Fuels/Technologies Screening – Fuel/Technology Screening Report

Facilities and Fleet Transition Plan

August 2024 | **FINAL**

Contents

List of Tables

List of Figures

Acronyms

ATU	Amalgamated Transit Union
BEB	battery electric bus
CBA	collective bargaining agreement
CHNG	compressed natural gas
CO_2	carbon dioxide
CRMF	Commuter Rail Maintenance Facility
DHEB	diesel hybrid electric bus
DUS	Denver Union Station
EPA	U.S. Environmental Protection Agency
EV	electric vehicle
FCEB	fuel cell electric bus
FFTP	RTD Low and No Emission Facilities and Fleet Transition Plan
FOA	Funding Opportunity Announcement
FTA	Federal Transit Administration
GHG	greenhouse gas
GVWR	Gross Vehicle Weight Rating
H2	hydrogen
HDRD	hydrogenation-derived renewable diesel
HVAC	heating, ventilation, and air conditioning
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
MW	megawatt
NOFO	Notice of Funding Opportunity

NOx	nitrogen oxides
OEM	original equipment manufacturer
O&M	operations and maintenance
PM	particulate matter
PVR	peak vehicle requirement
RNG	renewable natural gas
RTD	Regional Transportation District
SC	Steering Committee
scf	standard cubic feet
SMR	steam methane reforming
SOP	System Optimization Plan
WG	Working Group
ZE	zero emission
ZEB	zero emission bus

1. Executive Summary

This chapter provides an executive summary of the **Fuel/Technology Screening Report**, including an overview of the Facilities and Fleet Transition Plan (FFTP) and the purpose of this report. This chapter also summarizes the key findings of this report, presents the recommendations resulting from the Fuel/Technology Screening Workshop, and identifies the next steps planned for Phase 2.

1.1 Project Overview

The Regional Transportation District (RTD) is currently planning the transition of its facilities and fleet to low- and no-emission fuels/technologies (also referred to as zero emission [ZE] fuels/technologies). This effort is pursuant to the RTD Board's authorization to evaluate pathways to achieving net ZE for RTD's facilities and fleet by 2050. RTD's transition to alternative fuels/technologies will improve air quality in the RTD service area, make the RTD system more environmentally sustainable, and improve the overall experience for RTD's riders and the region.

To achieve the 2050 goal, RTD is developing the FFTP, a framework and technical vision to guide the agency in transitioning its fixed-route fleet to alternative fuels. The FFTP consists of two corresponding plans. The first, the Facilities Transition Blueprint (Blueprint), is a comprehensive document that details the strategy and actions that RTD should take to meet the 2050 goal. The second, the ZE Fleet Transition Plan (FTA Plan), is a Federal Transit Administration (FTA)-compliant plan that enables RTD to pursue certain federal bus and infrastructure funding opportunities.

The FFTP is being developed in two distinct phases. Phase 1 involved the initial screening analysis of five alternative fuels/technologies that RTD is considering to meet the 2050 goal. Phase 1 consisted of independent screening reports evaluating each alternative fuel/technology based on its respective impact to fleet, facilities, workforce and training, costs, and emissions. At the conclusion of Phase 1, RTD staff determined which two fuels/technologies are the most ideal for RTD's future facilities and fleet. Phase 2 (Facilities and Fleet Transition Plan) involves developing tailored technical plans (advancing Phase 1 reports) for the two selected fuels/technologies, ultimately culminating with the Blueprint and FTA Plan, thereby positioning RTD to begin the process of meeting its 2050 goal.

1.2 Report Purpose

This report represents the last deliverable of the Phase 1 project and summarizes the technical analyses completed to date. It also documents the technology screening process, which involved comparing impacts associated with each fuel/technology choice, and input received from RTD staff at the Fuel/Technology Screening Workshop, which guided the final selection of the preferred fuel/technology.

1.3 Fuel/Technology Screening Summary

All Phase 1 subject-specific technical reports were completed and encapsulated into a system level comparison reflecting level of impacts assuming the whole fleet will fully transition into each of the alternative fuels/technologies. The project team presented the key findings to RTD staff during the in-person Fuel/Technology Screening Workshop and collected staff input and assessments. The project team also led smaller roundtable discussions to gather further feedback from various operating functions. The report findings and workshop discussions resulted in the recommendation of a two-phase transition schedule that first focuses on the replacement of diesel buses with diesel hybrid electric buses, paired with the expansion of battery electric bus (BEB) deployment. The plan also recommends using renewable diesel, as available, to further assist with greenhouse gas reductions in alignment with ZE goals. The next phase of the transition schedule, which serves long-term considerations, will explore transition to an all BEB fleet or potentially a mixed BEB and fuel cell electric bus (FCEB) fleet.

