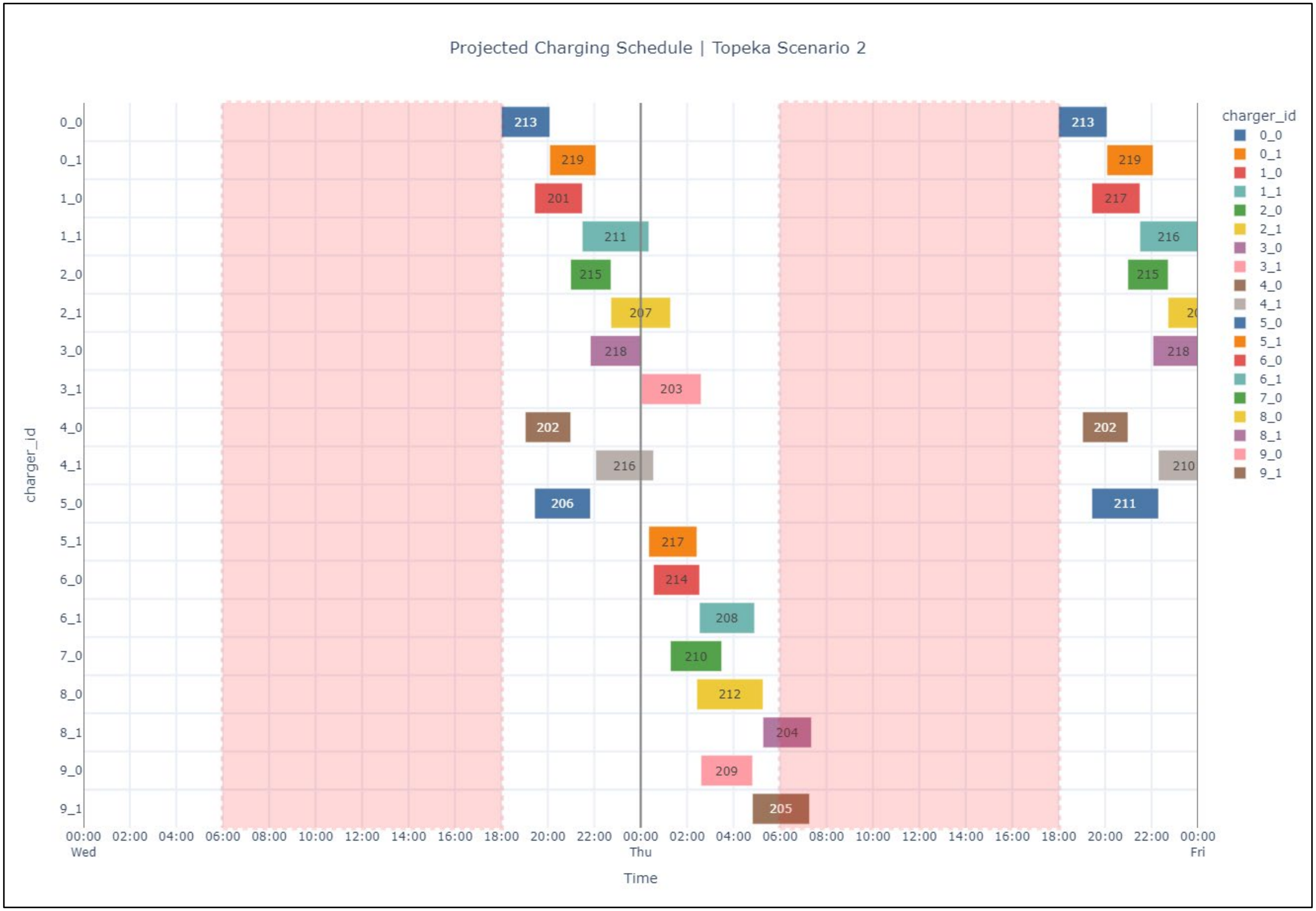


Figure 43. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Overnight Charging Schedule (Wednesday-Thursday Shown)

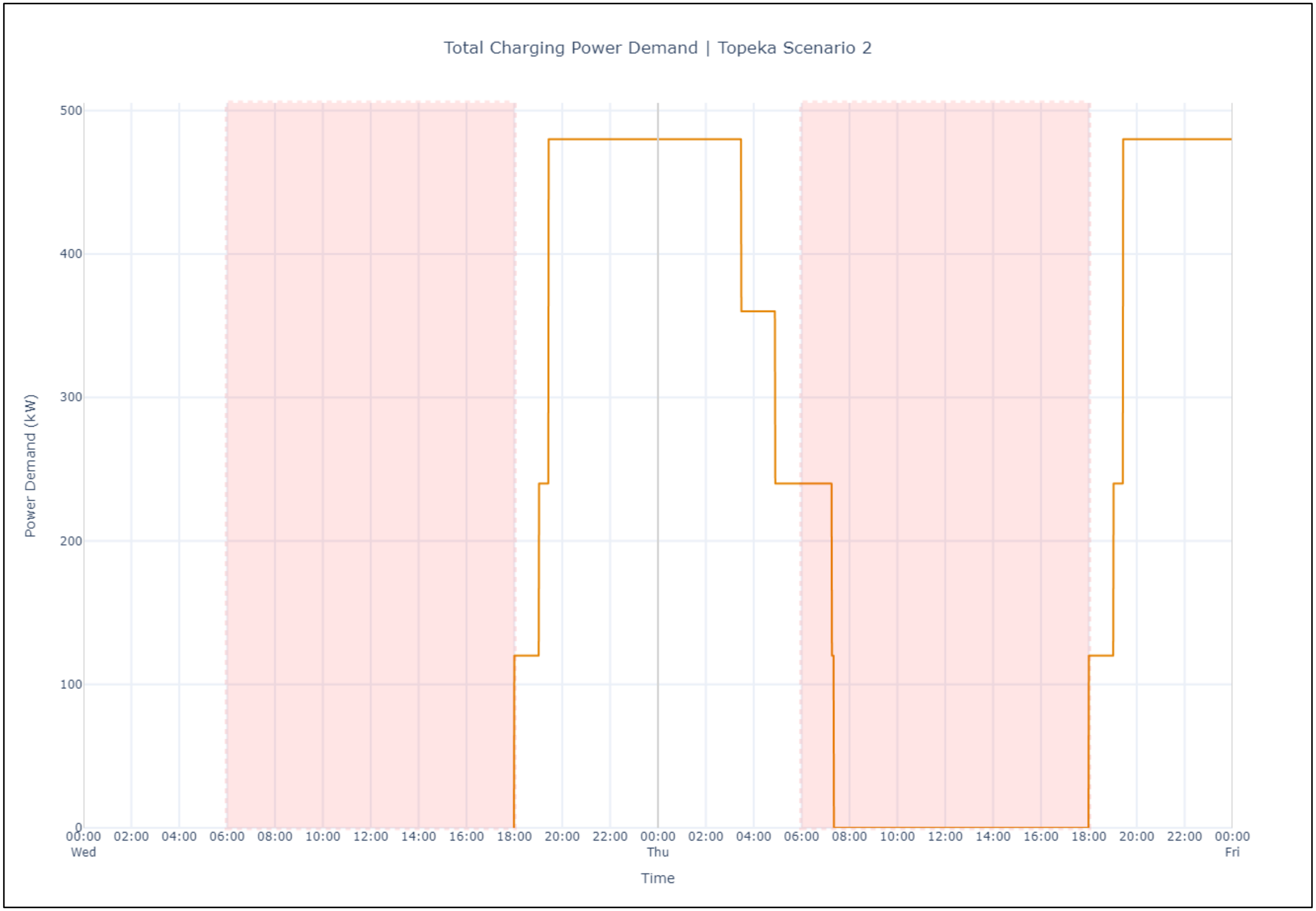


Figure 44. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups) – Overnight Charging Power Demand (Wednesday-Thursday Shown)

2.4.5.2 Associated Costs

Table 17 provides a high-level 12-year cost estimate for a 100% BEB fleet under Scenario 2.

Table 17. Scenario 2: Midday Charging in Depot and at QSS (Short Top-Ups)– Associated Costs

ITEM	UNITS	UNIT COST	TOTAL
Extra Buses (capital only based on current quote)	2 Buses	$1,100,000	$2,200,000
On-route Chargers (high-level device and engineering)	3 Chargers + 1 Spare	$500,000	$2,000,000
Demand Charge QSS	900 kW	$3.90 / kW / month	$505,440
Additional Staff	0 FTE	$64,687	$0
TOTAL			**$4,705,440**

2.4.6 Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers)

Scenario 3 examines the operational, fleet size, and high-level fixed infrastructure impact of transitioning to a BEB fleet using mid-block charging at the depot and at QSS for 30-minute layovers at low power rates (150 kW). Battery capacity was assumed to remain at 450 kWh, aligning with the specifications of the vehicles currently on order from Proterra.

2.4.6.1 Re-Blocking and Charging Simulation Results

Key findings for Scenario 3 are presented in Table 18 below.

Table 18. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers)

MAJOR FINDING OF MODELED SCENARIO	PROJECTED OUTPUT VALUE	COMPARISON TO BASELINE	
		(2022)	(2023)
Peak daily dispatch size	20 buses (weekday)	20 buses	18 buses
Peak mid-block depot charging	4 buses × 120 kW = 480 kW	N/A	N/A
Peak mid-block QSS charging	2 buses × 150 kW = 300 kW	N/A	N/A
Peak overnight depot charging	4 buses × 120 kW = 480 kW	N/A	N/A
Operational changes	• 52 weekday deadheads • 28 Saturday deadheads • Drivers in revenue service would step back at QSS and board new vehicles (See **Section 5.4.4**) • Limited number of buses deadheading between QSS and the depot for charging • Staffing increase of up to 1 FTE when one or more on-route chargers are not in service	• 50 weekday deadheads • 24 Saturday deadheads	• 46 weekday deadheads • 24 Saturday deadheads

The re-blocked schedule and associated midday charging requirements for Scenario 3 are presented in the figures on the pages below, as follows:

- **Figure 45** & **Figure 46:** Scenario 3 Re-Blocked Schedule (Weekday and Saturday)
- **Figure 47** & **Figure 48:** Scenario 3 Net Energy Consumption (Weekday and Saturday)
- **Figure 49** & **Figure 50:** Scenario 3 Mid-Block Charging (Weekday and Saturday)
- **Figure 51:** Overnight Charging Schedule (Most Constrained Case)
- **Figure 52:** Overnight Charging Demand (Most Constrained Case)

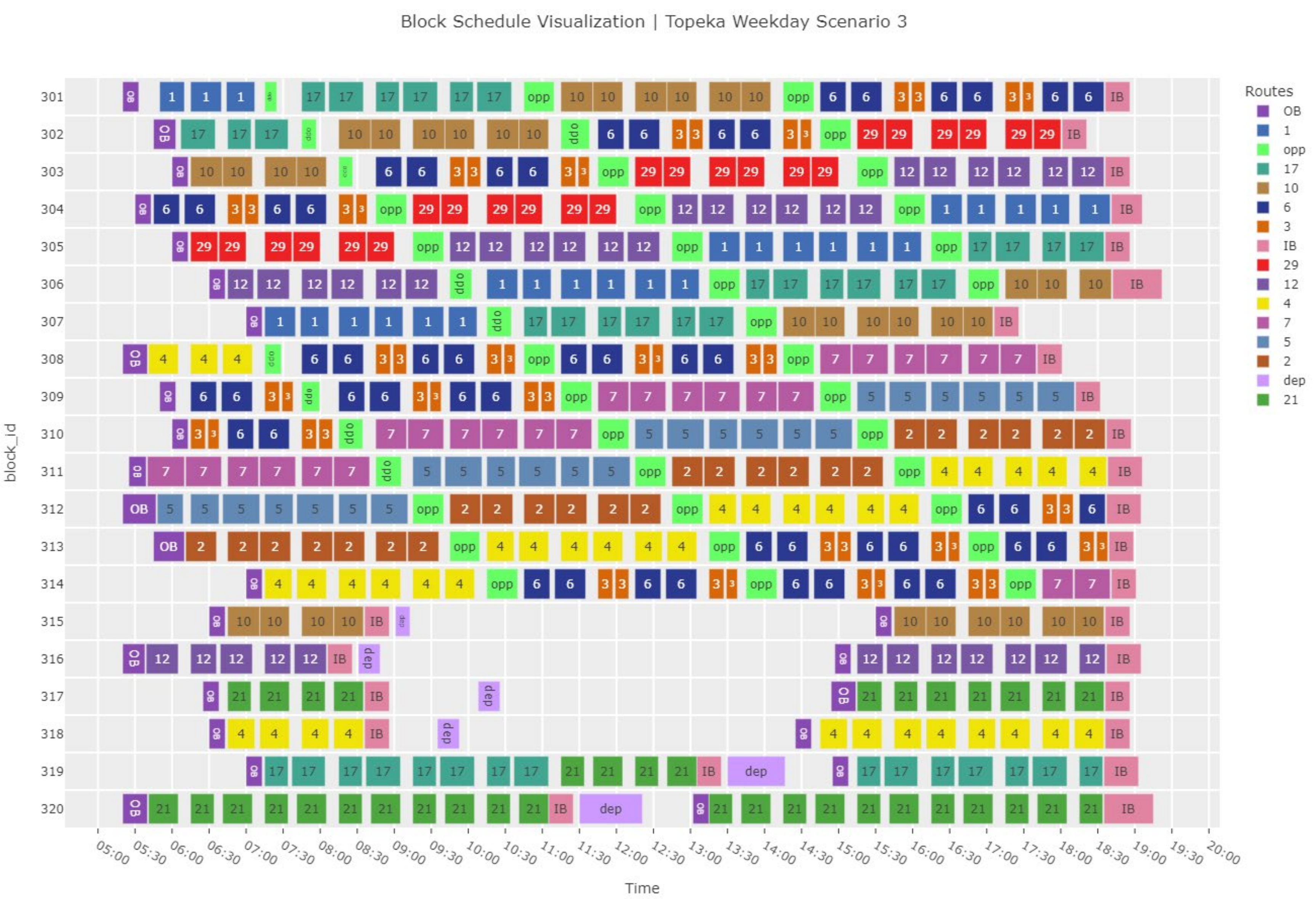


Figure 45. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers)– Re-Blocked Weekday Schedule

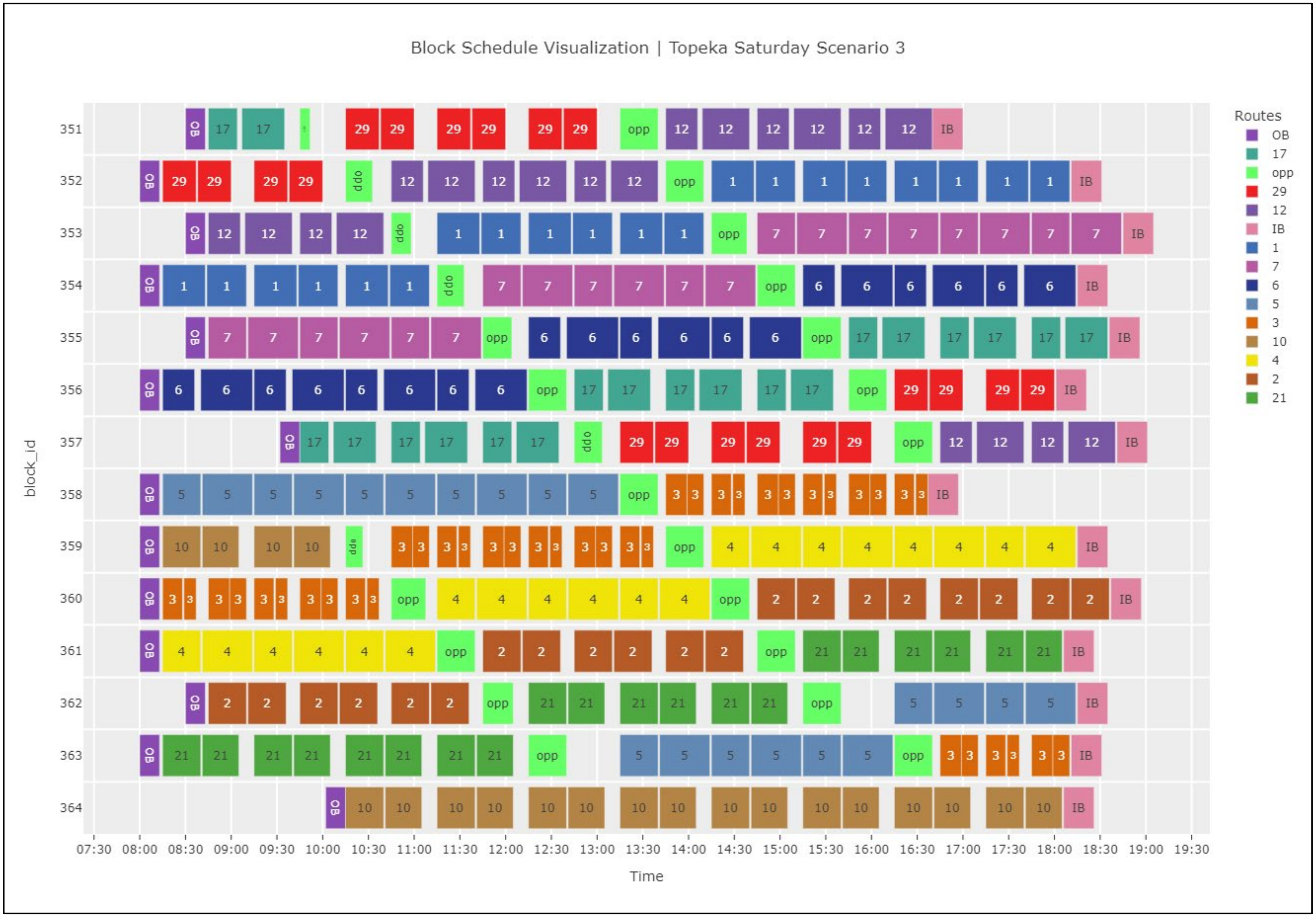


Figure 46. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers)– Re-Blocked Saturday Schedule

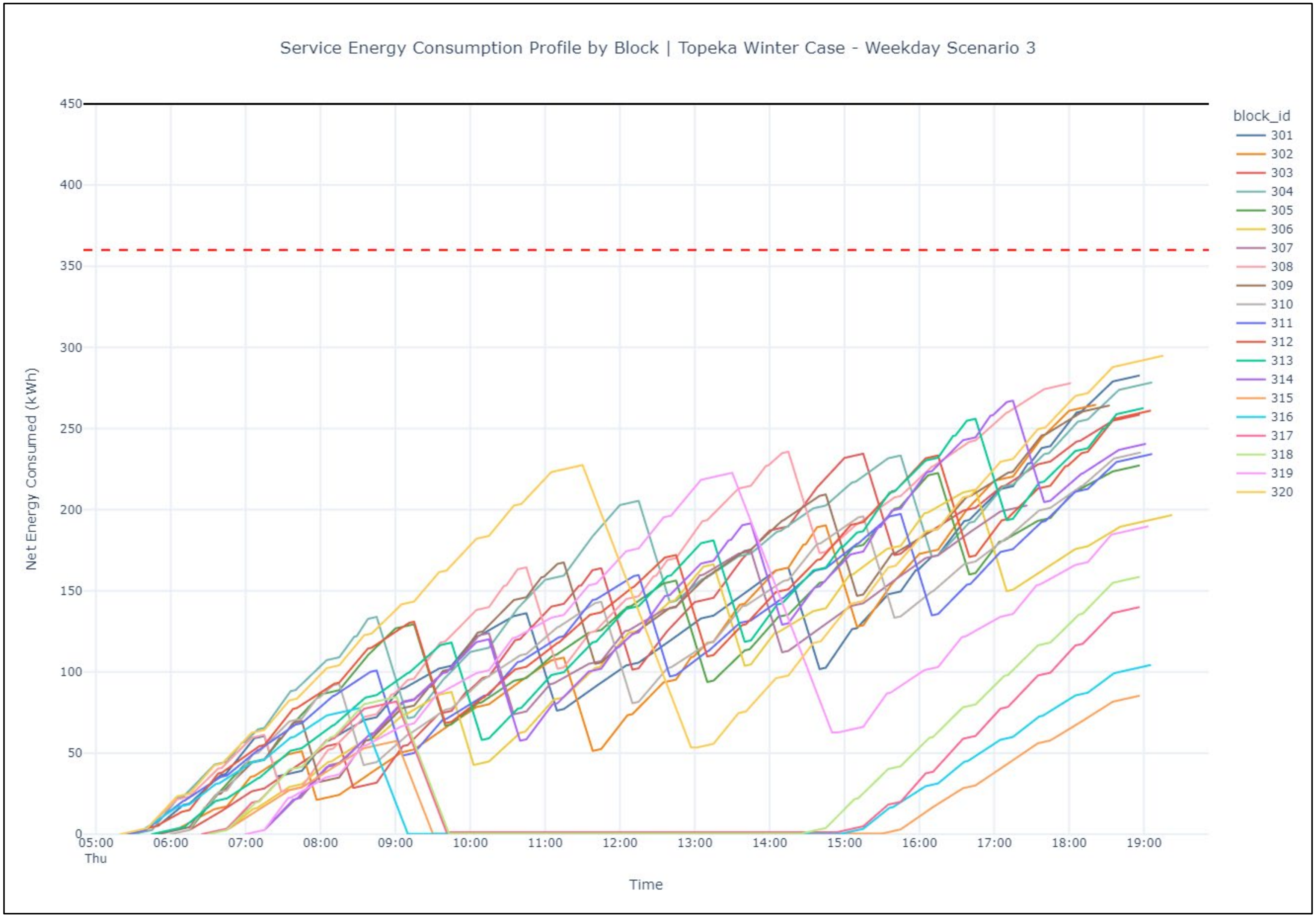


Figure 47. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers)– Weekday Net Energy Consumption Projections

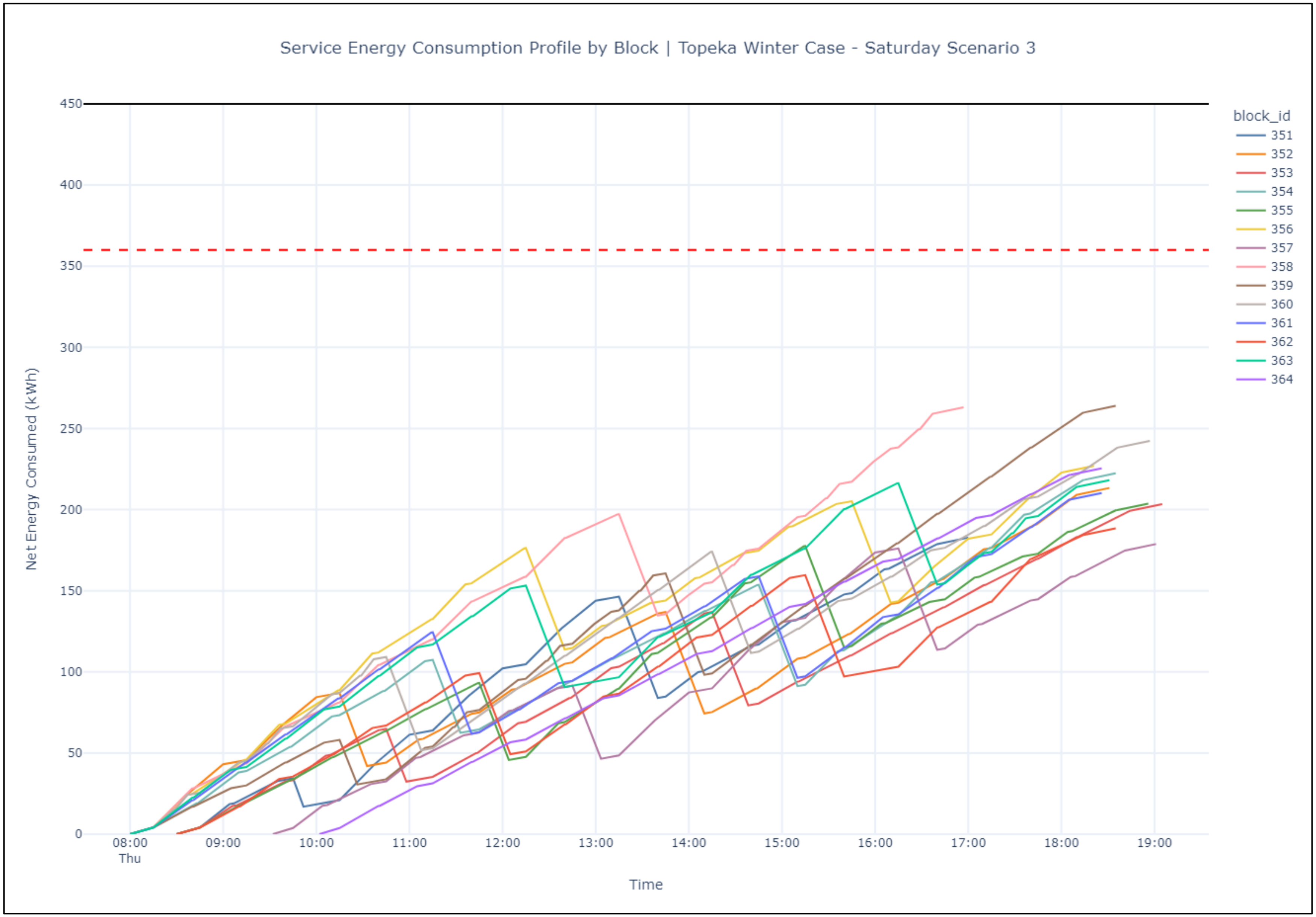


Figure 48. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers)– Saturday Net Energy Consumption Projections

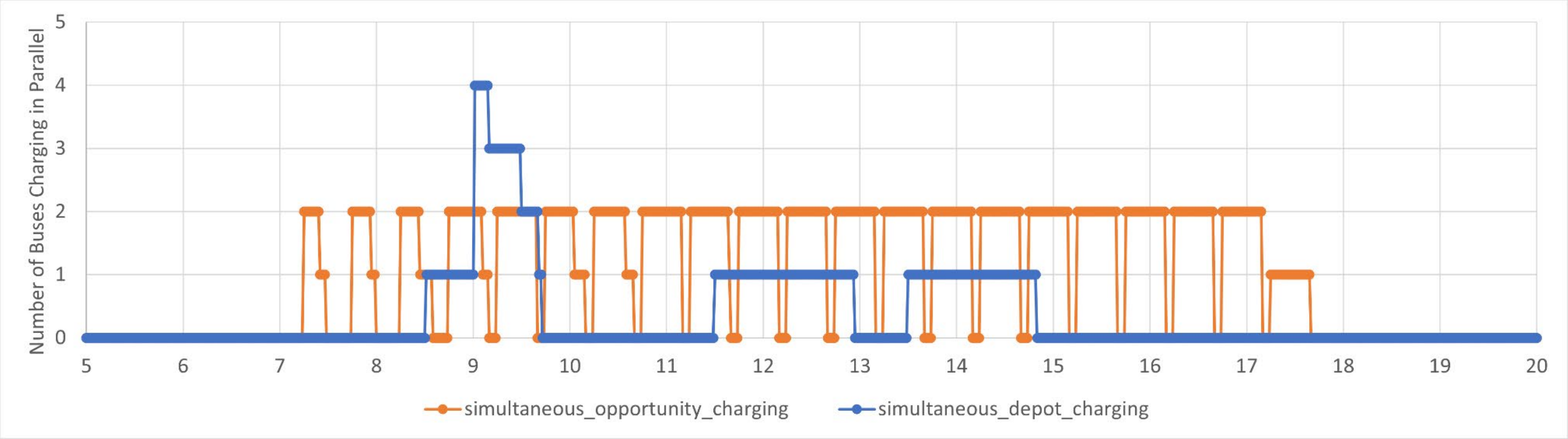


Figure 49. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers) – Weekday Midday Charging

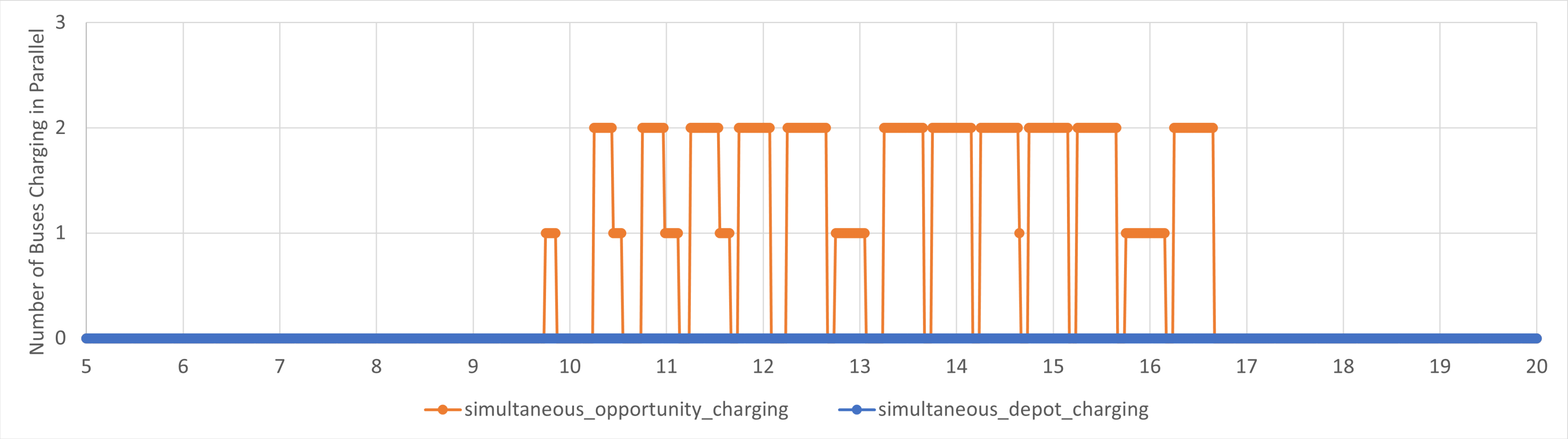


Figure 50. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers) – Saturday Midday Charging

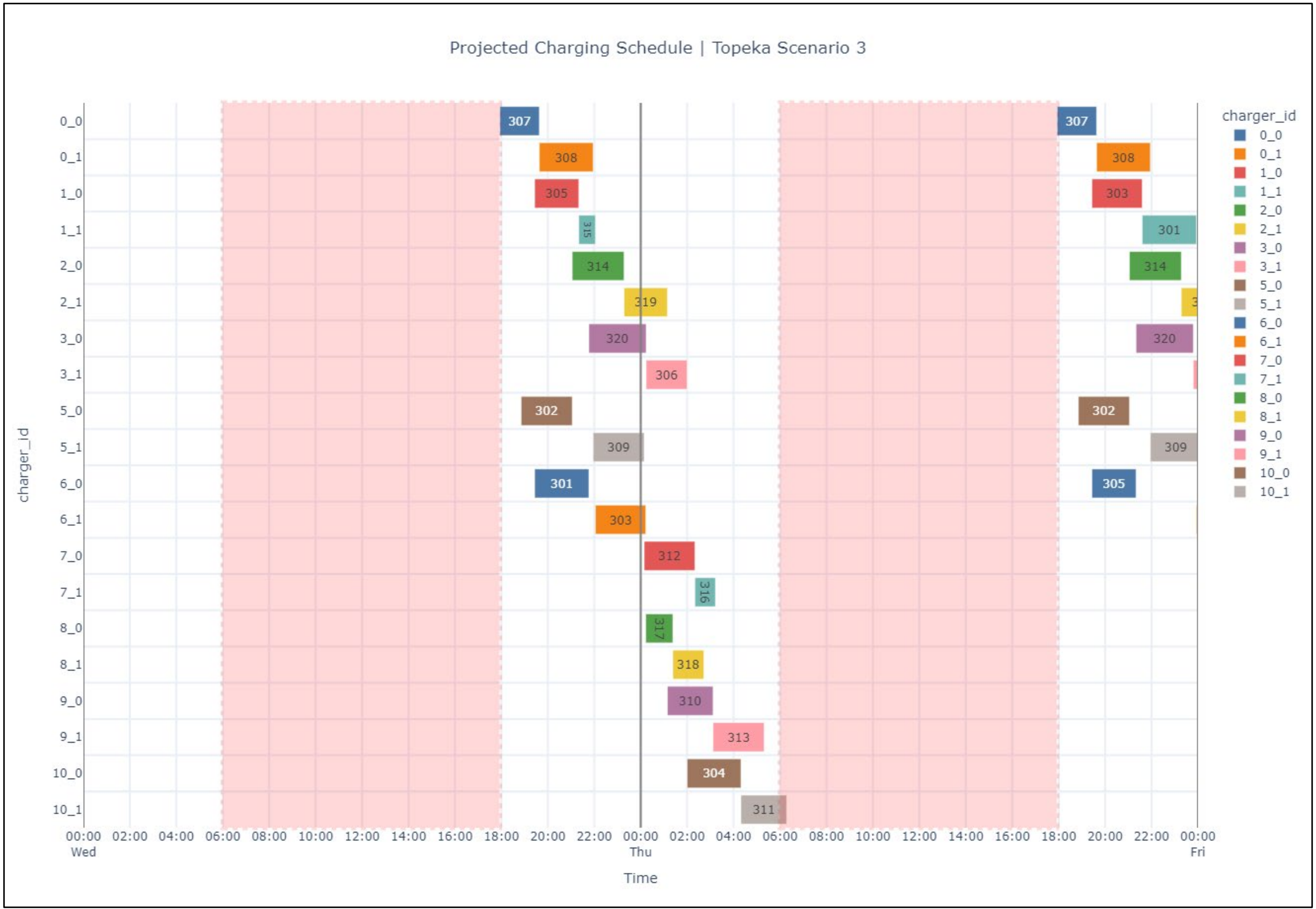


Figure 51. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers) – Overnight Charging Schedule (Wednesday-Thursday Shown)

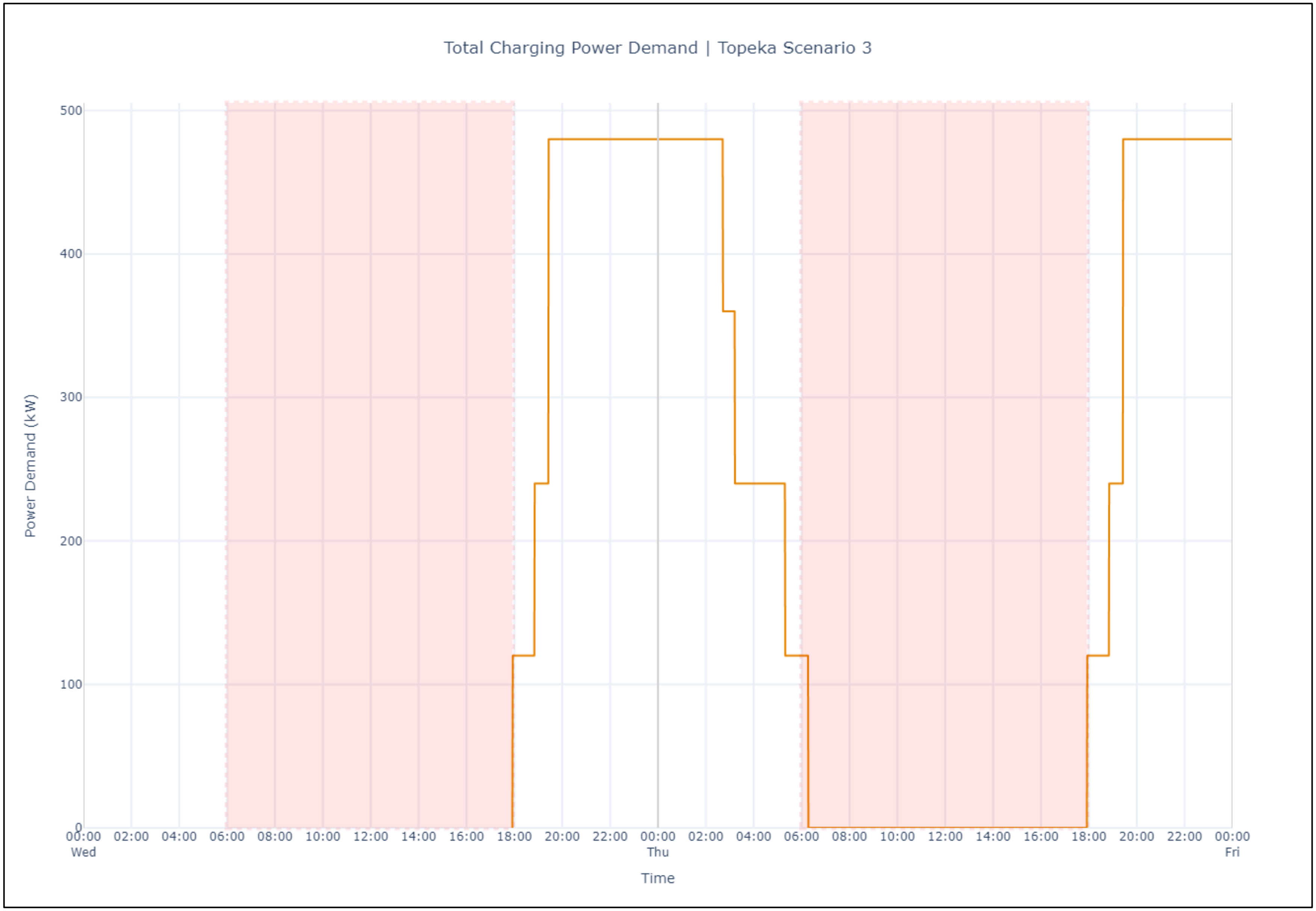


Figure 52. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers) – Overnight Charging Power Demand (Wednesday-Thursday Shown)

2.4.6.2 Associated Costs

Table 19 provides a high-level 12-year cost estimate for a 100% BEB fleet under Scenario 3.

Table 19. Scenario 3: Midday Charging in Depot and at QSS (30–min Layovers) – Associated Costs

ITEM	UNITS	UNIT COST	TOTAL
Extra Buses (capital only based on current quote)	2 Buses	$1,100,000	$2,200,000
On-route Chargers (high-level device and engineering)	2 Chargers + 1 Spare	$500,000	$1,500,000
Demand Charge QSS	300 kW	$3.90 / kW / month	$168,480
Additional Staff	0 FTE	$64,687	$0
TOTAL			**$3,868,480**

2.4.7 Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size

Scenario 4 examines the operational, fleet size, and high-level fixed infrastructure impact of transitioning to a BEB fleet using depot charging only, and increasing the absolute battery capacity to 492 kWh, equal to the current high-capacity BEB model offered by Proterra.

2.4.7.1 Re-Blocking and Charging Simulation Results

Key findings for Scenario 4 are presented in **Table 20** below.

Table 20. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size – Key Findings

MAJOR FINDING OF MODELED SCENARIO	PROJECTED OUTPUT VALUE	COMPARISON TO BASELINE	
		(2022)	(2023)
Dispatch size	18 buses (weekday)	20 buses	18 buses
Peak mid-block depot charging	4 buses × 120 kW = 480 kW	N/A	N/A
Peak overnight depot charging	5 buses × 120 kW = 600 kW	N/A	N/A
Operational changes	• 72 weekday deadheads • 44 Saturday deadheads • Half of all blocks must be run by buses with batteries less than 50% along the degradation curve (>87.5% of original capacity) • Increased interlining within blocks, to reduce differences in energy consumption between blocks • Buses deadheading between QSS and the depot for charging, at a rate of approx. 1-2 every 30 minutes • Staffing increase of 1-2 full-time equivalents (FTE) to shuttle buses • Drivers in passenger service would conduct service changeovers at QSS.	• 50 weekday deadheads • 24 Saturday deadheads	• 46 weekday deadheads • 24 Saturday deadheads

The re-blocked schedule and associated midday charging requirements for Scenario 4 are presented in the figures on the pages below, as follows:

- **Figure 53** & **Figure 54:** Scenario 4 Re-Blocked Schedule (Weekday and Saturday)
- **Figure 55** & **Figure 56:** Scenario 4 Net Energy Consumption (Weekday and Saturday)
- **Figure 57** & **Figure 58:** Scenario 4 Mid-Block Charging (Weekday and Saturday)
- **Figure 59:** Overnight Charging Schedule (Most Constrained Case)
- **Figure 60:** Overnight Charging Demand (Most Constrained Case)

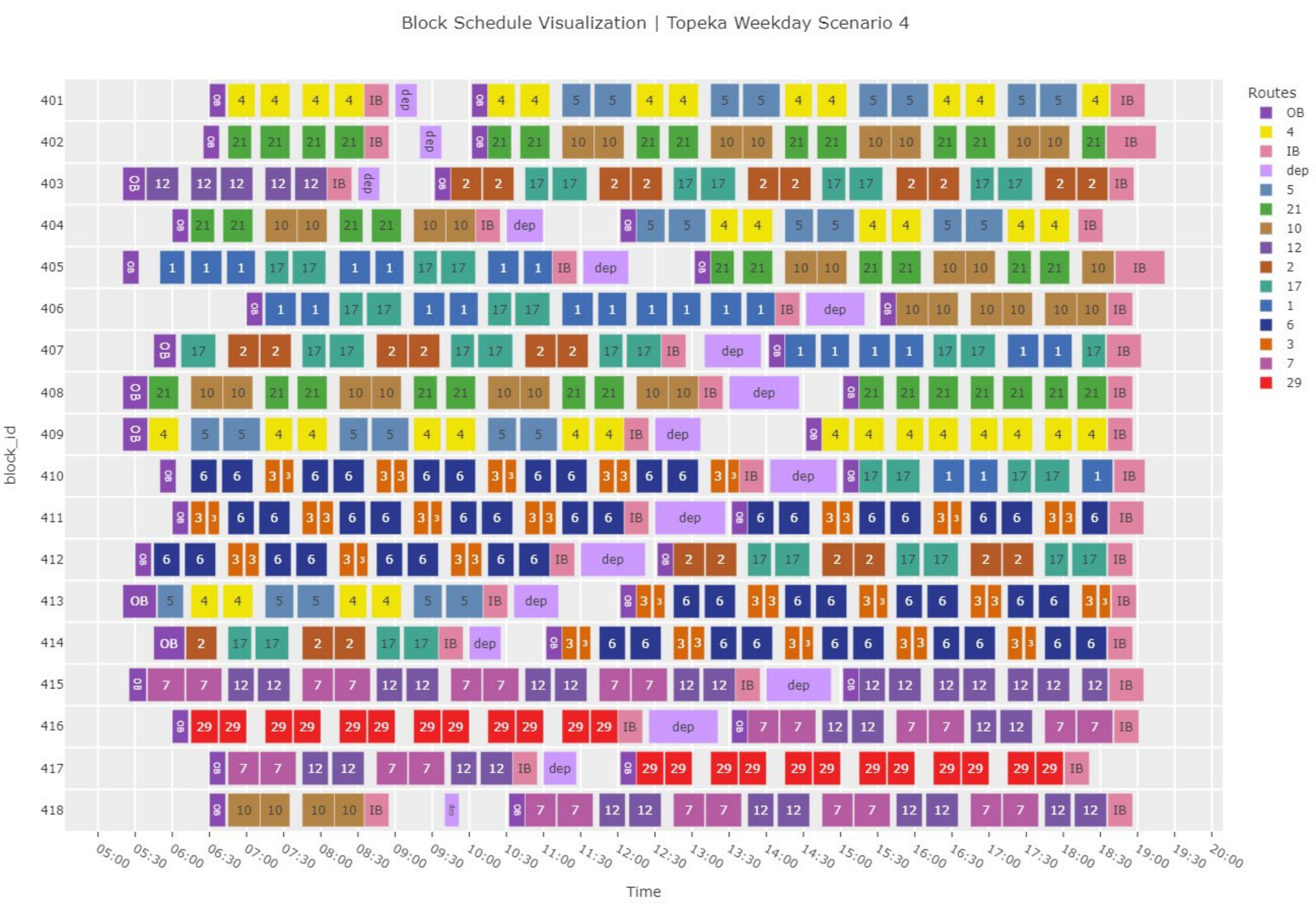


Figure 53. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size– Re-Blocked Weekday Schedule

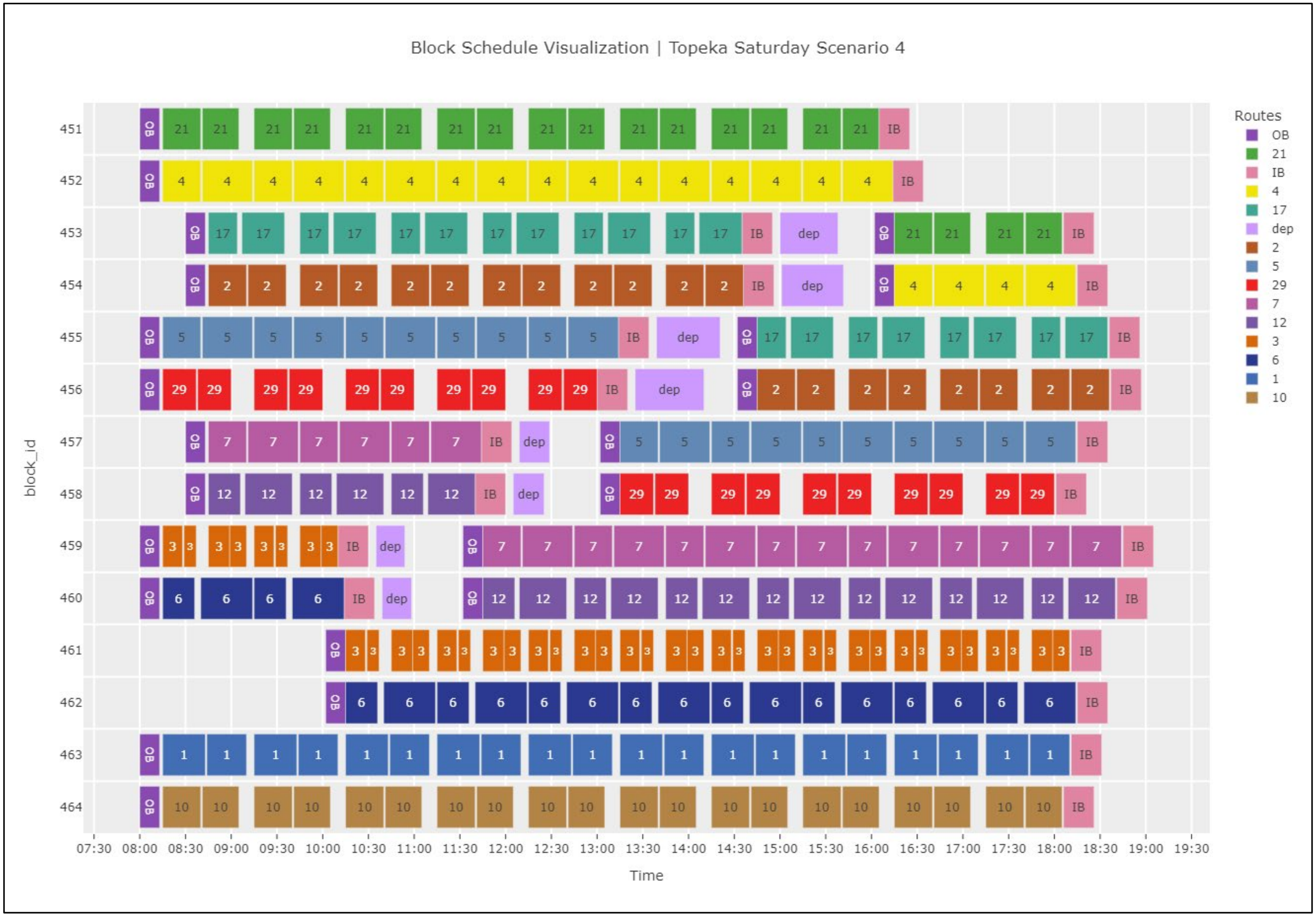


Figure 54. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size – Re-Blocked Saturday Schedule

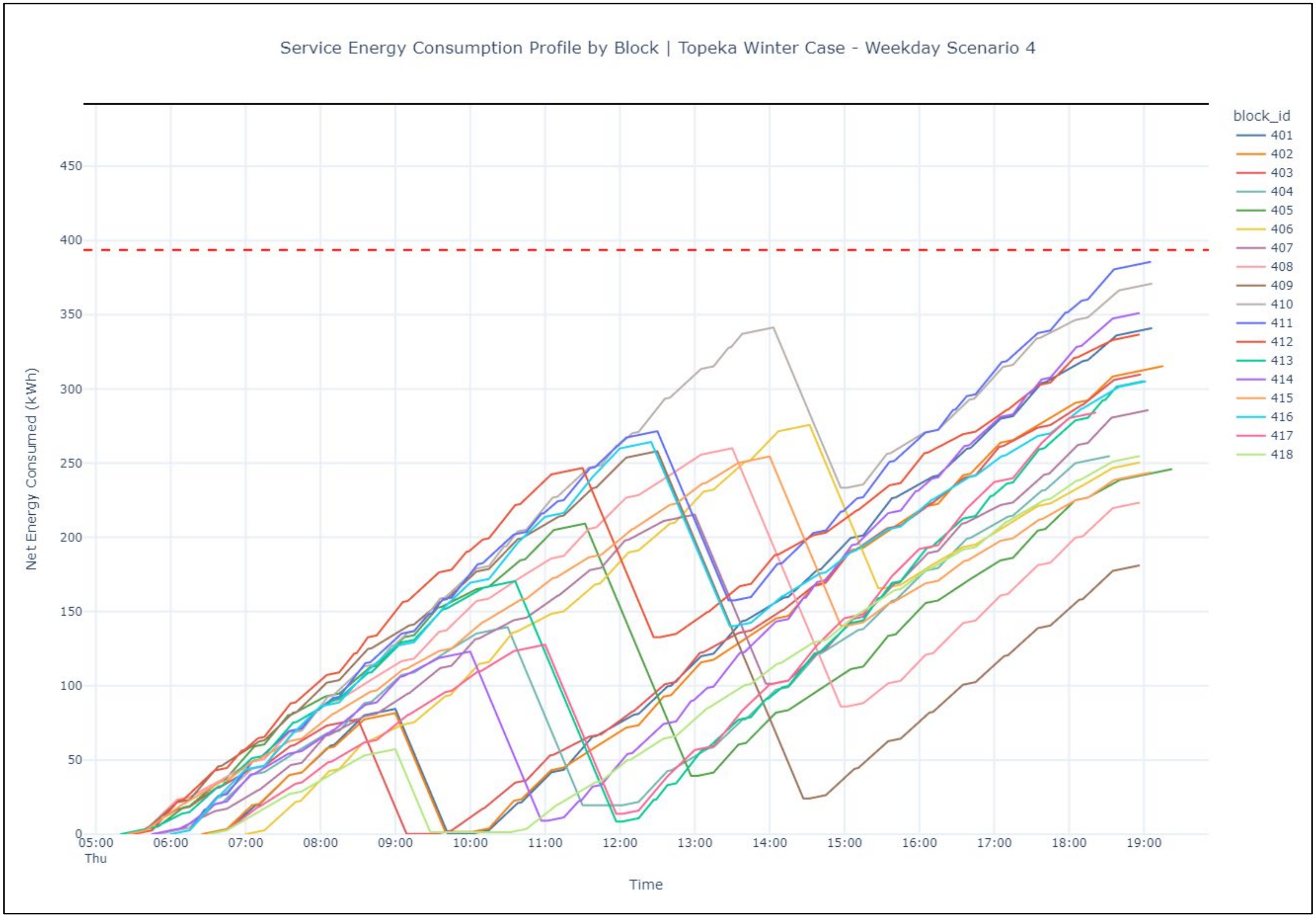


Figure 55. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size – Weekday Net Energy Consumption Projections

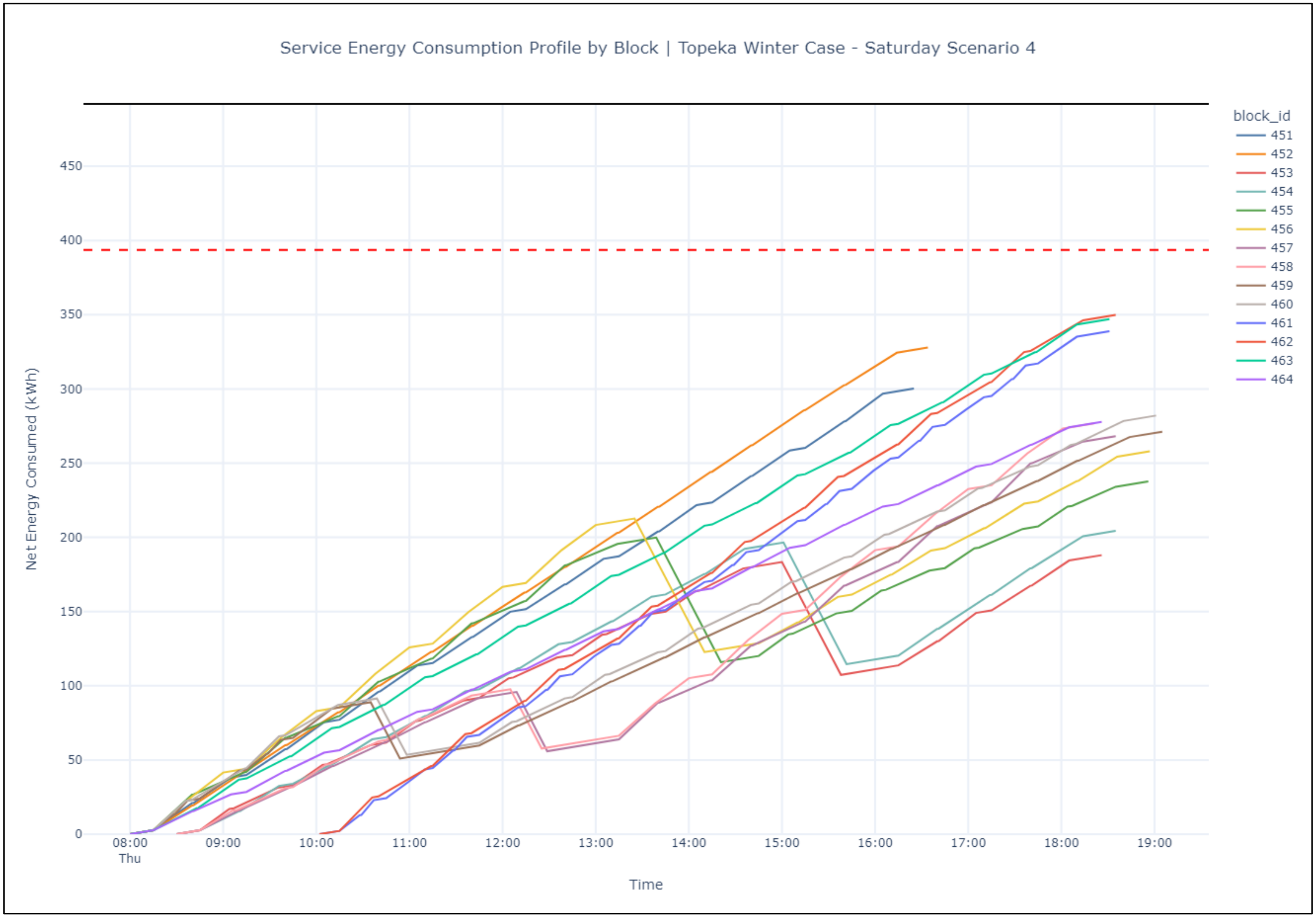


Figure 56. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size – Saturday Net Energy Consumption Projections

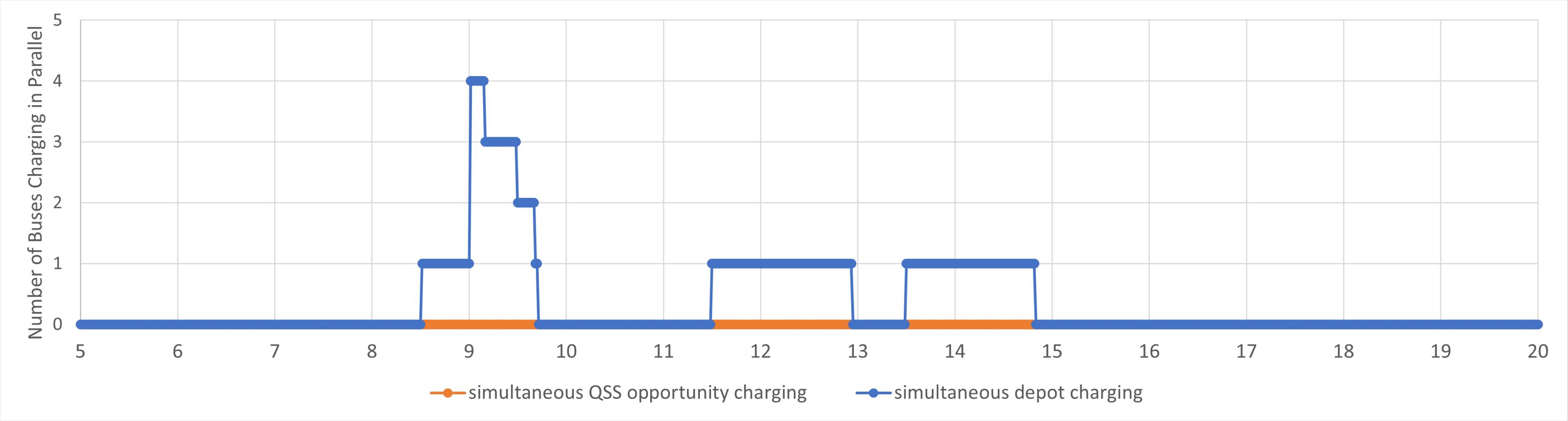


Figure 57. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size - Weekday Midday Charging

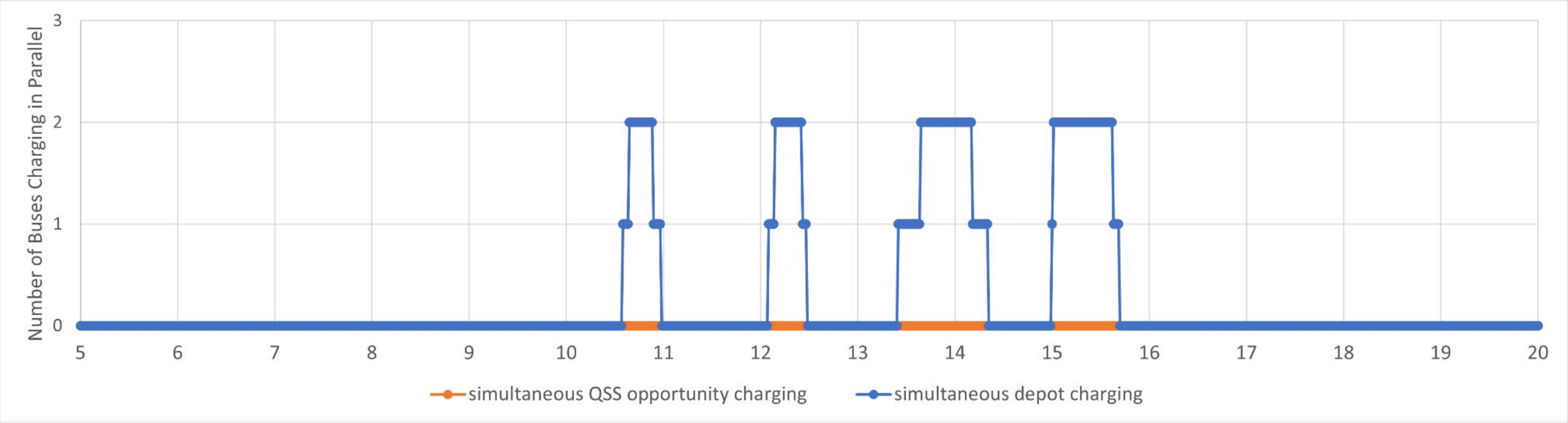


Figure 58. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size - Saturday Midday Charging

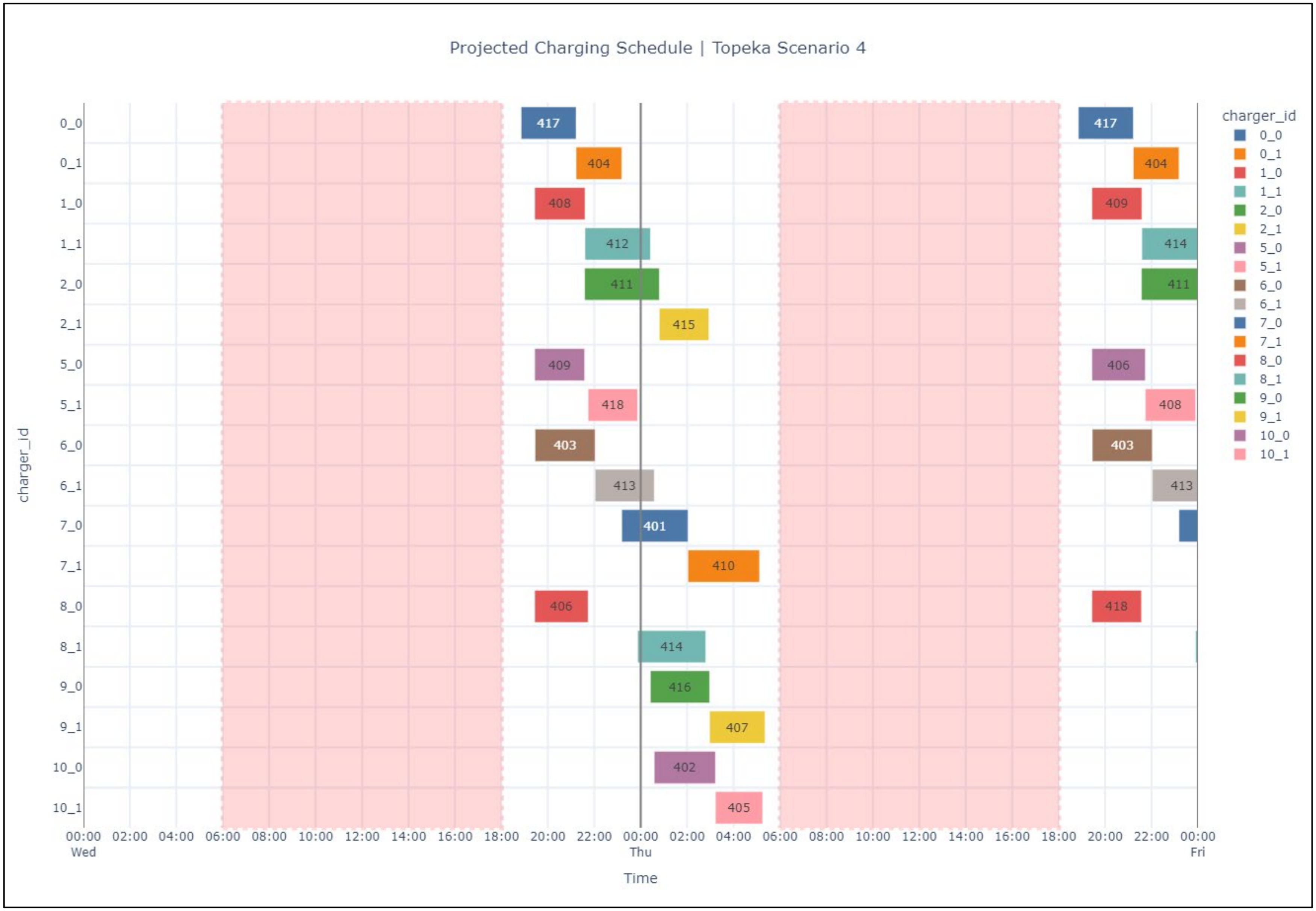


Figure 59. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size – Overnight Charging Schedule (Wednesday-Thursday Shown)

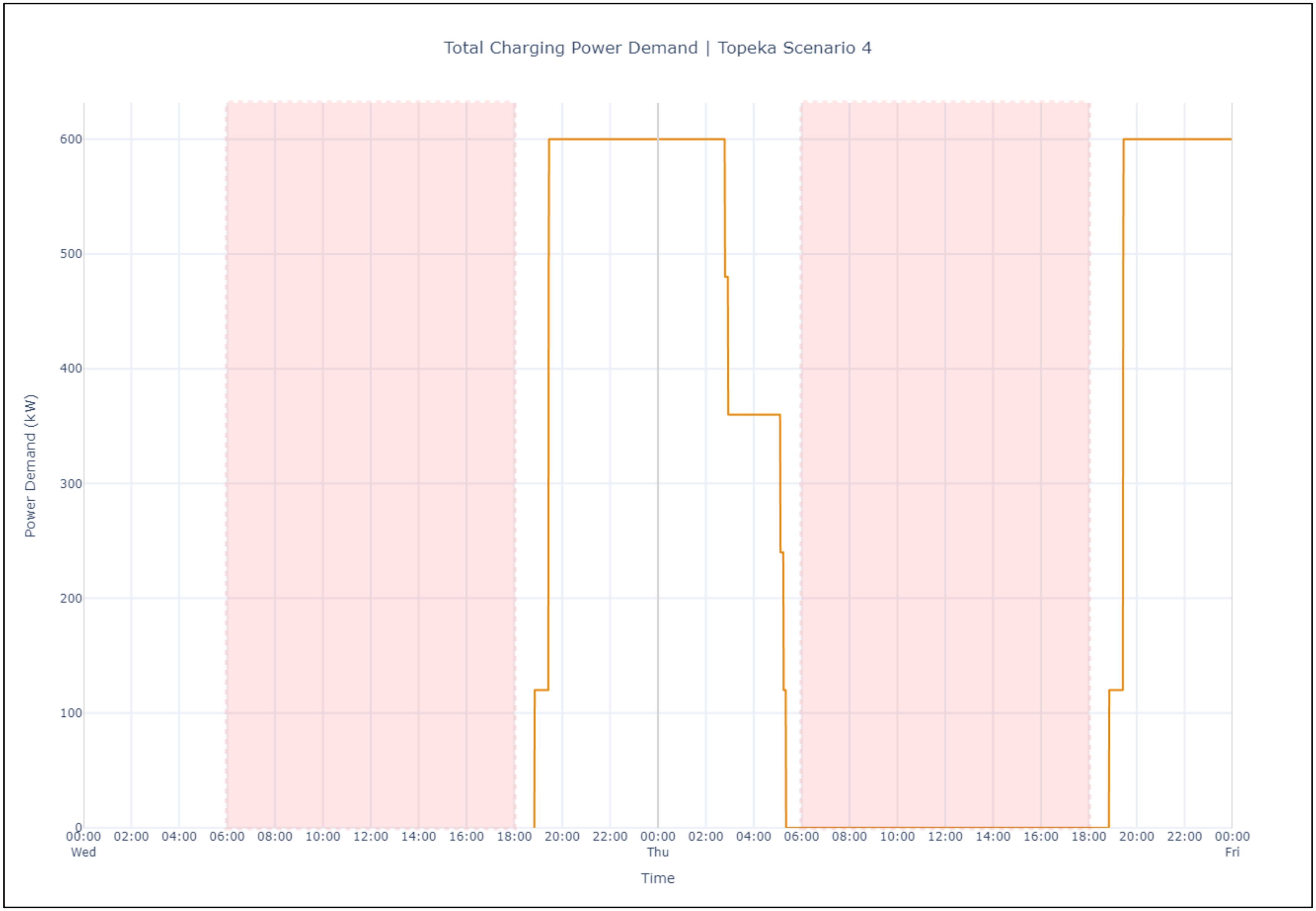


Figure 60. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size – Overnight Charging Power Demand (Wednesday-Thursday Shown)

2.4.7.2 *Associated Costs*

Table 21 provides a high-level 12-year cost estimate for an 100% BEB fleet under Scenario 4.

Table 21. Scenario 4: Midday Charging in Depot Only, Enlarged Battery Size – Associated Costs

ITEM	UNITS	UNIT COST	TOTAL
Extra Buses (capital only based on current quote)	0 Buses	$1,100,000	$0
On-route Chargers (high-level device and engineering)	0 Chargers	$500,000	$0
Demand Charge QSS	0 kW	$3.90 / kW / month	$0
Additional Staff	2 FTE	$64,687	$1,552,476
Increased Battery Size	26	$50,000	$1,300,000
TOTAL			$2,852,476

2.4.8 Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size

Scenario 5 examines the operational, fleet size, and high-level fixed infrastructure impact of transitioning to a BEB fleet using mid-block charging at the depot and at QSS for 30-minute layovers at low power rates (150 kW), combined with enlarging the absolute battery capacity to 492 kWh, equal to the current high-capacity BEB model offered by Proterra.

2.4.8.1 *Re-Blocking and Charging Simulation Results*

Key findings for Scenario 5 are presented in **Table 22** below.

Table 22. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Key Findings

MAJOR FINDING OF MODELED SCENARIO	PROJECTED OUTPUT VALUE	COMPARISON TO BASELINE	
		(2022)	(2023)
Dispatch size	18 buses (weekday)	20 buses	18 buses
Peak mid-block depot charging	2 buses × 120 kW = 240 kW	N/A	N/A
Peak mid-block QSS charging	2 × 150 kW = 300 kW	N/A	N/A
Operational changes	• 72 weekday deadheads • 44 Saturday deadheads • Half of all blocks must be run by buses with batteries less than 50% along the degradation curve (>87.5% of original capacity) • Increased interlining within blocks, to reduce differences in energy consumption between blocks • Drivers in revenue service would step back at QSS and board new vehicles (See **Section 5.4.4**) • Limited number of buses deadheading between QSS and the depot for charging • Staffing increase of up to 1 FTE when one or more on-route chargers are not in service	• 50 weekday deadheads • 24 Saturday deadheads	• 46 weekday deadheads • 24 Saturday deadheads

The re-blocked schedule and associated midday charging requirements for Scenario 5 are presented in the figures on the pages below, as follows:

- **Figure 61** & **Figure 62:** Scenario 5 Re-Blocked Schedule (Weekday and Saturday)
- **Figure 63** & **Figure 64:** Scenario 5 Net Energy Consumption (Weekday and Saturday)
- **Figure 65** & **Figure 66:** Scenario 5 Mid-Block Charging (Weekday and Saturday)
- **Figure 59:** Overnight Charging Schedule (Most Constrained Case)
- **Figure 60:** Overnight Charging Demand (Most Constrained Case)

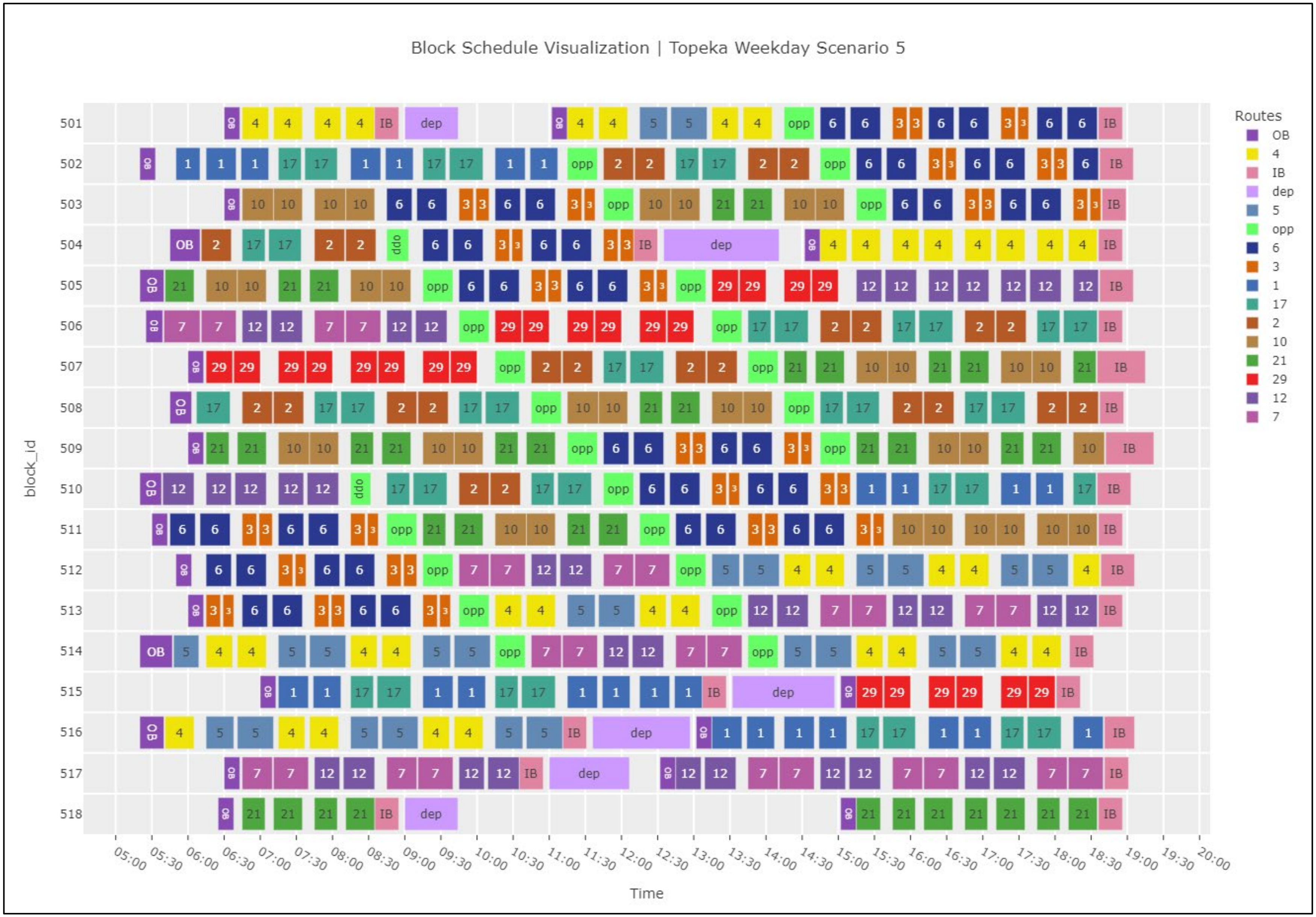


Figure 61. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Re-Blocked Weekday Schedule

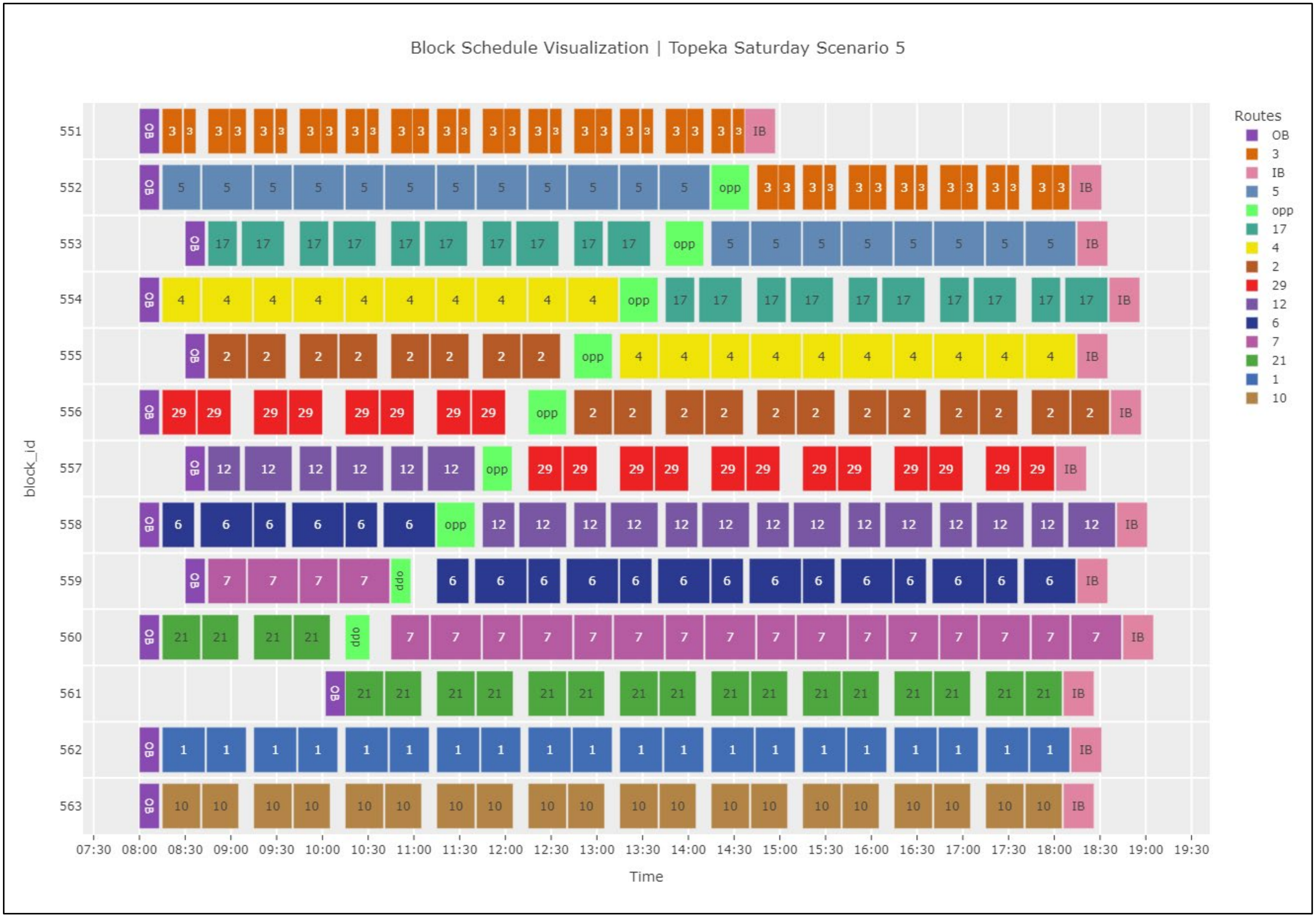


Figure 62. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Re-Blocked Saturday Schedule

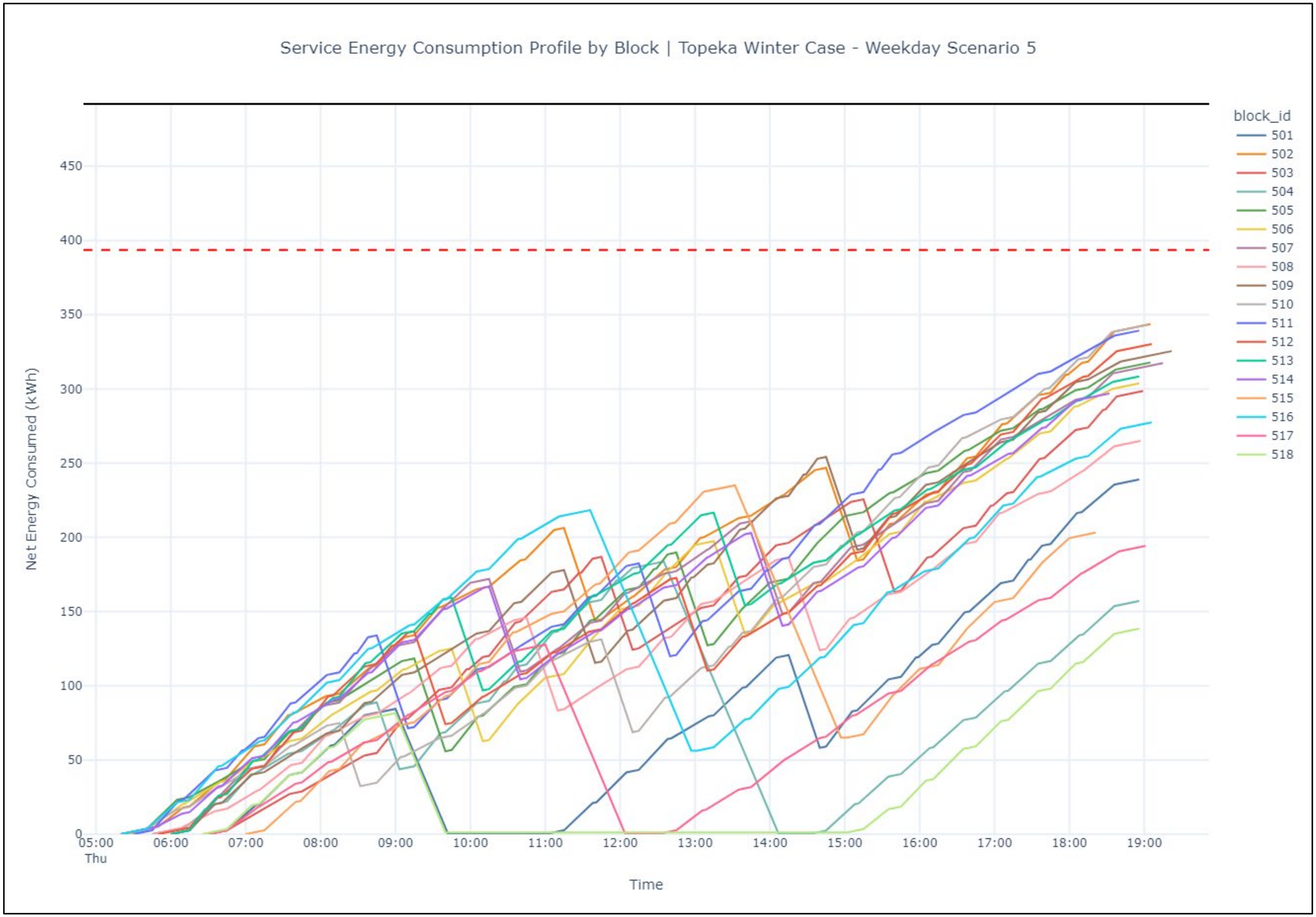


Figure 63. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Weekday Net Energy Consumption Projections

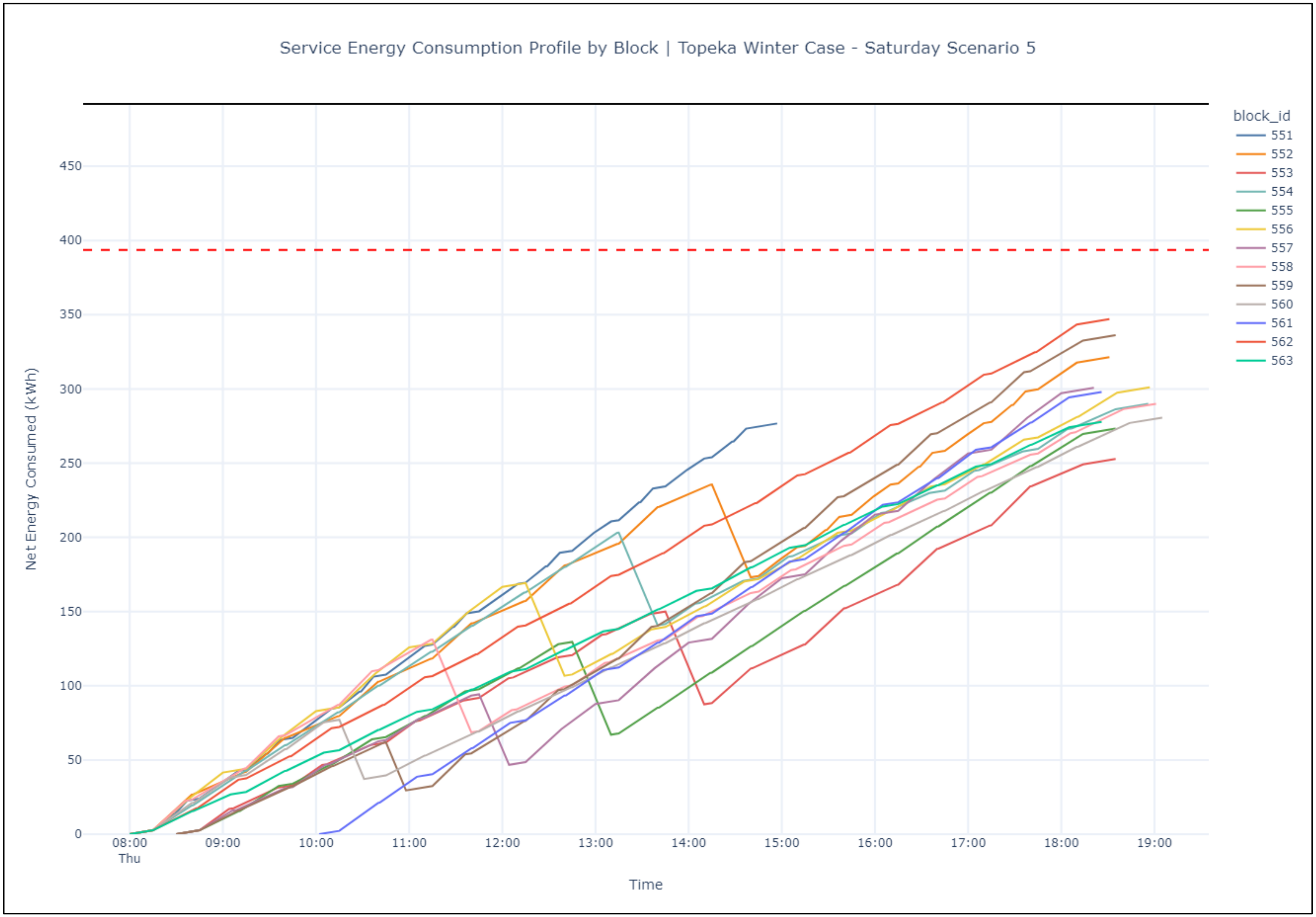


Figure 64. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Saturday Net Energy Consumption Projections

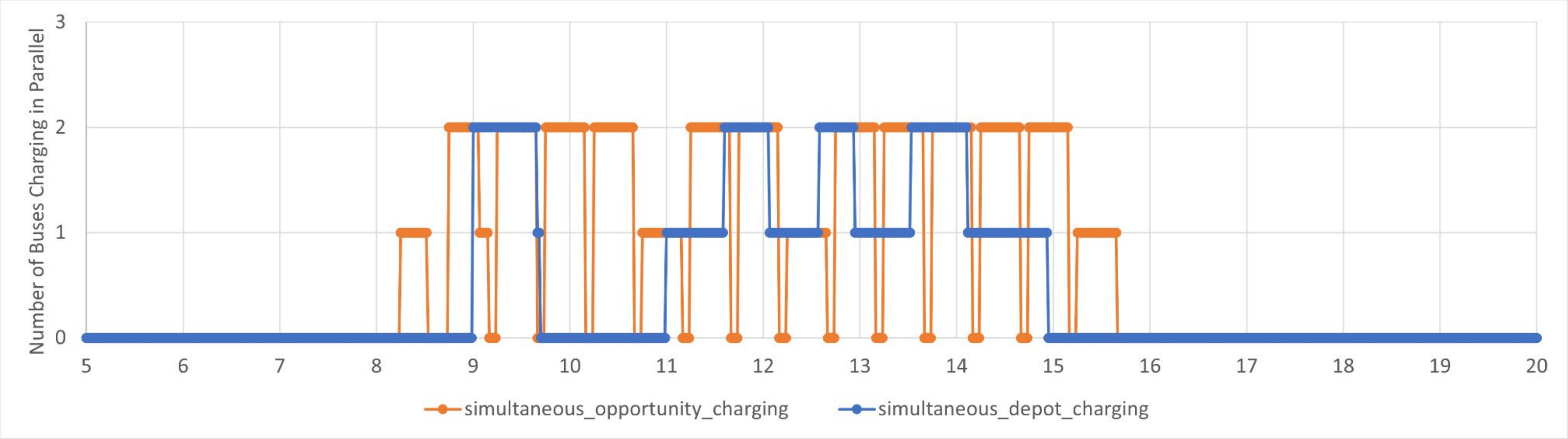


Figure 65. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Weekday Midday Charging

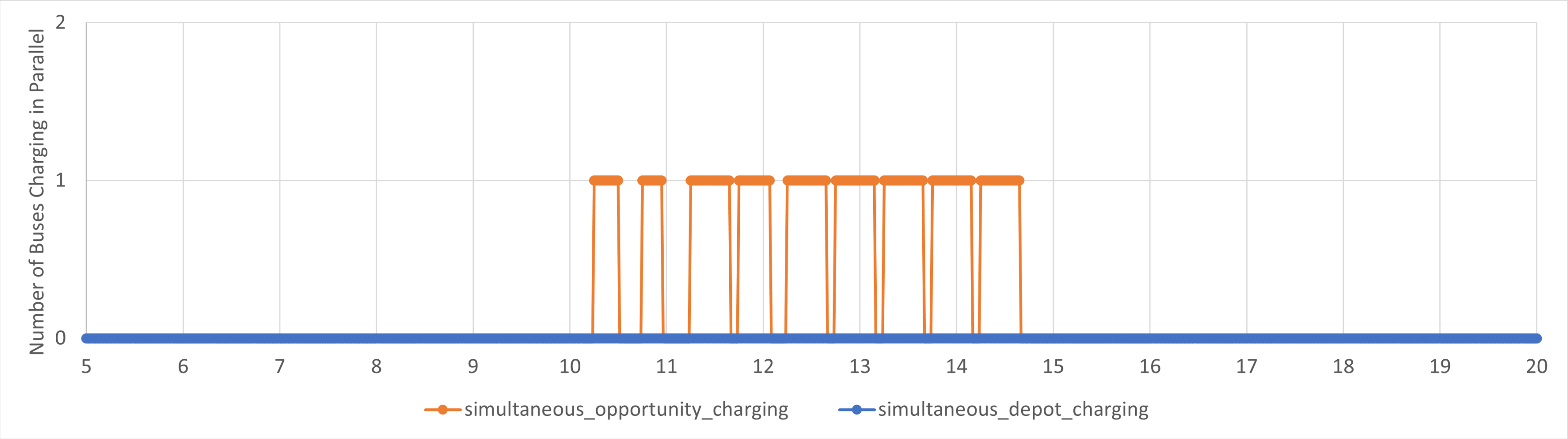


Figure 66. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Saturday Midday Charging

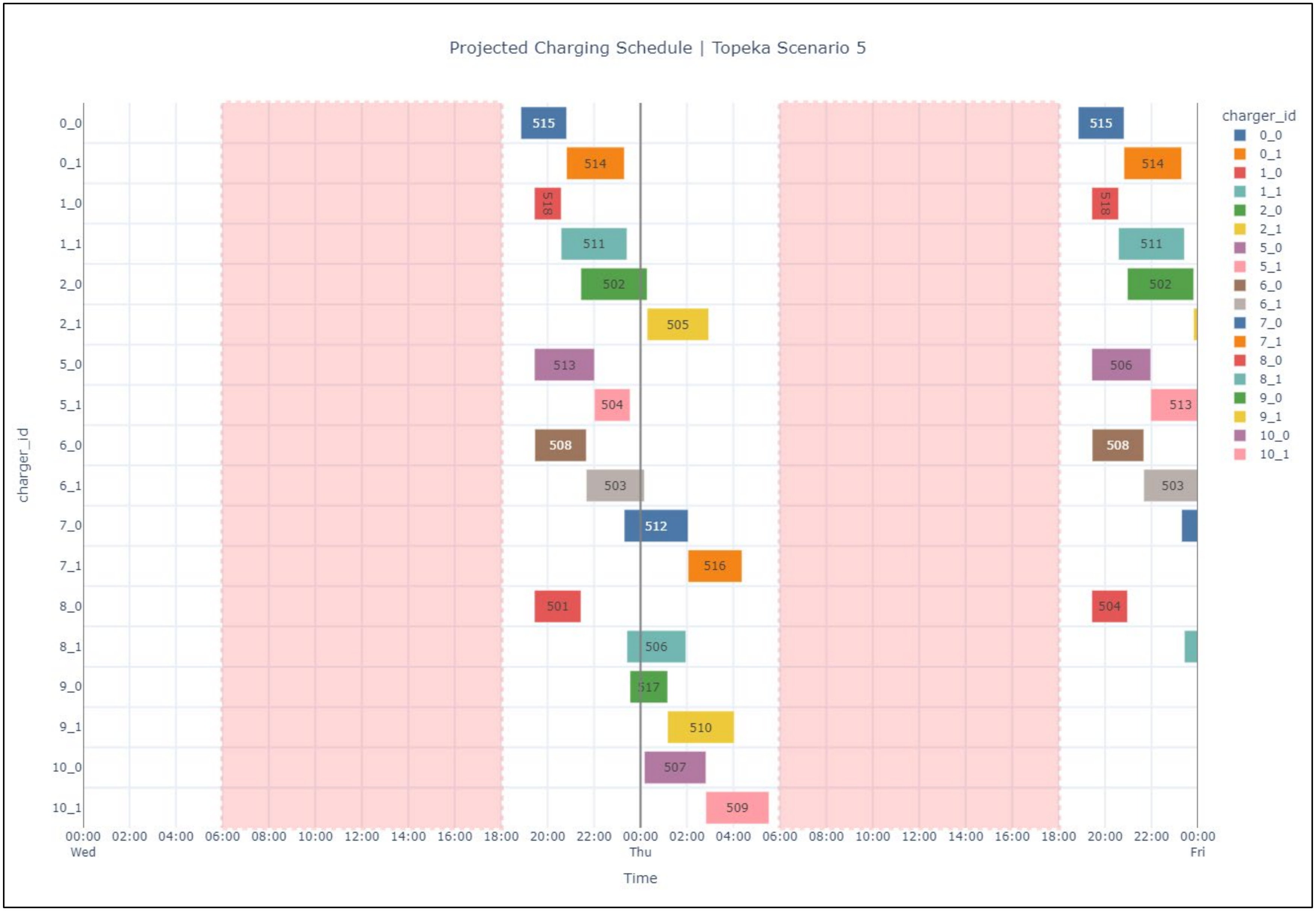


Figure 67. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Overnight Charging Schedule (Wednesday-Thursday Shown)

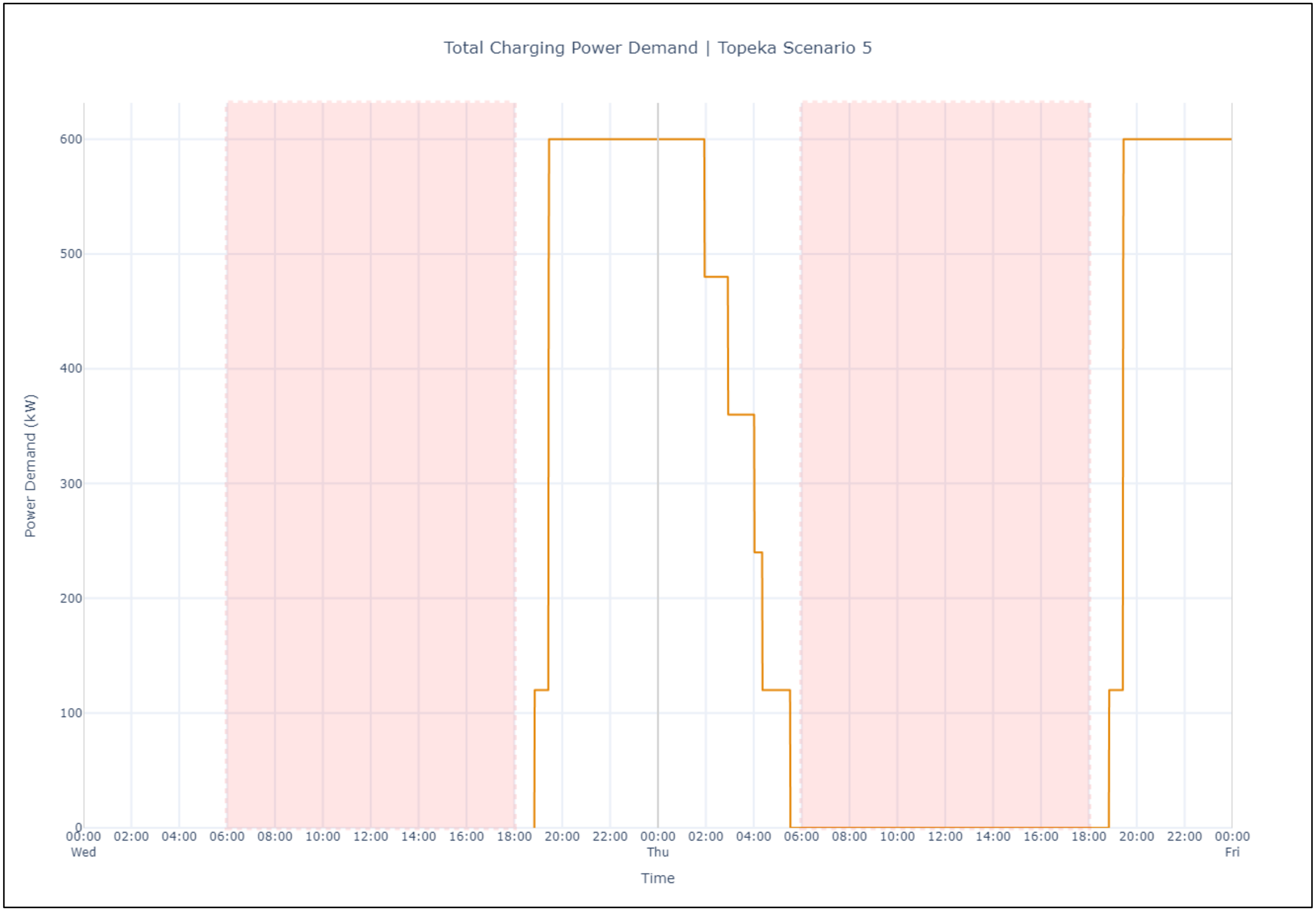


Figure 68. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Overnight Charging Power Demand (Wednesday-Thursday Shown)

2.4.8.2 Associated Costs

Table 23 provides a high-level 12-year cost estimate for an 100% BEB fleet under Scenario 5.

Table 23. Scenario 5: Midday Charging in Depot and at QSS (30-min Layovers), Enlarged Battery Size – Associated Costs

ITEM	UNITS	UNIT COST	TOTAL
Extra Buses (capital only based on current quote)	0 Buses	$1,000,000	$0
On-route Chargers (high-level device and engineering)	2 Chargers + 1 Spare	$500,000	$1,500,000
Demand Charge QSS	300 kW	$3.90 / kW / month	$168,480
Additional Staff	2 FTE	$64,687	$1,552,476
Increased Battery Size	26	$50,000	$1,300,000
TOTAL			**$4,520,956**

3 Infrastructure Analysis

3.1 Ryan Building Retrofit

The proposed Ryan Building Facility retrofit, depicted in **Figure 69** below, was developed to abide by existing structural limitations. During the early stages of the project, it was determined that the facility was not designed to support pantograph charging and would not be able to without a full structural engineering review[11]. In addition, the existing roof height does not support pantographs.

The proposed layout provides a potential layout to support 11 × 120 kW plug-style chargers that are equipped to charge 22 BEBs with battery capacities equal to or larger than 450 kWh. To support the transition of demand response vehicles, this layout provides a potential to service 6 Level 2 chargers.

The Proterra dispensers that Topeka Metro expects to take delivery of in 2023 must be installed within a maximum cabling distance of 500 ft from the converter cabinets. It is recommended to assume a similar constraint for future devices. Under this proposed facility layout, the cabinets would be installed in the southwest corner of the garage interior, out of the bus storage area.

Conduits would be run from the cabinets across the ceiling and down to the dispensers, with the dispensers positioned between parking lanes, on the east and or west sides of the existing 16” × 16” concrete columns. It is recommended to install bollards on the exposed side of chargers and dispensers to add protection against vehicle strikes.

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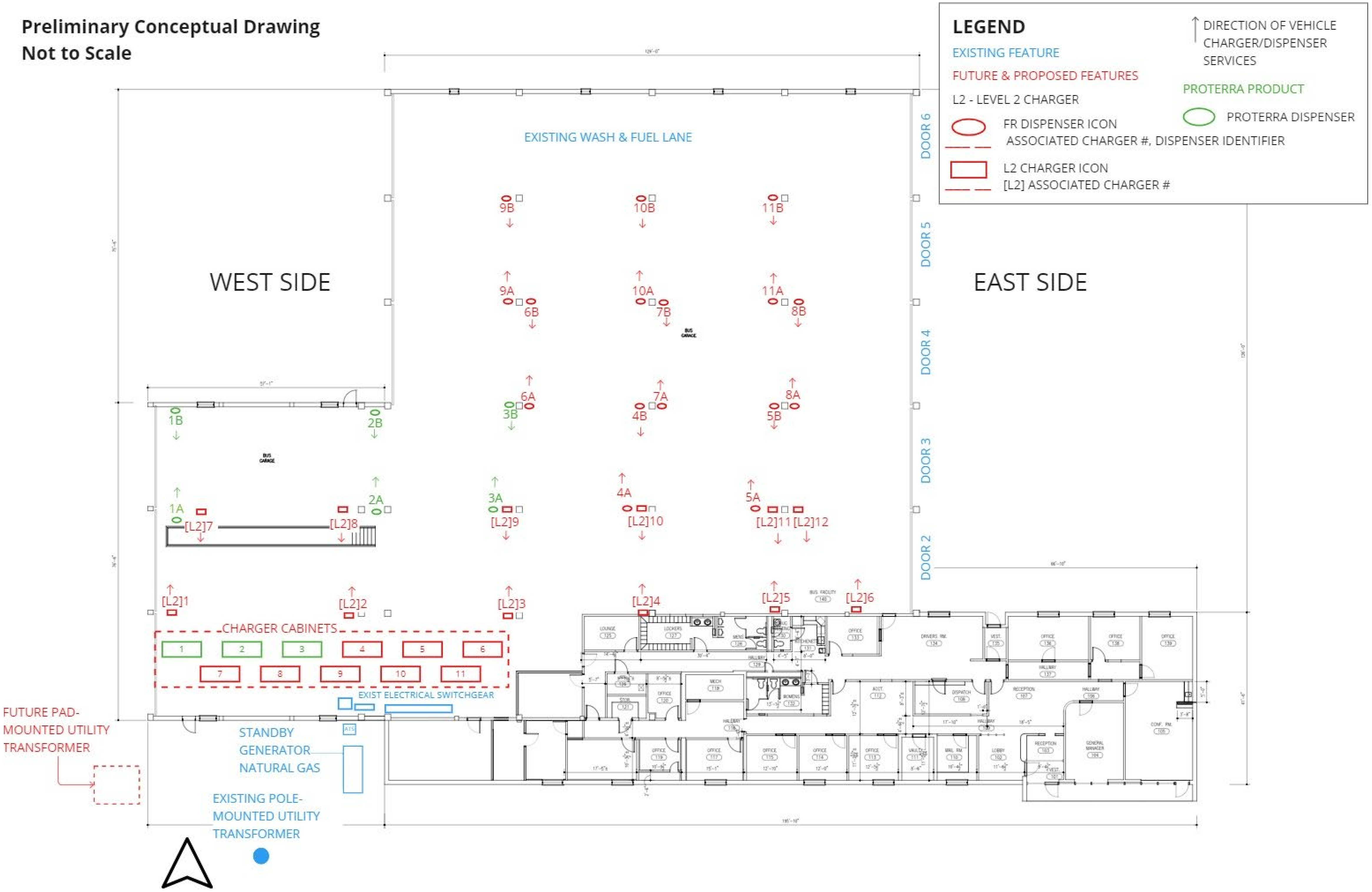

Figure 69: Ryan Building Facility Proposed Retrofit Layout

Figure 70 illustrates a current example of dispensers installed next to existing columns in a garage protected by bollards in a high-traffic area. The installation pictured includes two dispensers facing either side of the island.

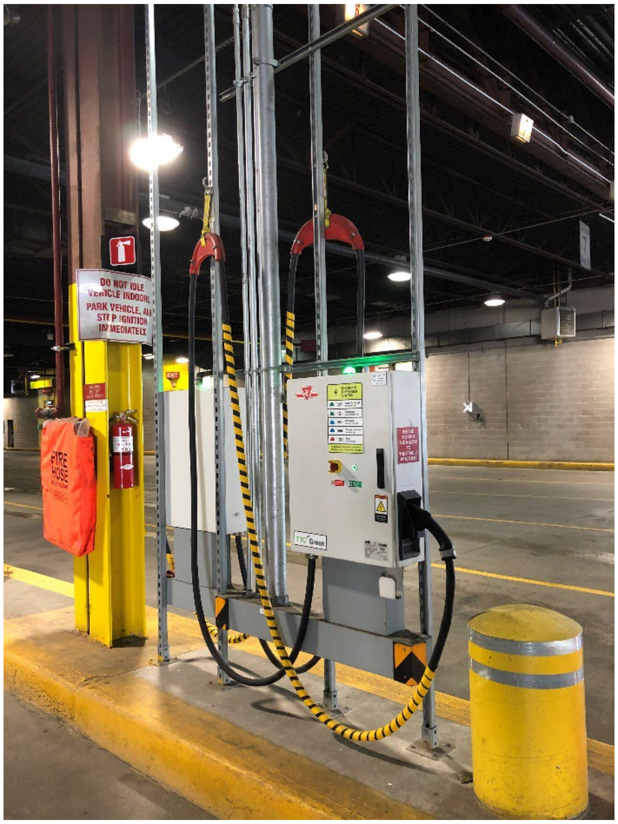

Figure 70: Example 150 kW Dispenser Layout for Fixed Route Vehicles, with Bollards

This layout would not require major modifications to Topeka Metro's existing garage line-up process described in **Figure 71.** Under this layout, the transition from a diesel and gasoline fleet to an all-BEV fleet would require Topeka Metro to strategically place BEV in garage spaces that have a dispenser. In addition, the existing fuel and wash lane will remain throughout the entirety of the transition allowing diesel and gasoline vehicles to continue to follow the existing pull-in, line-up, and pull-out processes.

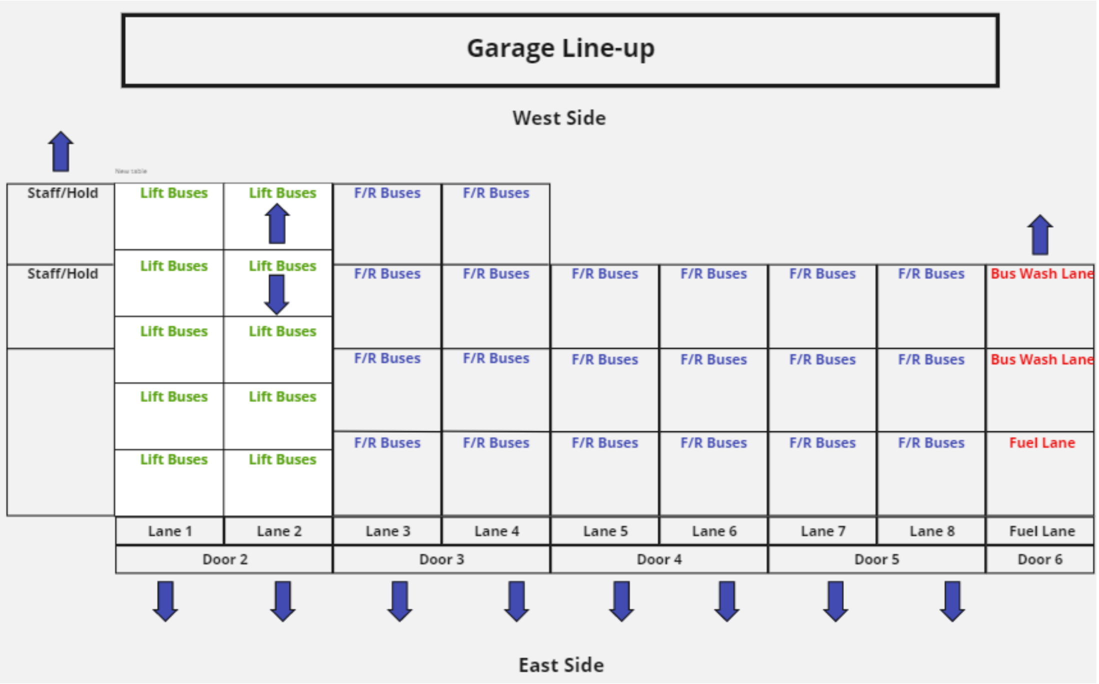

Figure 71: Existing Garage Line-Up

3.2 Maintenance Facility Retrofit

Under existing conditions at Topeka Metro, the maintenance facility hosts 4 of the 26 fixed route vehicles to provide maintenance and or shelter/parking space due to space capacity limits in the garage. Under a BEB transition, it is recommended, 2 mobile chargers are used to provide charging in the maintenance facility. Mobile chargers will provide a flexible method of charging for maintenance staff and will not require major infrastructural changes to the facility. These chargers are not intended to provide daily charger needs but to provide a flexible charging solution for maintenance needs. **Figure 72** presents an example of a 50kW mobile charger currently on the market.

Figure 72. Example Mobile 50kW Charger (Manufacturer: Heliox)

3.3 Quincy Street Station Retrofit

To support on-route charging at QSS, Arcadis IBI Group initially proposed 7 potential charging locations on the site, for refinement with Topeka Metro stakeholders. **Figure 73** identifies these locations.

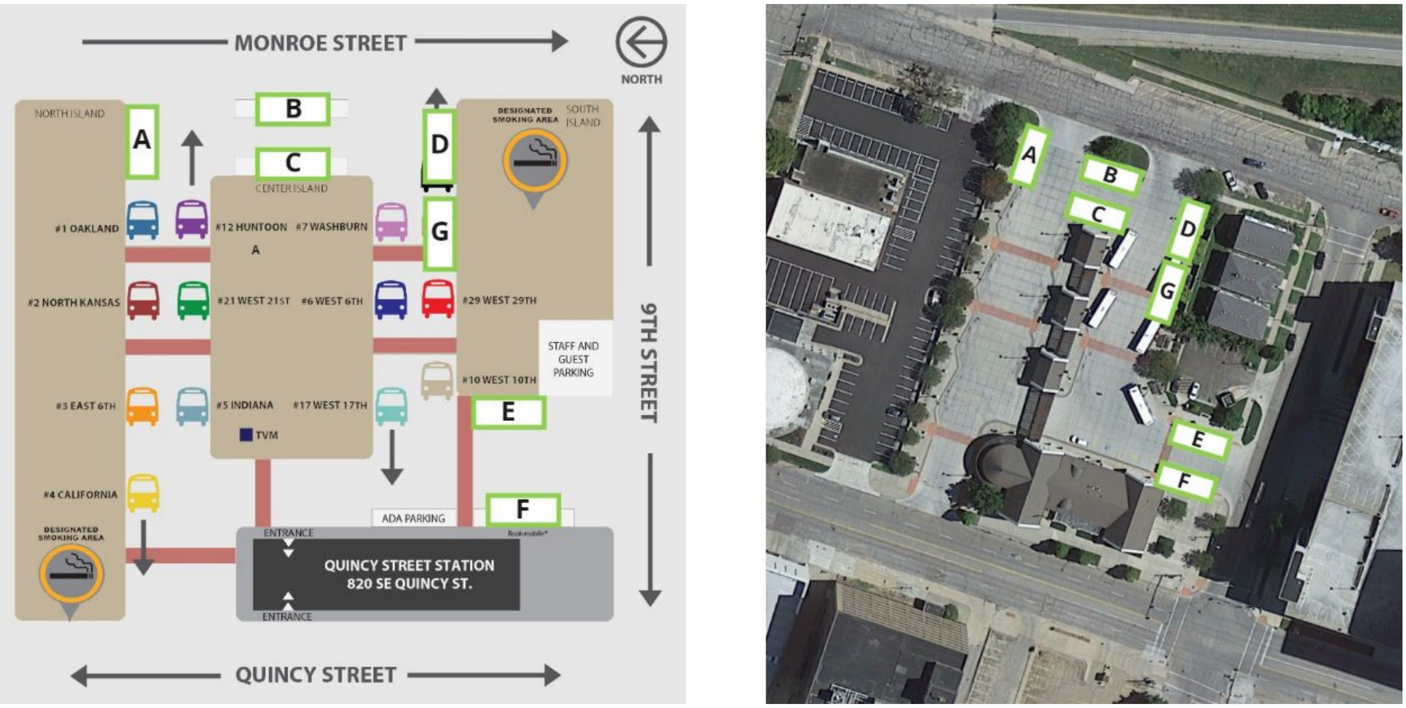

Figure 73: Potential On-Route Charging Locations Proposed to Topeka Metro

Through discussion with Topeka Metro, it was determined that:

- charging location “A” would not be a suitable location as it would create dangerous pull-in environment for buses entering the station from Monroe Street.
- Charging location “B” is not an existing platform designed for passenger use, which would cause more movements in the terminal, as buses would be prevented from unloading and charging at the same location.
- Charging locations “E” and “F” could not be simultaneously used as they would constrain the existing tight turning geometry followed by buses.

Based on these considerations, charging locations “C,” “D,” “E,” and “G” were carried forward. These locations are at existing passenger platforms, which would allow buses to unload passengers and charge in-place, simplifying movement through the station. The following subsections identify two on-route charging layouts that would be used to support on-route charging at QSS. Each alternative was developed to support specific mitigation scenarios as discussed in **Section 2.4.1**.

Configuration 1. Charging Locations C, E, and G

On-route charging configuration 1, depicted in **Figure 74**, has been developed to support the projected charging demands under mitigation scenarios 3 and 5, each of which build in 30-minute layovers at QSS for charging at 150 kW.

This alternative would require 3 × 150 kW dispensers to support mid-day on-route charging: 2 scheduled to be active simultaneously, and a third to provide redundancy in case of equipment failure or a delay in vacating a space after charging. Charging locations “C” and “E” would displace existing staff parking. Charging location “G” would occupy an unassigned platform, previously assigned to Route 10 Special before its cancelation.

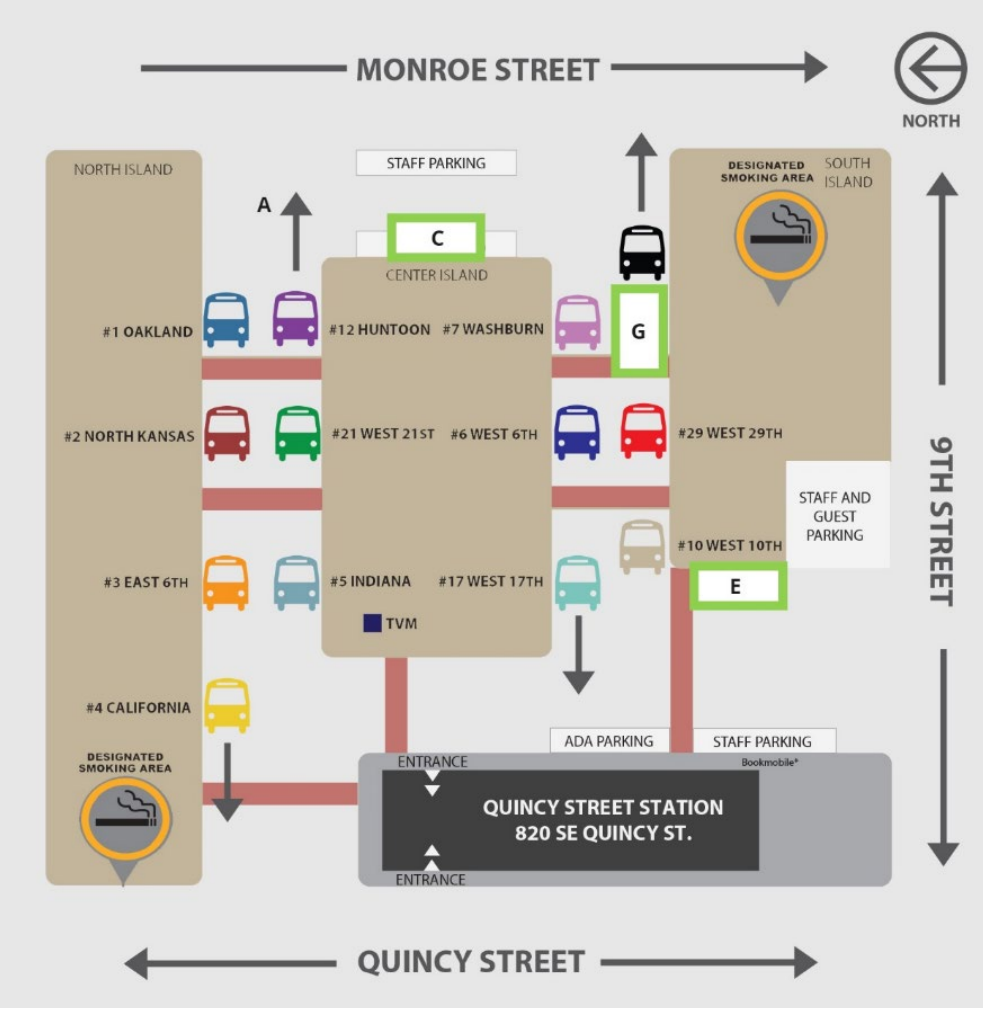

Figure 74. Alternative 1. Charging Locations “C,” “E,” and “G”

Modifications would consist of:

- 3 gantry-mounted pantograph dispensers capable of charging at 150 kW, positioned at locations “C”, “E”, and “G”
- 3 converter cabinets (1:1 cabinet-dispenser ratio)
- Underground conduit between the site transformer, cabinets, and dispenser footings
- Transformer upgrade to support at minimum an additional 300 kW load
- Re-location or removal of associated dedicated staff parking

Configuration 2. Charging Locations C, D, E, and G

On-route charging configuration 2, depicted in **Figure 75**, has been developed to support the projected charging demands under mitigation scenario 2, which builds in 5-minute top-up charging sessions at QSS for charging at 300 kW.

This alternative would require 4 × 300 kW dispensers to support mid-day on-route charging: 3 scheduled to be active simultaneously, and a fourth to provide redundancy in case of equipment failure or a delay in vacating a space after charging. Charging locations "C" and "E" would displace existing staff parking. Charging locations "D" and "G" would occupy unassigned platforms.

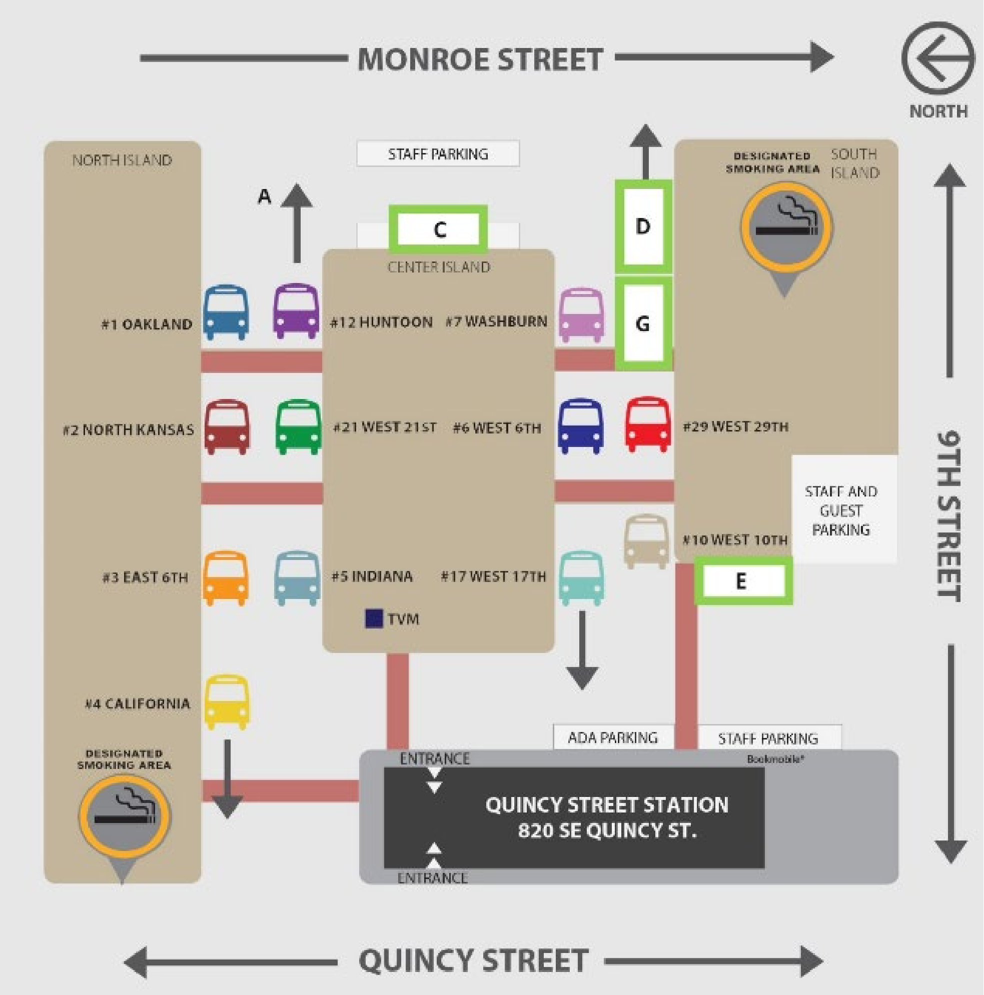

Figure 75. Alternative 2. Charging Locations C,D, E, and G

Modifications would consist of:

- 4 gantry-mounted pantograph dispensers capable of charging at 300 kW, positioned at locations "C", "D", "E", and "G"
- 4 converter cabinets (1:1 cabinet-dispenser ratio)
- Underground conduit between the site transformer, cabinets, and dispenser footings
- Transformer upgrade to support at minimum an additional 900 kW load
- Re-location or removal of associated dedicated staff parking

Disadvantages of this option include:

- Potentially constrained growth in 35' bus class due to limited number of appropriately sized parking spaces and vehicle turning radii for entering and exiting the station
- Re-location or removal of associated dedicated staff parking
- Likely to be more expensive than Alternative 1

Comparative Analysis

Both configurations present similar operational and space programming trade-offs. Positive elements include:

- Ample space in the drive aisles for safe bus operation
- All buses are accessible without being boxed in by parking arrangement
- All charging locations are safe and accessible for passenger unloading

Negative impacts of both configurations include:

- Potentially constrained growth in 35' bus class due to limited number of appropriately sized parking spaces and vehicle turning radii for entering and exiting the station
- Re-location or removal of associated dedicated staff parking

The primary differentiator is cost: configuration 2 requires 1 additional device compared with configuration 1, and the significantly higher power rating of these devices contributes to higher capital costs. Cost implications are discussed further in **Section 4**.

4 Financial Analysis

The cost of acquiring BEBs includes more than just the capital cost of the bus itself; the bus size and model type, charging type, charger and dispenser quantity, fuel costs, maintenance costs, and staff training all must be considered as well. This analysis includes a detailed look at the major operating and capital cost categories that affect the transition. Note that some smaller indirect costs that are not reflected in this report may be incurred (for example additional administrative staff hours for overseeing the rollout are not accounted for). However, these categories represent the major costs associated with ZEB transition and provide an accurate picture into financial outlook across each scenario.

This section first defines the capital and operating cost variables included in this analysis and provides information on unit and per-mile costs related to those variables. We then identify and price out additional mitigation costs that would be incurred if Topeka selects to transition to 75% or 100% BEBs, to account for on-route charging needs and/or additional capital and operating costs to accommodate service. These additional mitigation costs differ slightly depending on the mitigation strategy (see Modeling Step 3: Mitigation Scenarios); however, our recommendation (scenario 3) aims to limit both costs and service impacts. Once all capital, operating, and mitigation costs have been defined, we present a 16-year cost assessment for Topeka's baseline scenario (0% BEB), a 25% transition to BEBs, a 50% transition, a 75% transition, and a complete 100% transition.

4.1 Capital Costs

Table 24 highlights the various capital cost categories included in the analysis. The core categories of capital costs include vehicle purchases, upgrades to supporting infrastructure (additional grid upgrades), and charging infrastructure (chargers, dispensers, etc.). For each variable listed, the table shows the unit cost, a definition of the item, and information for how cost estimates were gathered.

Table 24. Capital Costs

VARIABLE	UNIT COST (2023$)	DESCRIPTION	SOURCE
Vehicles			
Fixed-Route (FR) Battery Electric Bus (BEB)	$ 971,642	Total cost of a FR BEB, inclusive of warranties, configurables, tax and shipping.	Existing Proterra quote for Topeka Metro
FR Diesel Buses	$ 550,000	Total cost of a FR diesel bus	Topeka Metro current fleet replacement plan
Demand Response (DR) Battery Electric Cutaways	$ 300,000	Total cost of a BEB Cutaway inclusive of warranty, tax, and shipping.	Arcadis IBI Group research
DR Diesel Vehicles	$ 132,613	Total cost of a diesel cutaway	Topeka Metro current fleet replacement plan
Supporting Infrastructure Upgrades			
Supporting Infrastructure Upgrades (Depot)	$ 140,000	Supporting infrastructure upgrades include the Everly Redundant Electrical Connection that will support up to 5 BEB chargers; while we expect economies of scale to drive down this cost, we currently budget 140k per charger for grid upgrades conservatively.	Data provided by Topeka Metro
Chargers, Dispensers, and Installation			
FR BEB 120 kW Dispensers (Depot) + Installation	$ 3,487	Ports for dispensing energy from 120 kW chargers. Each charger can support up to 4 dispensers but for faster charging, we assume 1:1 dispenser to charger ratio with spares available on some chargers	Existing Proterra quote
FR BRB 120 kW Chargers (Depot) + Installation	$ 79,275	Chargers are provided at a 1:1 ratio with buses.	NREL[12], adjusted for inflation

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[12] https://afdc.energy.gov/files/u/publication/financial_analysis_be_transit_buses.pdf

VARIABLE	UNIT COST (2023$)	DESCRIPTION	SOURCE
FR BEB 150 kW Chargers (QSS) + Installation	$ 500,000	To support on-route charging for some mitigation scenarios, 150 kW chargers are procured to support quick 30-minute top-ups at Quincy Street Station.	Arcadis IBI Group Research
FR BEB 150 kW Dispensers (QSS) + Installation	$ 5,000	Dispensers for 150 kW chargers may have a slightly higher associate cost that 120kW.	Arcadis IBI Group Research
DR Battery Electric Cutaways Level 2 Chargers, Dispensers + Installation	$ 9,450	Level 2 chargers at a minimum are required to support battery electric cutaways	Arcadis IBI Group Research
Mobile Chargers	$10,000	Chargers that are installed in maintenance bays for use primarily if a battery dies.	Arcadis IBI Group Research

4.2 Operating Costs

Table 25 shows all operating costs that were considered as part of this analysis. The main categories that differ in operating costs for ZEBs compared to legacy fuel buses are fuel costs, maintenance costs related to vehicles and chargers, and training costs. Other variables such as additional administrative hours may impact overall costs but are less concrete.

Table 25: Operating Costs

Fuel			
VARIABLE	**UNIT COST (2023$)**	**DEFINITION**	**SOURCE**
Diesel	$ 0.44/mile	The total diesel fuel cost divided by total vehicle miles in a fleet	2021 NTD data for Topeka Metro
BEB	$ 0.21/mile	The total kWh cost divided by total vehicle miles in a fleet	Topeka provided energy data, Proterra estimated fuel efficiency, and EIA inflationary projections
Training and Transition			
Training, manuals, diagnostic tools spare parts	$ 10,727	Upfront cost associated with training staff and providing resources related to BEB operation and maintenance	Existing Proterra quote
Maintenance			

Diesel 35’	$ 1.04/mile	Maintenance cost includes all parts and labor for vehicle components.	NREL, adjusted to 2023 dollars
BEB 35’	$ 0.28/mile		Arcadis IBI Group research
Diesel Cutaways	$ 1.04/mile		NREL/USDOT , adjusted to 2023 dollars
BEB Cutaways	$ 0.22/mile		Arcadis IBI Group research
Chargers	$ 3,000	Maintenance of depot or on-route charging equipment	NREL

4.3 Mitigation Costs

In addition to the capital and operating costs incurred above, for a 75% or 100% transition to be successful certain mitigation costs would be encountered as well. These costs vary depending on the approach selected, and more details about their unit costs can be found in . Our recommended approach to mitigation is scenario 3, which limits costs to the agency while considering operational impacts.

Note that the costs described in the mitigation scenarios section above are described as a 12-year cost to contextualize their cost over the lifetime of a fixed-route bus. As those costs are applied to a 16-year span, adjusted for inflation, and adjusted to account for procurement schedules, the total cost of mitigation changes. Additionally, mitigation costs below are only reflective of mitigation scenario 3 costs; Topeka Metro could select an alternative mitigation approach to be substituted, and these alternative costs are not reflected in the 75% and 100% BEB transition costs presented below.

Each transition scenario below also assumes inflation in the price of goods over time. For fuels, U.S. Energy Information Administration (EIA) estimates were used; for maintenance and construction projects, Arcadis IBI Group assumed 3% in line with industry standards; for capital costs like vehicles and chargers, we assume 2% inflation.

Note that the ‘Demand Response Replacement Plan’ (see Appendix A) provided by Topeka Metro calls for two demand responses vehicles to be van purchases rather than cutaways in 2028; for the purposes of this analysis all demand response vehicles were treated as cutaways, to ensure service could be operated effectively and to leverage more reliable industry data. Since cutaways have a higher unit cost than vans, the total capital and operating cost values in each scenario for demand response may be slightly higher than actual if vans were procured; however, relative costs across scenarios can still be compared.

4.3.1 Baseline Scenario

4.3.1.1 Fleet Replacement

The baseline scenario provides Topeka Metro with a control to compare electrification costs associated with several transition scenarios. The baseline scenario assumes zero battery electric vehicles, equipment, or technology and reflects continued operation of diesel vehicles for the next 16 years.

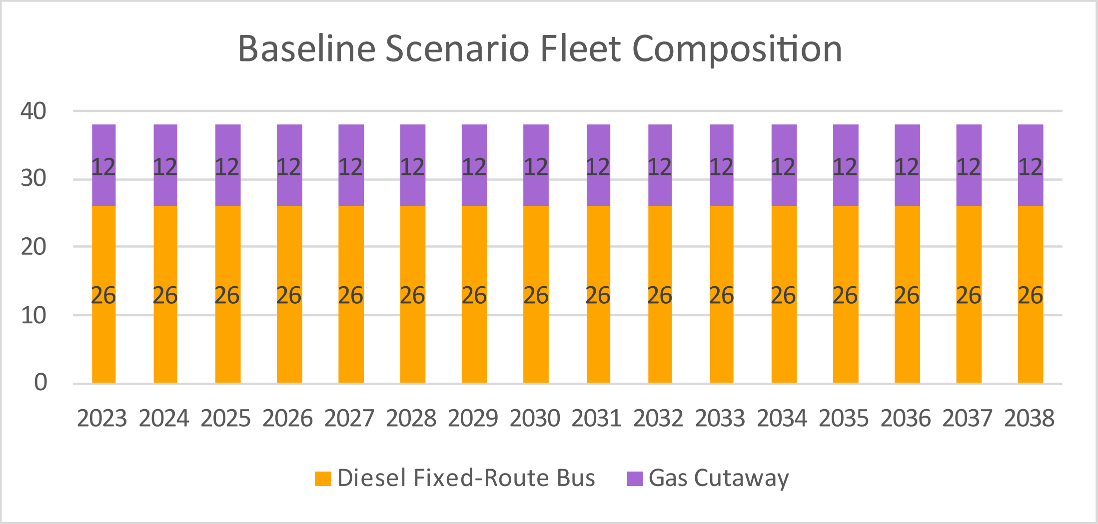


Figure 76. Baseline Scenario Fleet Composition

4.3.1.2 Cost Breakdown

Table 27 on the following page shows the total cost per year in the baseline scenario. The table incorporates data on average vehicle mileage, in addition to the fleet replacement schedule and unit costs depicted in **Table 24** and **Table 25** to arrive at an estimated annual cost. The total 16-year cost in the baseline scenario is $62,481,473.

Table 26. Baseline Scenario - Total Cost Per Year

COST CATEGORY	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	TOTAL 16 YEAR
Fleet	$3,697,839	$3,399,000	$1,750,485	$2,404,000	$2,923,891	$2,220,271	$316,692	$489,291	$0	$0	$0	$550,701	$5,461,304	$5,235,656	$3,097,536	$3,427,528	$17,201,469
Fuel	$436,664	$419,989	$419,046	$418,597	$419,686	$422,983	$425,459	$424,783	$436,077	$437,860	$440,275	$441,009	$442,839	$446,188	$449,877	$452,344	$6,933,678
Maintenance	$1,020,665	$1,051,286	$1,082,826	$1,115,312	$1,148,773	$1,183,237	$1,218,735	$1,255,299	$1,292,959	$1,331,749	$1,371,703	$1,412,855	$1,455,243	$1,498,901	$1,543,870	$1,590,188	$20,573,601
Total Cost	$5,155,168	$4,870,276	$3,252,357	$3,937,909	$4,492,350	$3,826,491	$1,960,887	$2,169,373	$1,729,036	$1,769,609	$1,811,978	$2,404,565	$7,359,385	$7,180,745	$5,091,283	$5,470,060	$62,481,473

4.4 Performance Monitoring and Service Planning

The implementation of performance monitoring evaluations is integral to successful fleet transitions. Valuable insights gleaned from such evaluations can offer opportunities for Topeka Metro to enhance its services prior to proceeding with a comprehensive transition. It is highly recommended that a performance evaluation be conducted after each phase (25%, 50%, 75%, 100%) to proactively identify and rectify any potential issues before they escalate into service wide or systemic concerns. Moreover, solicitating feedback from both customers and staff members can inform future transition strategies based on observed and or expressed needs, ultimately improving the overall transition process.

It is advised that a through service planning and re-blocking analysis be carried out once 50% of the fleet has been transition to battery electric technology. This will enable a better understanding of how to enhance the experiences of both staff and customers though the implementation of effective service planning strategies.

4.4.1 25% BEB Scenario

4.4.1.1 Fleet Replacement

BEB operating ranges are expected to improve as the technologies continue to mature, and as these range advancements will likely involve battery capacity increases. it is in the best interest of Topeka Metro to time the purchase and deployment of new technologies for when they are needed. Arcadis IBI Group has recommended strategic fleet replacement plans that reflect Topeka Metro's fleet replacement needs. By following our recommended fleet replacement plans it is expected that most vehicle procurements will have battery capacity options larger than 440 kWh to choose from.

Figure 77 below presents an annual fleet composition breakdown by year for the next 16 years under a 25% BEV fleet transition scenario. Under the following fleet composition breakdown, by 2038, Topeka Metro would have replaced four diesel powered fixed route vehicles and four gasoline cutaways with seven BEBs and four battery electric cutaways. 2038 would be the largest replacement and procurement year.

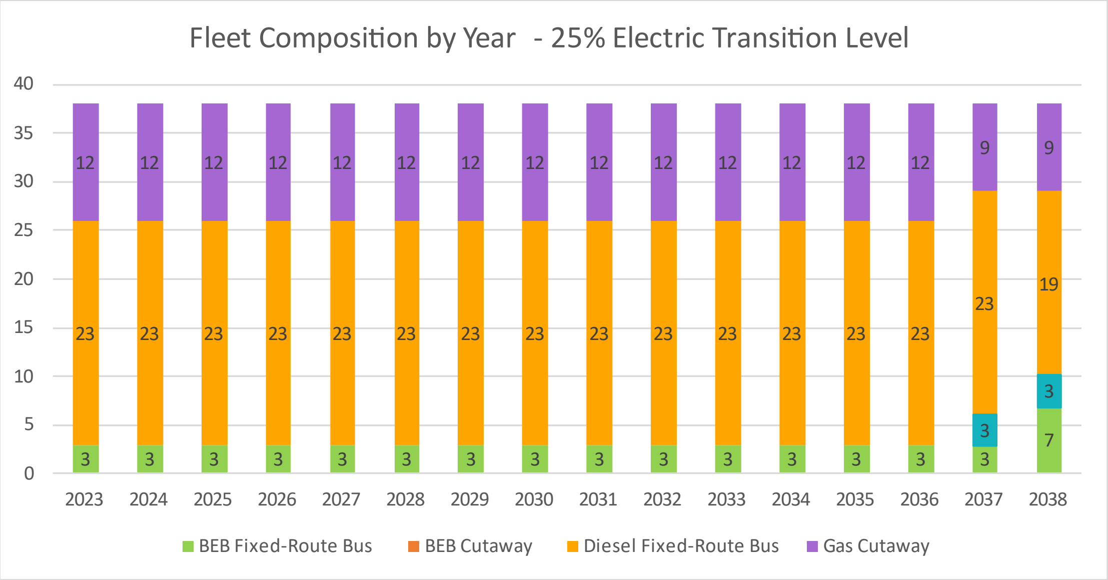


Figure 77. 25% BEB Fleet Transition Composition

4.4.1.2 Cost Breakdown

Table 28 on the following page shows the total cost per year in the 25% scenario. The 25% scenario includes the same elements as the baseline scenario, but introduces additional costs such as BEBs, chargers, dispensers, and training. Differences in maintenance and fuel operating costs for BEBs also start to impact overall costs. The total for this assessment over sixteen years is $65,774,950**.**

Table 27. 25% Transition Level - Total Cost Per Year

COST CATEGORY	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	TOTAL 16 YEAR
Fleet	$ 4,962,765	$3,399,000	$1,750,485	$2,404,000	$2,923,891	$2,527,739	$316,692	$489,291	$0	$0	$0	$550,701	$5,461,304	$5,235,656	$3,683,303	$5,230,809	$38,935,636
Infrastructure	$698,748	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$42,882	$963,063	$1,704,693
Training & Transition	$10,727	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$10,727
Fuel	$415,967	$399,865	$397,813	$396,459	$396,573	$398,726	$400,196	$398,794	$408,102	$409,038	$410,609	$410,683	$411,590	$413,743	$410,448	$368,809	$6,447,416
Maintenance	$944,249	$963,306	$992,206	$1,021,972	$1,052,631	$1,084,210	$1,116,736	$1,150,238	$1,184,745	$1,220,288	$1,256,896	$1,294,603	$1,333,441	$1,373,445	$1,404,523	$1,282,989	$18,676,478
Total Cost	$7,032,456	$4,762,171	$3,140,504	$3,822,431	$4,373,095	$4,010,675	$1,833,624	$2,038,324	$1,592,847	$1,629,325	$1,667,506	$2,255,987	$7,206,335	$7,022,844	$5,541,155	$7,845,669	$65,774,950

4.4.2 50% BEB Scenario

4.4.2.1 Fleet Replacement

Figure 78 below presents a detailed fleet composition breakdown by year for the next 16 years under a 50% BEV fleet transition scenario. Under the following fleet composition breakdown, by 2038, Topeka Metro would have replaced 10 diesel powered fixed route vehicles and four gasoline cutaways with thirteen BEBs and seven battery electric cutaways. 2037 would be the largest replacement and procurement year.

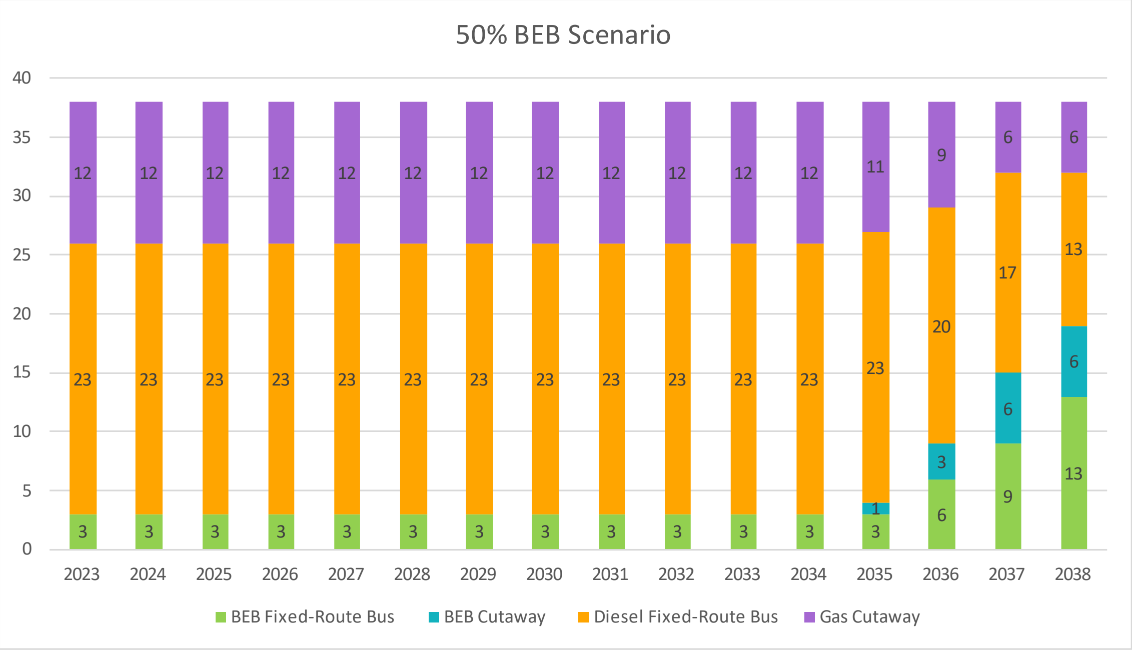


Figure 78: 50% BEB Fleet Transition Composition

4.4.2.2 Cost Breakdown

Table 29 on the following page shows the total cost per year in the 50% scenario. The same variables in the 25% scenario apply in the 50% scenario as well. Additional BEBs lead to greater capital costs and lower operating costs. The total for this assessment is $70,255,864.

Table 28. 50% Transition Level - Total Cost Per Year

COST CATEGORY	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	TOTAL 16 YEAR
Fleet	$4,962,765	$3,399,000	$1,750,485	$2,404,000	$2,923,891	$2,527,739	$316,692	$489,291	$0	$0	$0	$550,701	$5,652,703	$7,006,982	$5,071,422	$5,282,091	$42,337,761
Infrastructure	$698,748	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$26,947	$935,688	$972,620	$957,521	$3,591,524
Training & Transition	$10,727	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$10,727
Fuel	$415,967	$399,865	$397,813	$396,459	$396,573	$398,726	$400,196	$398,794	$408,102	$409,038	$410,609	$410,683	$409,844	$378,747	$343,131	$298,887	$6,273,436
Maintenance	$944,249	$963,306	$992,206	$1,021,972	$1,052,631	$1,084,210	$1,116,736	$1,150,238	$1,184,745	$1,220,288	$1,256,896	$1,294,603	$1,334,537	$1,256,720	$1,156,044	$1,013,034	$18,042,416
Total Cost	$7,032,456	$4,762,171	$3,140,504	$3,822,431	$4,373,095	$4,010,675	$1,833,624	$2,038,324	$1,592,847	$1,629,325	$1,667,506	$2,255,987	$7,424,031	$9,578,137	$7,543,216	$7,551,533	$70,255,864

4.4.3 75% BEB Scenario

4.4.3.1 Fleet Replacement

Figure 79 provides a detailed fleet composition breakdown by year for the next 16 years under a 75% BEV fleet transition scenario. Under the following fleet composition breakdown, by 2038, Topeka Metro would have replaced seventeen diesel powered fixed route vehicles and ten gasoline cutaways with twenty BEBs and ten battery electric cutaways. 2036 would be the largest replacement and procurement year. In addition, the fleet size grows by two in 2037 to account for additional buses needed to operate service under mitigation scenario 3.

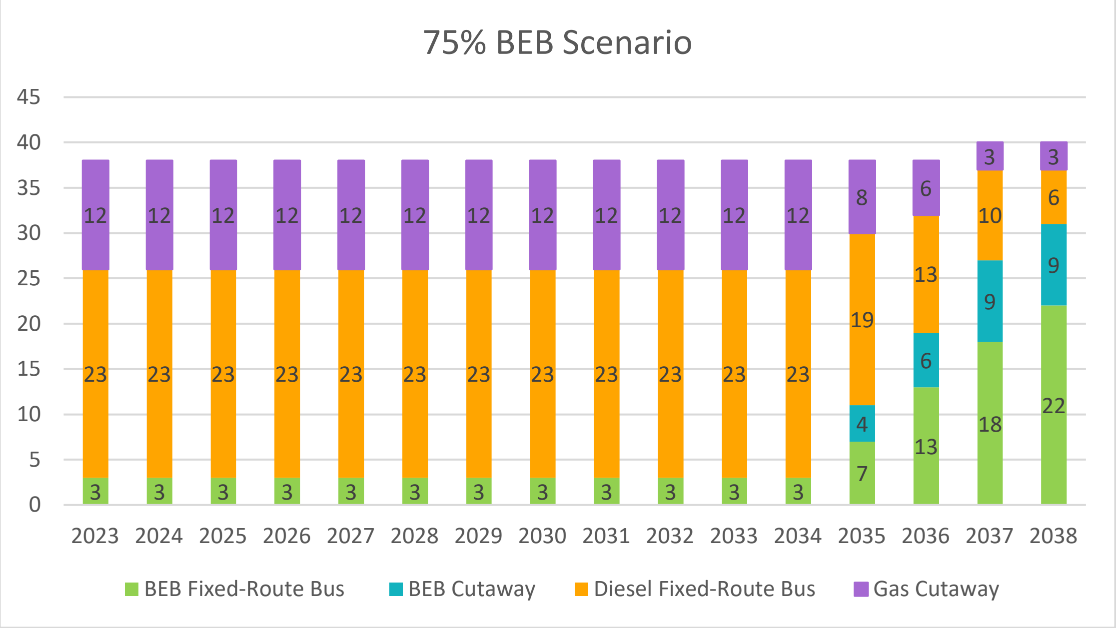


Figure 79: 75% BEB Fleet Transition Composition

4.4.3.2 Cost Breakdown

Table 30 on the following page shows the total cost per year in the 75% scenario. Cost categories are similar in this breakdown to previous BEB scenarios but reflect additional vehicles and chargers. In addition, mitigation costs (scenario 3) are included in the fleet, fuel, and infrastructure categories to account for additional buses, chargers, and changes in operating costs. The total 16-year valuation is $79,234,979.

Table 29. 75% Transition Level - Total Cost Per Year

COST CATEGORY	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	TOTAL 16 YEAR
Fleet	$4,962,765	$3,399,000	$1,750,485	$2,404,000	$2,923,891	$2,527,739	$316,692	$489,291	$0	$0	$0	$550,701	$8,019,334	$8,317,699	$7,597,836	$5,230,809	$48,490,242
Infrastructure	$698,748	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$932,052	$1,248,574	$3,818,374	$957,521	$7,655,269
Training & Transition	$10,727	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$10,727
Fuel	$409,473	$395,042	$393,801	$392,405	$392,438	$394,630	$396,172	$394,976	$404,443	$405,410	$407,000	$407,153	$358,393	$290,832	$283,472	$234,589	$5,960,228
Maintenance	$944,249	$963,306	$992,206	$1,021,972	$1,052,631	$1,084,210	$1,116,736	$1,150,238	$1,184,745	$1,220,288	$1,256,896	$1,294,603	$1,179,490	$968,099	$926,383	$762,461	$17,118,513
Total Cost	**$7,025,962**	**$4,757,348**	**$3,136,491**	**$3,818,376**	**$4,368,960**	**$4,006,578**	**$1,829,600**	**$2,034,506**	**$1,589,189**	**$1,625,697**	**$1,663,896**	**$2,252,458**	**$10,489,268**	**$10,825,204**	**$12,626,065**	**$7,185,380**	**$79,234,979**

4.4.4 100% BEB Scenario

4.4.4.1 Fleet Replacement

Figure 80 below provides a detailed fleet composition breakdown by year for the next 16 years under a 100% BEV fleet transition scenario. Under the following fleet composition breakdown, by 2038, Topeka Metro would have replaced all 26-diesel powered fixed route vehicles and twelve gasoline cutaways with twenty-six BEBs and twelve electric cutaways. 2035 would be the largest replacement and procurement year. In addition, the fleet size grows by two in 2027 to account for additional buses needed to operate service under mitigation scenario 3.

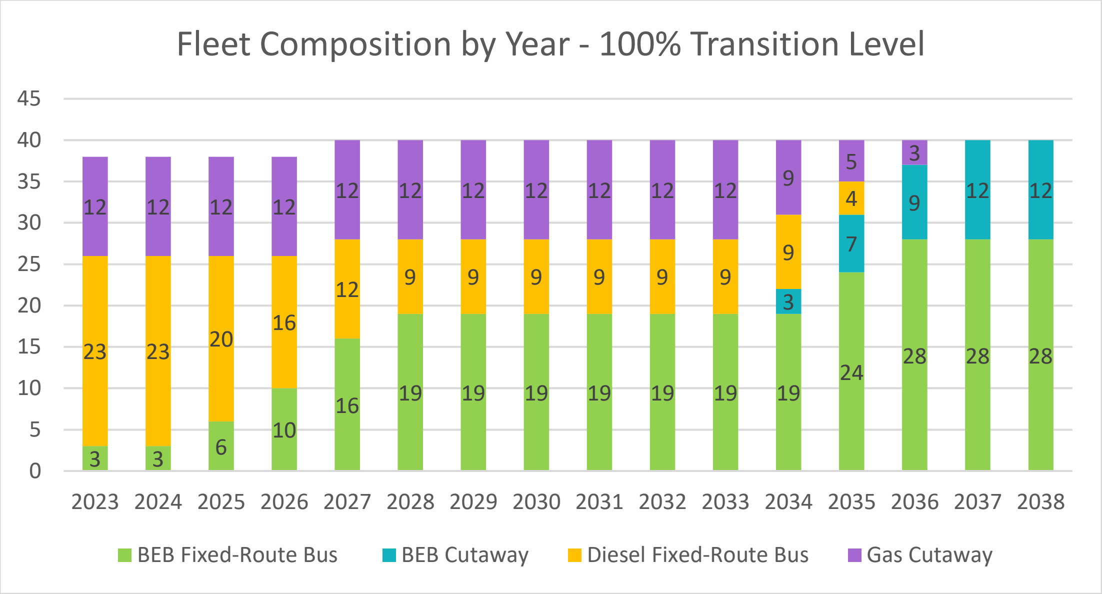


Figure 80. 100% BEB Fleet Transition Composition

4.4.4.2 Cost Breakdown

Table 31 on the following page shows the total cost per year in the 100% scenario. The cost breakdown for this approach is similar to 75% scenario but assumes a full transition to BEBs occurring in 2038. In addition, mitigation costs (scenario 3) are included in the fleet, fuel, and infrastructure categories to account for additional buses, chargers, and changes in operating costs. Total cost of ownership in this scenario is $82,866,400.

Table 30. 100% Transition Level - Total Cost Per Year

COST CATEGORY	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	TOTAL 16 YEAR
Fleet	$4,962,765	$3,399,000	$3,032,689	$4,124,457	$6,758,190	$3,833,250	$316,692	$489,291	$0	$0	$0	$1,119,037	$8,915,552	$8,317,699	$5,033,714	$5,230,809	$55,533,145
Infrastructure	$698,748	$0	$700,376	$720,828	$2,892,654	$751,547	$0	$0	$0	$0	$0	$39,243	$1,232,577	$1,248,574	$972,620	$957,521	$10,214,688
Training & Transition	$10,727	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$10,727
Fuel	$415,967	$399,865	$379,302	$351,149	$369,556	$345,526	$341,895	$336,522	$336,463	$333,172	$330,670	$322,413	$264,264	$214,964	$200,656	$191,282	$5,133,666
Maintenance	$944,249	$963,306	$918,165	$830,916	$791,296	$713,262	$723,914	$745,631	$768,000	$791,040	$814,771	$829,948	$654,896	$500,498	$491,775	$492,506	$11,974,174
Total Cost	**$7,032,456**	**$4,762,171**	**$5,030,533**	**$6,027,350**	**$10,811,696**	**$5,643,585**	**$1,382,501**	**$1,571,444**	**$1,104,463**	**$1,124,212**	**$1,145,442**	**$2,310,641**	**$11,067,289**	**$10,281,736**	**$6,698,764**	**$6,872,117**	**$82,866,400**

4.5 Total Cost of Ownership Comparison

This section outlines the cost of ownership by year and in total, over 16-years by transition scenario. As shown in the scenario tables above, BEBs have a higher capital cost and a lower operating cost. Overall, capital costs outweigh operating costs, making BEB transition scenarios more expensive. However, as the industry matures, additional changes may make batteries more efficient and buses more affordable. This approach is intended to provide a realistic and conservative approach that outlines the full cost of BEB acquisition.

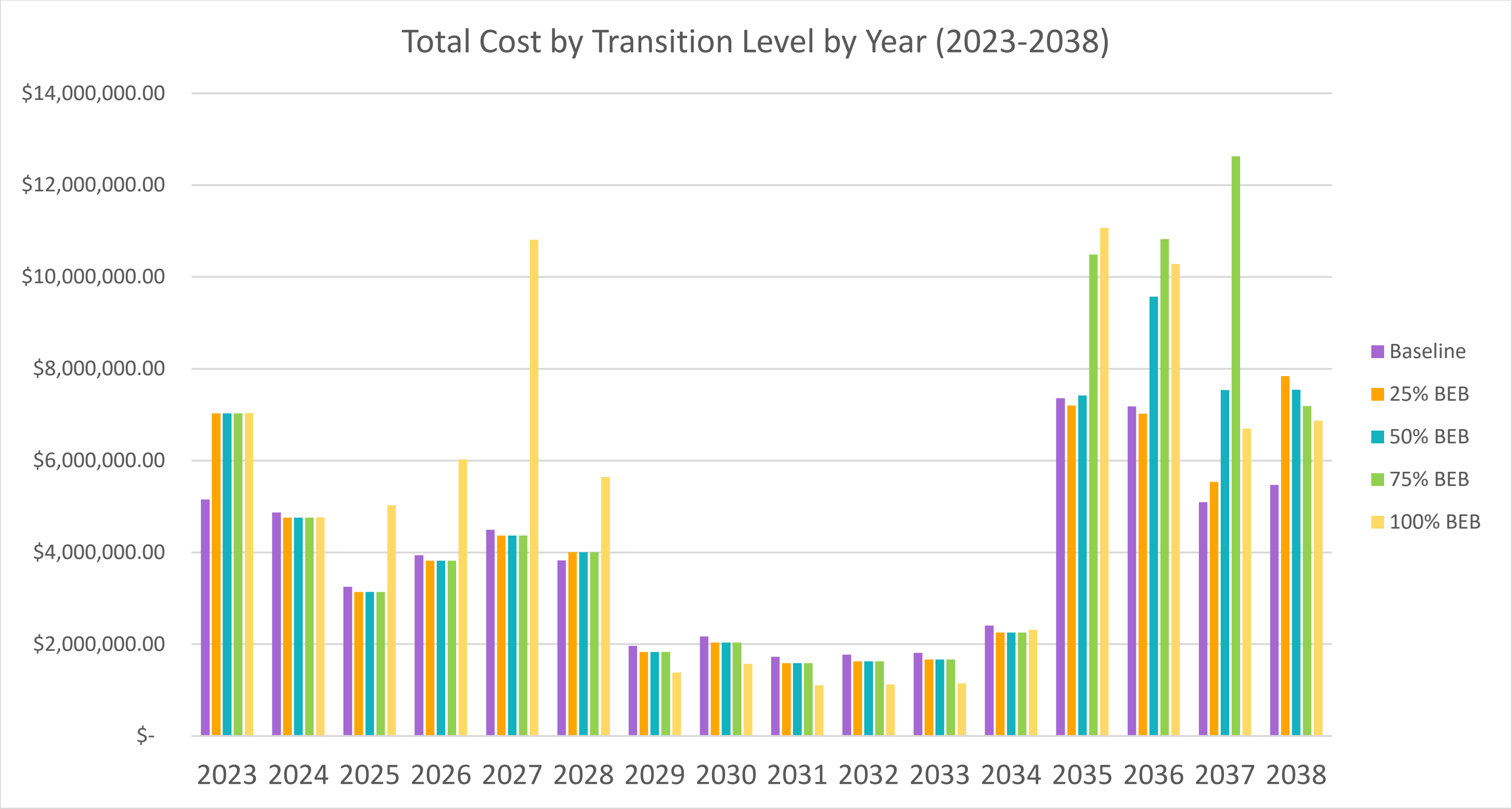


Figure 81. Cost by Replacement Scenario (2023-2038)

For each year of operation, the bulk of cost is still associated with capital vehicle procurements. Because fixed route buses and cutaways are not scheduled to be procured from 2029-2032, overall costs are lower regardless of the scenario. Similarly, a high number of vehicle procurements (nine) drives costs up in 2023 relative to other years.

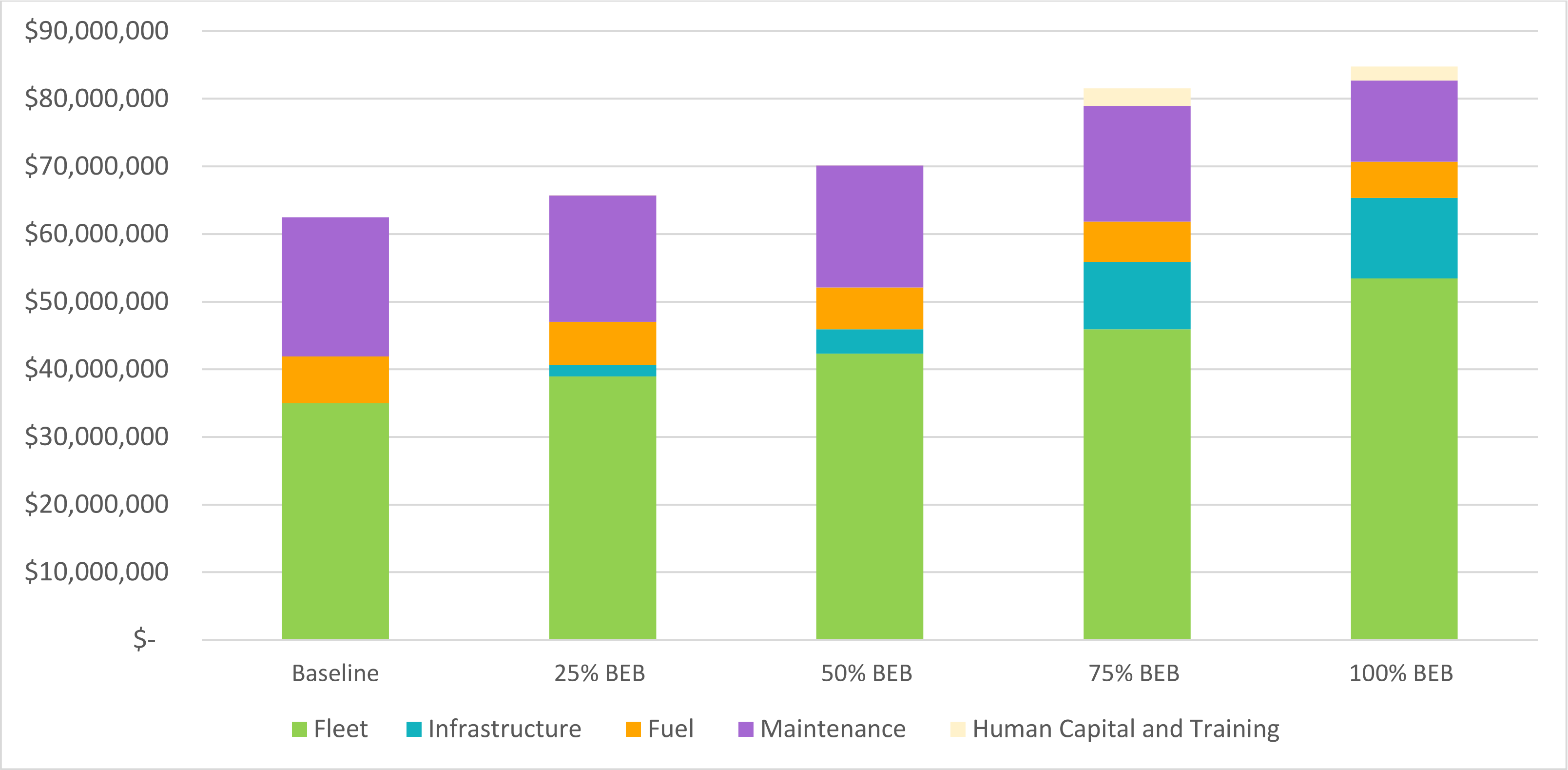


Figure 82. Total 16-Year Cost of Ownership by Transition Scenario

The largest increase in total operating costs is from 50% to 75% BEBs, as additional on-route charging and buses would be acquired to ensure continuity of service. However, over 16 years, a full transition to BEBs relative to the baseline represents an estimated $19.4 million (or around $1.2 million annually). This represents an “all-in” cost that would include everything from capital investments to operational expenses and even additional training and labor required. Federal funds available this year and in coming years are likely a viable solution to addressing some or most of these transition costs.

Note that this costs also exclude facilities modifications or land acquisition; should there need to be more space created for pantograph charging rather than plugins for example, these could be required that would carry with them additional associated costs. Section 7 outlines more details related to facility planning.

5 Implementation Plan

The analysis and findings in Section 2 and Section 4 have identified two optimal paths forward. Scenario 3 which involves on-route charging likely with step backs and Scenario 4 which uses larger batteries and shuttles buses back to the bus garage for midday charging. The first Scenario 3 requires additional vehicles and on-route charging while Scenario 4 requires additional staffing produces increased deadheading. The choice to diverge between these two scenarios is not required until more than approximately 50% of blocks are transitioned to electric vehicles which is unlikely to occur until early- to mid-2030 so the implication of both implementation approaches will be discussed below. This is in part because the trade off between these two alternatives is impacted by:

- Improvements in battery technology
- Improvements in charging technology
- Operator availability
- Service changes

5.1 Procurement Phasing and Programs

When developing the implementation plan a focus was placed on developing a flexible approach that was phased to efficiently stage the transition. At the same the implementation approach was shaped by the following five key drivers:

1. **Fixed-route vehicle age and useful life**. As all current fixed-route buses in Topeka Metro's fleet are approaching or have reached their 12-year FTA useful life, all 26 vehicles have to be replaced by 2028. These vehicles are not expected to be replaced until at least 2034. As Topeka Metro is not equipped to entirely electrify the entire fleet over the next 5 years, a portion of these will have to remain diesel and will not be scheduled to be replaced until at least 2034.
2. **Demand vehicle age and useful life**. As demand response vehicles have a useful life of 7 years as opposed to the 12-year useful life of fixed-route buses, it is possible to delay the conversion of gasoline demand-response vehicles and still fully convert them at or before fixed-route buses are finished transitioning.
3. **Structure the transition in phases.** We recommend structuring procurement into as few separate contracts as possible. Standardization of vehicles and charging equipment across suppliers is progressing in the BEB market, however it is not yet at a point of completely seamless interchangeability. The aim would be to minimize new costs associated with managing equipment across multiple providers in addition to the fixed-route and demand-response sub-fleets that Topeka Metro already expects to manage.
4. **Opportunity for funding.** Currently there is significant funding available for low- and zero-emission vehicle deployments. Topeka Metro is already a recipient of some of these funds in the form of an FTA Lo-No Grant. This grant significantly expanded in FY21 to $1.66 billion to support 150 projects (>$11 million / project).
5. **Workforce training, experience, and market maturation.** A phased approach allows staff to become comfortable with the technology and build up to a more significant transition. At the same time technology is continuing to evolve and present further opportunities moving forward. In particular, deployment of electric demand-response vehicles is limited as of January 2023, and few vehicle models are even approved to be bought with FTA funds. By

delaying the electrification of demand-response vehicles, Topeka Metro can wait until the market is more mature, similar to the market for fixed-route BEBs.

Based on the following key drivers, the following implementation schedule has been developed Figure 83. This project has been broken into three phases:

1. **Proterra Pilot.** Topeka Metro is procuring three Proterra battery electric buses and chargers that are expected to enter service in 2023. Topeka Metro has been working with Proterra on the build specifications for three 35’ ZX5 BEBs with 440 kWh batteries and three Industrial Series 120 kW DC fast chargers with 2 dispensers each.
2. **Phase 1.** Aims to group the bus procurements for 14 buses between 2025 and 2028. This phase should include funding applications, infrastructure upgrades, vehicle procurements, and evaluation. This may be further grouped with the additional 6 diesel buses that are being procured between 2024 and 205 particularly if these are hybrid-electric buses. It may also make sense to do an electric cutaway pilot during this time period depending on the maturity of this technology.
3. **Phase 2.** Depending on the success of Phase 1 this project will determine which portion of the remaining 50% of the fleet should be electrified. In the case 75% or 100% of the fleet is electrified it will be necessary to evaluate whether on-route charging or extended batteries is the most cost effective and effective method to support electrification.

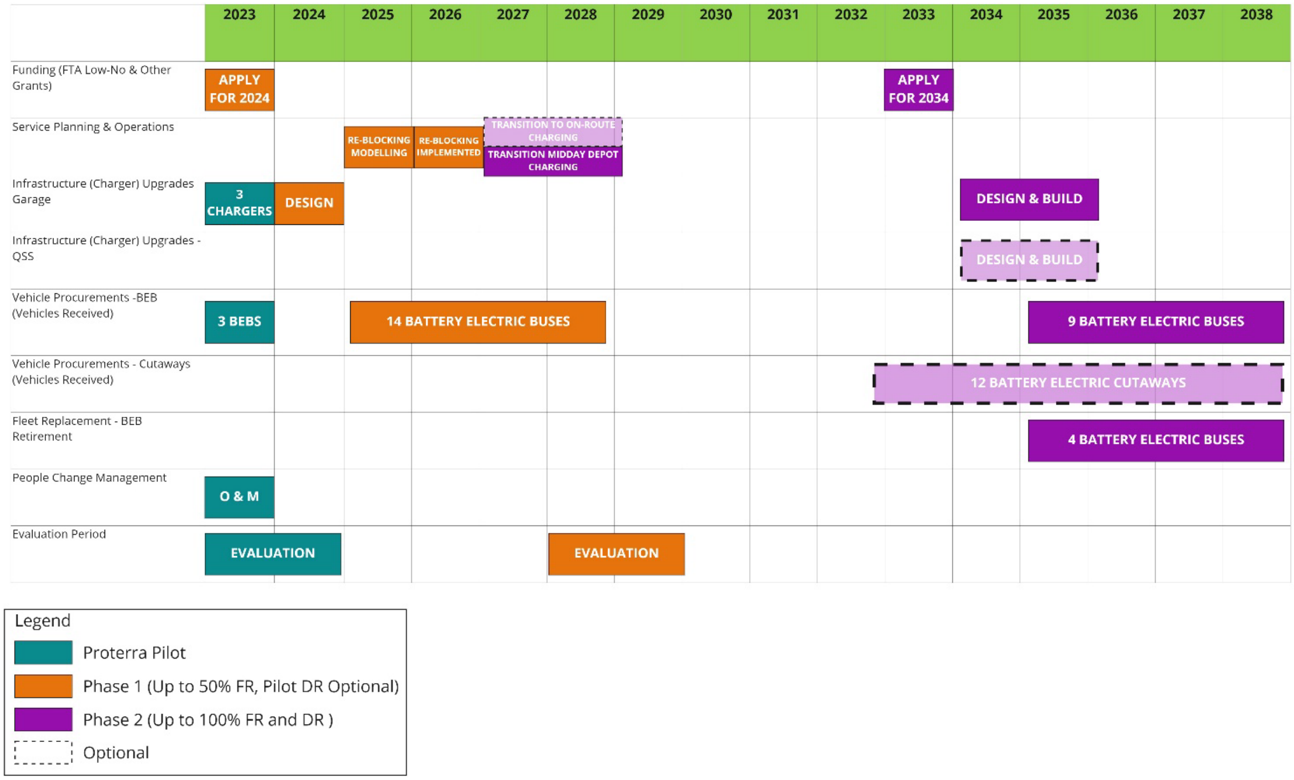


Figure 83. Implementation Plan

The impacts on specific components including vehicle procurement, infrastructure upgrades, and people change management will be discussed in depth in the sections below.

5.2 Infrastructure Upgrades

5.2.1 Ryan Building Upgrades

Staging and mixed fleet support is key to a successful BEV fleet transition, given the fundamental differences in space utilization and maintenance workflow. This section addresses potential phasing and operational / policy changes that are recommended to support a BEB fleet transition. It is critical that infrastructure be scheduled so that it is completed before the corresponding vehicles are delivered. The building upgrades that need to be completed as part of each phase are described below:

- **Proterra Pilot.** Topeka Metro has been working with Proterra on the build specifications for three 35’ ZX5 BEBs with 440 kWh batteries and three Industrial Series 120 kW DC fast chargers with 2 dispensers each. The layout and design for these chargers should be identified to support future additional placements of charging infrastructure and should be located to coordinate with future phases.
- **Phase 1.** As part of this phase the goal will be to transition from charging 3 pilot buses up to 17 fixed-route buses and 2-3 paratransit vehicles. This will could involve the installation of 6 more fixed-route chargers with a total of 14 dispensers and 2-3 Lever 2 Chargers. At this stage the goal will likely to be minimize all on-route charger and so additional chargers may need to be procured for the garage to support resilience.
- **Phase 2.** As part of this phase the remaining charging infrastructure will be installed at the depot and may involve electrifying the remainder of the fleet. This would involve procuring any remaining charging equipment to support eleven 120 kW plug-style chargers to charged fixed-route buses and six Level 2 chargers to charge the Lift vans.

  Now that more than 50% of the fleet is electrified a focus should be placed on additional ways to build in resiliency. This could include a second charging location provided by on-route chargers, a back-up generator, or on-site power generation.

  At this phase it might be necessary to make further utility upgrades. The current scenarios appeared to be within the available power provided by the transformer but have limited capacity to support unexpected changes such as larger batteries, expanded fleet size, or increased building load.

Additional items around workforce training are covered in **Section 5.5**.

5.2.2 QSS Upgrades (Option)

As part of the Proterra Pilot and Phase 1 projects the goal would be to minimize the need for any on-route charging at QSS. For phase 3 based on the recommended scenario it will be necessary to install three chargers on-route chargers capable of providing at least 150 kW of power with minimal driver interaction. Currently the most common approach to do this is pantograph chargers though some agencies are using inductive chargers.

5.3 Vehicle Procurements

Vehicle procurements often have a fairly fixed scheduled replacement that is dictated by the vehicles useful life as determined by mileage and years. Due to the nature of vehicle procurements it is typically necessary to purchase a number of vehicles at a time and so agencies purchase buses in batches. Currently vehicle procurements also take 12 to 16 month and so require significant planning. In addition, BEBs unlike traditional diesel vehicles frequently require infrastructure upgrades such as depot and on-route charges to be completed before the buses can be used. Should on-route charging be selected vehicles will need to be designed to accommodate the on-route chargers (likely either pantograph or inductive charging).

Vehicle purchases frequently heavily rely on federal funds with federal funding match available up to 80% the cost of the bus. Therefore, significant vehicle purchases should be coordinated with requests for funding. To date agencies have been able to apply for Low-No funds for vehicle purchases for BEBs as well as other low emission technology such as hybrid-electric vehicles, CNG, and propane. Agencies also frequently either use state contracts or partner with peer agencies to get better rates on vehicles.

It is recommended that the vendor offer a 12-year warrant for vehicles that do not surpass battery state of health standards. In the event that a vehicle exceeds these standards within the first 12 years, it is recommended that the vendor provide a midlife battery overhaul. To ensure all potential overhauls are included in cost estimates when applying foe grant funding it is suggested that Topeka Metro factor in the cost of overhauls as part of capital costs

5.4 Service Planning & Operations

In concert with the strategic recommendations on facility and fleet conversion it is necessary to identify and plan for transit operational changes. Some key service planning and operations changes considered as part of the scenarios are discussed below.

5.4.1 Re-blocking – Interlining and Route Groups

Topeka Metro's Weekday dispatch includes 18 morning pull-outs. It was assumed that AM-PM splits are run by the same bus and so 18 buses are needed for current daily service. Based on that and the modeling analysis in **Section 2** the following thresholds were identified as shown in **Figure 84.**

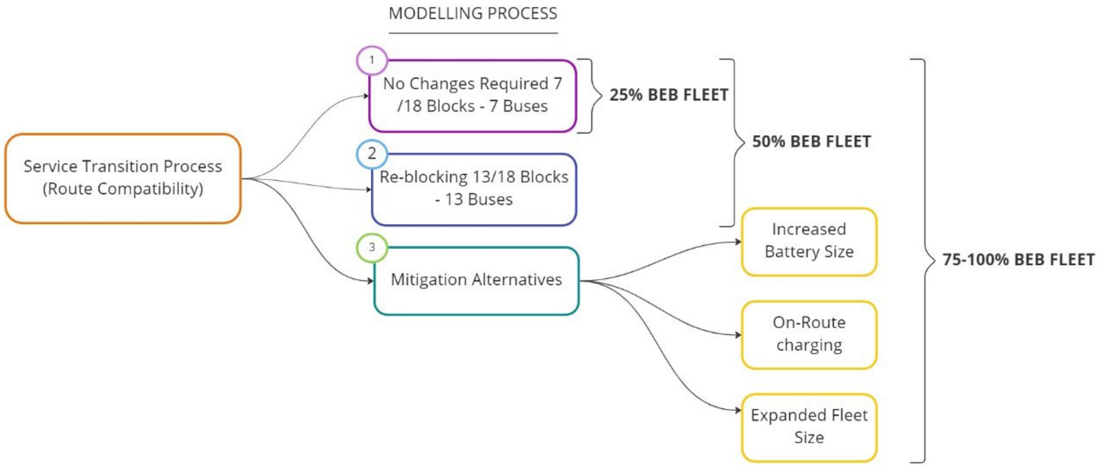


Figure 84. Service Transition Process (Route Compatibility)

- It was projected that up to 7 of the 18 chains of blocks (mainly paired AM-PM splits, limited straights) can be run with the BEB technology currently on order, without re-blocking, in winter conditions. Therefore, it was determined that approximately 25% of the fleet (~7 / 26 buses) could operate under BEB technology under the assumption that all BEBs were dispatched.

- Under re-blocking strategies, it was projected that up to approximately 75% of service (13 / 18 blocks) can electrified in winter conditions. Therefore, it was determined that approximately 50% of the fleet (13/ 26 buses) could operate using BEB technology under the assumption that all BEBs were dispatched.
- The remaining service would require additional assistance, potentially by using the following mitigation strategies:
    - Additionally dispatched buses
    - On-route charging
    - Enlarged battery capacity

All scenarios investigated re-blocking and increased interlining as this provides the opportunity to increase the number of blocks that can support electric vehicles without requiring an increase in the fleet size, number of drivers, or charging infrastructure. This does make blocks more complicated and shared routes interdependent, but this is also common throughout the industry and for reasons other than just electrification. A key success will be training staff and updating SOPs to support this change.

5.4.2 Pull-in and Pull-out Process

As electric vehicles are phased in and service is re-blocked, it will become more critical that vehicles are assigned to blocks that it can complete based on its battery state of charge as well as its battery state of health. In addition, vehicle pull-in will have to be coordinated to ensure vehicles are properly distributed to chargers lanes to ensure the vehicles at the front of the service lanes are adequately charged. This will require a more sophisticated process for morning bus line up and pull-out as well as vehicle assignment. This can be accomplished through a combination of updated standard operating procedures (SOPs) as well as technology. Technology to support the deployment of electric vehicles includes computer aided dispatch / automatic vehicle location systems, charge management systems, yard management systems, and workforce management systems. These systems are rapidly evolving as agencies transition from electric bus pilots to having a large portion of their fleet electric. Topeka Metro should evaluate the technology and processes it has to complete this or whether during Phase 1 it needs to update these.

In addition, as part of updating SOPs, Topeka Metro should consider potential changes to staff duties including refueling, connecting and disconnecting bus plugs, and checking the state of charge as part of the pre-trip inspection.

5.4.3 Support for Additional Deadheads

As part of Scenario 4, as well as Scenario 2 and all the other scenarios to a lesser extent, buses will need to deadhead between QSS and the depot for charging during the day. For many blocks vehicles (even with extended batteries) may not be able to complete the full day of service without mid-day charging at the depot. Where possible this will be accomplished by drivers starting or ending their day or completing split runs (to the level already being completed). For some scenarios like Scenario 4 due to the high volume of deadheads (approximately 2 every 30 minutes) it was assumed that staff accounting to multiple full-time equivalents (FTEs) could be required to shuttle buses

5.4.4 Step Backs and Additional Movements at QSS

In many of the scenarios but especially for Scenario 3, it is necessary to transfer from a bus with a battery with a lower state of charge to a bus with a battery of a higher state of charge so the bus with a lower state of charge can charge. The benefit of transferring buses as opposed to staying on-board a vehicle while it charges is you can provide it longer uninterrupted charging sessions while keeping your driver on the road.

An example of this is illustrated in Figure 85. In this case Bus A is charging without a driver at QSS. Bus B pulls into QSS and pulls into a space with a charger. The pantograph charger automatically connects and starts the bus charging. The driver now transfers from Bus B to Bus A which is nearly fully charged. The bus automatically disconnects from the pantograph and the driver can continue providing service. In parallel Bus B is now charging and will be more fully charged for when the next driver needs the bus.

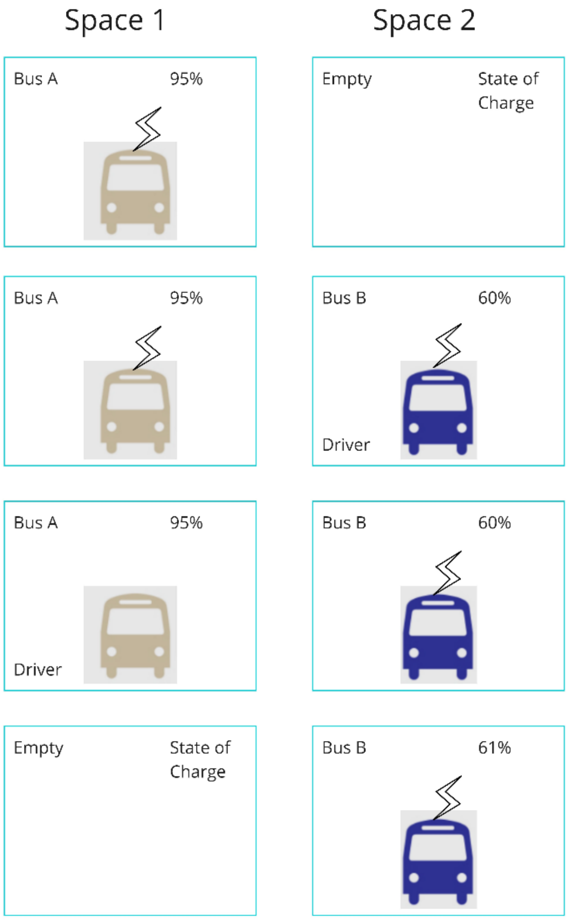


Figure 85. Step Back Procedure QSS

Consideration around where vehicles can be parked at QSS is discussed in **Section 108**. Depending on the number of step backs, available parking spaces, and number of chargers, it may be necessary to have a staff member located at QSS to help rotate vehicles to support an efficient step back process. In some cases a step back can be used when chargers are not available at QSS but so another staff member could take the bus back to the depot to charge.

5.5 People Change Management (PCM)

People change management (PCM) addresses how Topeka Metro staff can be best enabled to support electrification. Arcadis IBI Group recommends an agency-level approach to building collaboration and support, in addition to department-focused efforts. Electrification will alter how

Topeka Metro plans and delivers its service. Electrification will impact staff and operations in three major areas at Topeka Metro:

- Bus maintenance;
- Buses operations and dispatch; and
- Start- and end-of-day work procedures.

5.5.1 Safety First

The process of preparing Topeka Metro staff for electrification must start and continue with rigorous training and education into safely working in the new high-voltage environment. Emphasis should be placed on lock-out/tag-out (LOTO) procedures and correct use of Personal Protective Equipment (PPE). Although maintenance staff must have the most thorough training, all staff at Topeka Metro must receive, more than once, training on safety and the necessity of LOTO/PPE.

5.5.2 Approach and Tasks

This section sets out the general approach to PCM and highlights several near-term tasks to make PCM successful. **Figure** 86 outlines a potential approach to PCM: showing the levels of education suggested for each type of staff at Topeka Metro, including agency-wide and department-level components.

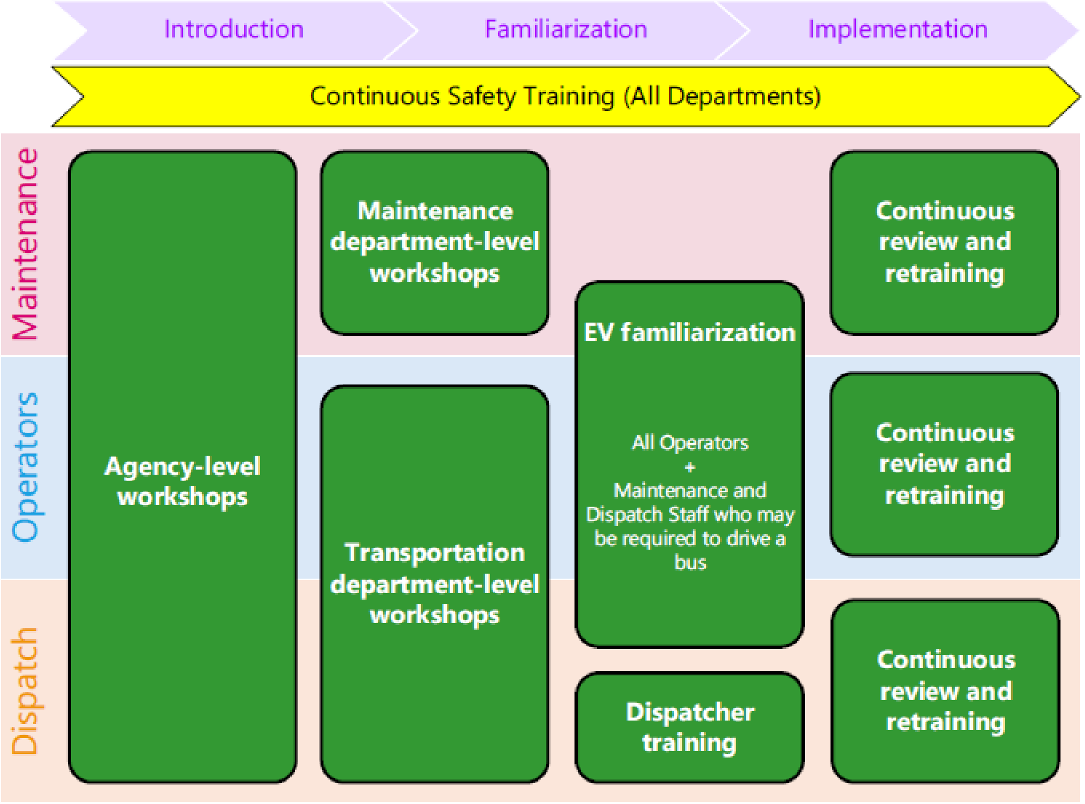


Figure 86. Potential Approach to PCM for Fleet Electrification

Near-Term Tasks

To prepare for a safe, efficient, and productive staff transition to an electrified fleet Arcadis IBI Group recommends that Topeka Metro undertake the following tasks:

- Identify alterations to work procedures early, especially those that may impinge on the Collective Bargaining Agreement (CBA), whether explicitly or not. For example, a change to operator work procedures might need to address whether the start-of-day procedures and midday recharging procedures will require the operator to disengage the bus from charging equipment (i.e., unplug it from a plug-style connector or disconnect a pantograph).
- Engage with the Amalgamated Transit Union Division 1360 as early as possible. Based on preliminary conversations with Topeka Metro as well as reviewing the labor agreement, 0 conflicts with the existing agreement have been identified when considering transitioning to an electric fleet. See **Section 1.5.1** for some of the key provisions relevant to electrification.
- It is recommended that Topeka Metro emphasize to the Union that although there is a strong health-and-safety aspect to electrification, there will also be changes throughout the organization. If the Union cannot participate formally, keeping the Union in particular and the employees in general well informed is extremely valuable to maximize buy-in and minimize resistance.
- Identify and engage “champions” within the maintenance and operations staff. These are staff especially keen on the opportunities and challenges presented by electrification. Being careful to respect the CBA, facilitate these champions’ participation

in most workshops and training, and for giving one-on-one informal guidance to colleagues.

- Organize agency-wide and department-level workshops timed to maximize participation. As much as practical, these workshops should be on paid time to build partnership and participation.

5.5.3 Agency Level Activities

Workshops

As far as practical (given the necessity to support service) Arcadis IBI Group recommends the electrification transition shall be supplemented with all-employee workshops on paid time, with ample time for questions and discussion. To promote engagement of all employees, multiple sessions could be planned each covering the same material and with employees able to select a time fitting their schedule. The agency-level workshops should be supported by breakout workshops for individual departments to get into more technical details related to their specific lines of work.

Collected feedback/questions and answers from all sessions should be shared among all employees for transparency. The presentation for such sessions should focus on:

- Highlights of the new safety regime;
- Why Topeka Metro is embarking on this transition;
- Benefits to the staff, such as:
    - The working environment will be cleaner, quieter, with a reduction or absence of diesel fumes;
    - People will gain skills with leading edge technologies;
- Timeline

Technical details of the transition can be provided in an infosite (discussed below).

Periodic Updates/Celebrations

Staff should be provided with updates periodically as electrification rolls out. During the transition, memos, emails, and or postings should be made to keep staff informed.

To mark major milestones and promote pride among the organization, Topeka Metro may find it engaging to hold internal “celebrations.” About one-third of the way into the transition, another all-employee workshop set could be held to update staff, and to collectively review the lessons learned and feedback.

Infosite

Topeka Metro can set up a website for employees to learn about the transition in general and the implementation plan in particular. This makes it easy to share very detailed information that some employees might want.

5.5.4 Bus Maintenance

Overview and Approach

Bus maintenance will see major changes brought by electrification.

First and foremost, the safety regime in the garage will be very different, including the personal protective equipment (PPE) that staff must wear during certain tasks. Many tasks also require a safety observer, which may be a significant change in work procedures. Training in new safety considerations, including proper use and care of PPE, must be front and center continually throughout the transition, and at all times thereafter.

Topeka Metro should contractually ensure that the BEB manufacturer takes the lead on this training. This is standard practice for the original equipment manufacturer (OEMs), however it is recommended that Topeka Metro identify clear desired outcomes from the training program in advance to ensure that they are met by the OEM training curriculum. The technical training discussed below will include major portions on good safety practices.

After safety, the transition of Topeka Metro maintenance department to BEBs falls into two major categories:

- Technical training on new and altered subsystems; and
- New work procedures.

Given the long service and compactness of the maintenance department we recommend that Topeka Metro put effort into assisting incumbent staff to transition to the new environment. This approach supports our understanding that Topeka Metro expects every mechanic to maintain every subsystem on a bus.

Technical Training

OEM Training

The BEB manufacturer will offer training for maintenance personnel. However, this training typically has the following prerequisite skills:

- Electrical theory;
- High-voltage safety;
- Use and care of PPE specialized for high-voltage environments;
- Use of specialized tools, particularly a digital multimeter (DMM) or digital volt-ohm-milliammeter (DVOM);
- Basic computer skills, especially with respect to troubleshooting electrical systems.

These skills would typically be gained during offsite courses as discussed in the next section.

Offsite Training

Prior to the arrival of BEBs, Topeka Metro's maintenance staff will need technical training in maintaining battery electric vehicles.

Phasing

We recommend that Topeka Metro rotate all maintenance staff through EV maintenance courses before the BEB manufacturer provides its training—which in turn will be just before the BEBs come on site. Refresher training, even in basics, should be held shortly after the first BEBs go into revenue service, with care given to confirm that EV knowledge and safety practices are entrenched.

New Work Procedures

An EV garage is cleaner and quieter than an internal combustion engine (ICE) garage, but its safety protocols and work procedures can be radically different. Arcadis IBI Group recommends that after manufacturer training, Topeka Metro's maintenance supervisor, maintenance staff, and training representative(s) from the manufacturer conduct a workshop identifying their new work procedures. This will benefit both familiarization and buy-in. As discussed above, formalized Union representation is a plus.

One important area for management is the need for a safety observer during several procedures. Staffing needs to be adequate for this, and safety being paramount over "getting the job done fast" needs to be emphasized to staff.

Other Considerations

PPE

As noted above, personal protective equipment (PPE) in an EV garage is very different than AN ICE garage. The use and care of PPE will be covered in the safety training discussed above. Topeka Metro will need to accumulate the needed inventory of PPE and set up an exchange process for aged-out or compromised PPE.

Maintenance Bay Equipment

Access to roof-mounted systems, such as air-conditioning, will require OSHA-approved safety harness and platforms in maintenance bays. New equipment should also include a portable lift table for battery pack replacements. Lifting tables for this purpose are available through BendPak (model SL24EVT) and Mohawk (model ST 2000), as well as other reputable equipment manufacturers. Keeping in mind that the specific location for battery packs can vary between bus models. A mobile charging station should be available at the BEB service bay for charging system diagnostics. A stand-alone charging cabinet and dispenser should not be necessary within the Maintenance Facility.

Job Description

We recommend that Topeka Metro's job descriptions for maintenance staff be revised to include competency in EV maintenance.

5.5.5 Bus Operations Training

Changes to Bus Operations

Changes to bus operations brought by electrification will be significant. If an operator misses their training, they will still be able to apply the same fundamental skills of driving a bus. However, activities related to charging do not have an analogue in diesel operations for operators to rely on. Training will therefore be necessary for operators to perform their adjusted daily procedures.

Changes visible to operators include:

- More frequent bus changes;
- Changes to start time, end time, and relief points;
- Notable changes to the content of pre- and post-trip procedures;
- Introduction of midday charging procedures;

- Changes to the trouble lights; and
- Noticeable changes in how a bus accelerates and brakes (covered in the EV familiarization).

Overall, re-blocking for electrification will create dynamic and changing work for operators. Some operators may be used to particular work, and the change may require one-on-one or one-on-few discussions. Trainers and management should be prepared with talking points, following on the agency-level communication discussed above so they can explain in detail why electrification matters, what it does, and how it affects drivers.

Approach to Operator Change Management

Arcadis IBI Group proposes a short course be offered to operators, several times over the course of about ten days or two weeks. The course would discuss the above points and highlight the operator-focused benefits—chiefly the reduced exposure to diesel exhaust, and the quieter work environment.

An operator should drive an EV before revenue service. This will enable them to get used to vehicle performance. EV acceleration tends to be more sensitive than that of diesel vehicles and can create passenger discomfort if the operator is not familiarized with new driving techniques. Also, braking is different with the regenerative braking in place.

Certain work procedure changes may impinge on a customary understanding of who does what inside the agency. These changes and new work procedures must be identified early in the transition, ideally with collaboration of the employees whose work is affected (i.e., with the Union-sanctioned staff representation described above), and then refined in a collaborative way so that there are neither loose ends nor bad feelings (and therefore non-co-operation with the transition).

Dispatchers and Supervisors

Software from the BEB manufacturer can alert a central dispatch that a bus on the road has less charge than it is likely to need to complete its block. Topeka Metro can establish procedures for dispatchers or supervisory staff to be aware of these alerts and to take appropriate actions (typically to arrange an end-of-trip bus swap between the operator and a mechanic). We recommend that Topeka Metro take contractual steps to ensure that the manufacturer arranges training on these features.

5.5.6 Familiarization with Operating Electric Vehicles

Every employee of Topeka Metro whose job requires or permits them to drive a bus on or off the yard, in revenue service or not—will benefit from familiarization with driving an electric vehicle. This familiarization will focus on how an electric vehicle handles during acceleration and braking, and on any trouble signals unique to an electric vehicle. Familiarization should take place on a regular bus or van. For those whose jobs permit or require them to drive on public streets, the familiarization should include that environment, outside revenue service. This familiarization is in addition to any operator training Topeka Metro normally offers or requires.

5.5.7 First and Second Responder Trainer

Responding to incidents involving BEBs such as a fire or rollover collision requires different procedures from internal combustion engine vehicles. Topeka Metro should co-ordinate with the fire department to ensure that firefighters are familiar with the differences and approaches, especially with respect to entry points, cribbing procedures, and fire suppression.

5.6 Other Change Management Considerations

5.6.1 Evaluation Period

Transitioning to a BEB fleet generally requires an initial evaluation period in which the performance of BEBs is monitored in a lower-stakes context, where range is not going to be pushed to its limit. OEM claims for BEB performance can be more optimistic or context-specific than a real-world implementation, in terms of driving factors (traffic, passenger volumes, etc.) and seasonal climate factors. For this reason, we recommend that the evaluation period span a full winter, and ideally a full summer as well. This should be a primary goal of the Proterra pilot project.

After collecting performance data over a period of months and establishing real-world trends, it will then become more advisable to schedule BEBs on more demanding services. At that point, service re-blocking becomes useful for inserting charging windows of appropriate duration and frequency to support the observed battery performance.

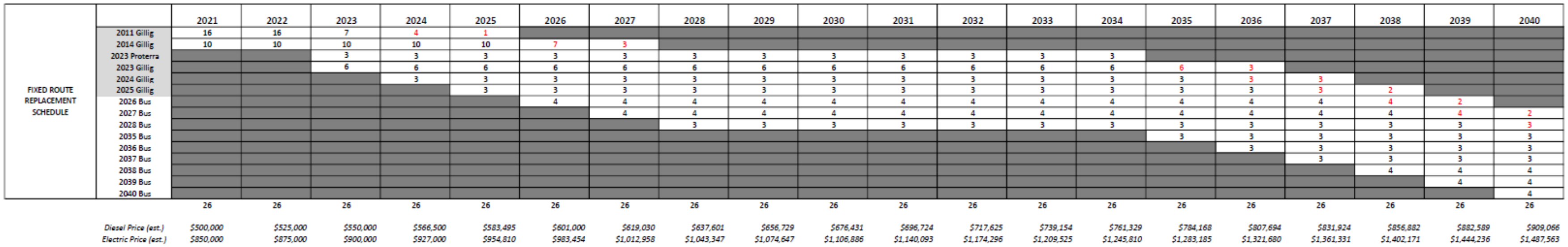
5.6.2 Consumables

As electrification proceeds, Topeka Metro’s consumption of fuel and lubricant will decrease in step with the program. Based on the fleet-replacement plan, Topeka Metro should prepare a plan for reducing any of its standing orders or contracts and drawing down inventory to the minimum safe level. This plan should be adjusted as the electrification plan is adjusted. There should be a plan for disposing of the remaining inventory when the fleet is fully electrified (e.g., transferring the residue to the City or, where practical, returning it to the vendor for credit).

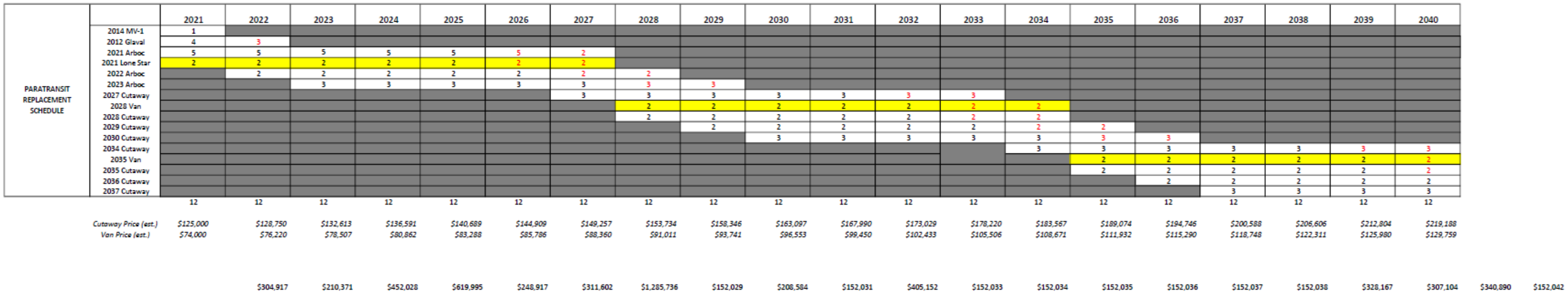
5.6.3 Spare Parts

As electrification proceeds, Topeka Metro’s need for spare power-train parts will also change. A plan for disposing of unneeded (but valuable) spare parts should be prepared, and contracts with buyers arranged.

Appendix A – Original FR Fleet Replacement Plan Provided by Topeka Metro



FIXED ROUTE REPLACEMENT SCHEDULE		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
	2011 Gillig	16	16	7	4	1															
	2014 Gillig	10	10	10	10	10	7	3													
	2023 Proterra			3	3	3	3	3	3	3	3	3	3	3	3						
	2023 Gillig			6	6	6	6	6	6	6	6	6	6	6	6	6	3				
	2024 Gillig				3	3	3	3	3	3	3	3	3	3	3	3	3	3			
	2025 Gillig					3	3	3	3	3	3	3	3	3	3	3	3	3	2		
	2026 Bus						4	4	4	4	4	4	4	4	4	4	4	4	4	2	
	2027 Bus							4	4	4	4	4	4	4	4	4	4	4	4	4	2
	2028 Bus								3	3	3	3	3	3	3	3	3	3	3	3	3
	2035 Bus															3	3	3	3	3	3
	2036 Bus																3	3	3	3	3
	2037 Bus																	3	3	3	3
	2038 Bus																		4	4	4
	2039 Bus																			4	4
	2040 Bus																				4
		26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
	Diesel Price (est.)	*$500,000*	*$525,000*	*$550,000*	*$566,500*	*$583,495*	*$601,000*	*$619,030*	*$637,601*	*$656,729*	*$676,431*	*$696,724*	*$717,625*	*$739,154*	*$761,329*	*$784,168*	*$807,694*	*$831,924*	*$856,882*	*$882,589*	*$909,066*
	Electric Price (est.)	*$850,000*	*$875,000*	*$900,000*	*$927,000*	*$954,810*	*$983,454*	*$1,012,958*	*$1,043,347*	*$1,074,647*	*$1,106,886*	*$1,140,093*	*$1,174,296*	*$1,209,525*	*$1,245,810*	*$1,283,185*	*$1,321,680*	*$1,361,331*	*$1,402,171*	*$1,444,236*	*$1,487,563*



PARATRANSIT REPLACEMENT SCHEDULE		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040		
	2014 MV-1	1																					
	2012 Glaval	4	3																				
	2021 Arboc	5	5	5	5	5	5	2															
	2021 Lone Star	2	2	2	2	2	2	2															
	2022 Arboc		2	2	2	2	2	2	2														
	2023 Arboc			3	3	3	3	3	3	3													
	2027 Cutaway							3	3	3	3	3	3	3									
	2028 Van								2	2	2	2	2	2	2								
	2028 Cutaway								2	2	2	2	2	2	2								
	2029 Cutaway									2	2	2	2	2	2	2							
	2030 Cutaway										3	3	3	3	3	3	3						
	2034 Cutaway														3	3	3	3	3	3	3		
	2035 Van															2	2	2	2	2	2		
	2035 Cutaway															2	2	2	2	2	2		
	2036 Cutaway																2	2	2	2	2		
	2037 Cutaway																	3	3	3	3		
		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		
	Cutaway Price (est.)	*$125,000*	*$128,750*	*$132,613*	*$136,591*	*$140,689*	*$144,909*	*$149,257*	*$153,734*	*$158,346*	*$163,097*	*$167,990*	*$173,029*	*$178,220*	*$183,567*	*$189,074*	*$194,746*	*$200,588*	*$206,606*	*$212,804*	*$219,188*		
	Van Price (est.)	*$74,000*	*$76,220*	*$78,507*	*$80,862*	*$83,288*	*$85,786*	*$88,360*	*$91,011*	*$93,741*	*$96,553*	*$99,450*	*$102,433*	*$105,506*	*$108,671*	*$111,932*	*$115,290*	*$118,748*	*$122,311*	*$125,980*	*$129,759*		
			$304,917	$210,371	$452,028	$619,995	$248,917	$311,602	$1,285,736	$152,029	$208,584	$152,031	$405,152	$152,033	$152,034	$152,035	$152,036	$152,037	$152,038	$328,167	$307,104	$340,890	$152,042