1.3.1 Fuels/Technologies Discussion

The following key themes emerged from the one-day screening workshop:

- Hydrogenation-derived renewable diesel (HDRD, or renewable diesel) is viewed as a bridging fuel/technology that should be used as soon as possible if supply is available. It is also generally recognized as a short-term strategy due to its high cost and inability to eliminate localized emissions. There is concern about its availability given that only one supplier has been identified in Wyoming.
- Compressed natural gas (CNG) buses are also viewed as a potential bridging fuel/technology for potential future transition to FCEB to achieve the best environmental benefits. At the same time, Maintenance staff is concerned about maintenance practices, safety, and space limitations based on previous experience with CNG buses. The transition to CNG buses would also require significant changes to RTD's facilities, and staff felt the environmental benefit realized through the conversion to CNG buses was not great enough to warrant the level of effort and costs needed to transition to the technology.
- Most consider diesel hybrid electric buses (DHEBs) a short-term strategy to achieve some emission reductions while the technologies for BEB and FCEB continue to grow.
- FCEB is the only technology with zero tailpipe emissions and limited impact on service delivery. However, it is also the technology with the most uncertainties, and the upstream production is frequently neither green nor cheap with the current supply chain, depending on production method.

With state and federal support for green hydrogen production, staff were optimistic that the market will improve over time.

- BEBs have demonstrated their advantage in emissions reduction, with a power source—electricity—that is readily available. However, staff were concerned about the costs, challenges of service scheduling, and impacts on the future RTD workforce. Staff raised concerns about being unable to meet a 1:1 replacement ratio, prompting several suggestions to pursue a mixed-technology fleet.

1.3.2 Recommendations

Workshop discussions clearly showed that a two-phased approach defining both short-term and long-term strategies is warranted given that the future of BEBs, and especially FCEBs, remains unclear and volatile. Recommendations for near-term actions and long-term considerations include:

Near-term (2025–2035): Focus on deploying BEBs where they make sense and use DHEBs to replace existing diesel buses. This involves:

- Providing annual updates to the FFTP to reflect any fuel/technology and market updates.
- Replacing existing diesel buses with DHEBs to claim some environmental benefits and integrate the use of renewable diesel, if feasible, when available.
- Increasing the BEB fleet to the maximum extent possible based on infrastructure and service requirements.
- Considering a FCEB pilot.
- Planning for and potentially acquiring properties for long-term goals(s).
- Exploring facility improvements implementable in the near-term that facilitate emission reduction, such as on-route charging infrastructure and facility energy efficiency improvements.

Long-term (2036–2050): Consider BEB fleet and/or FCEB fleet. This involves:

- Providing annual updates to the FFTP to reflect any fuel/technology and market updates.
- Providing an expanded BEB fleet or a mixed BEB and FCEB fleet as the current goal for the future fleet.
- Replacing DHEBs with BEBs and/or FCEBs if the respective fuels/technologies have matured to an appropriate degree.
- Increasing the DHEB fleet if both technologies fail to mature at the expected rate.

1.4 Next Steps

This report marks the completion of Phase 1. The project team has initiated Phase 2 work and will develop a work plan that reflects the two-phase planning strategy. Anticipated work to be completed in Phase 2 includes:

- Refining the on-route charging analysis
- Conducting utility coordination
- Analyzing facilities, designing, and developing a concept that reflects the recommendations
- Developing the transition schedule and fleet procurement plan in alignment with the two transition phases
- Updating the Workforce and Training Plan
- Updating the Emissions Analysis
- Updating the Lifecycle Costs and Funding Plan
- Developing the final Facilities Transition Blueprint and FTA Fleet Transition Plan

2. Introduction

- The chapter provides an overview of the Facilities and Fleet Transition Plan (FFTP) process, including the phases that constitute the FFTP process, each Phase 1 report, and the purpose of this report.

2.1 Project Overview

The Regional Transportation District (RTD) is currently planning the transition of its facilities and fleet to low- and no-emission fuels/technologies (also referred to as zero emission [ZE]) fuels/technologies). This effort is pursuant to the RTD Board's authorization to evaluate pathways to achieving net ZE for RTD's facilities and fleet by 2050. RTD's transition to alternative fuels/technologies will improve air quality in the RTD service area, make the RTD system more environmentally sustainable, and improve the overall experience for RTD's riders and the region.

To achieve the 2050 goal, RTD is developing the FFTP, a framework and technical vision to guide the agency in its transition to alternative fuels. The FFTP consists of two corresponding plans. The first, the Facilities Transition Blueprint (Blueprint), is a comprehensive document that details the strategy and actions that RTD should take to meet the 2050 goal. The second, the ZE Fleet Transition Plan (FTA Plan), is a Federal Transit Administration (FTA)-compliant plan that enables RTD to pursue certain federal bus and infrastructure funding opportunities.

The FFTP is being developed in two distinct phases. Phase 1, which is the focus of and summarized in this report, involved the initial screening analysis of five alternative fuels/technologies that RTD is considering to meet the 2050 goal. Phase 1 consisted of independent screening reports evaluating each alternative fuel/technology based on its respective impact to RTD's fleet, facilities, workforce and training, costs, and emissions. At the conclusion of Phase 1 (June 2024), RTD staff determined the two fuels/technologies that best meet the 2050 goal, with consideration of the impacts that they would have on the aforementioned categories. The preferred fuels/technologies will now be carried into Phase 2 (Facilities and Fleet Transition Plan), which will focus on the development of tailored technical plans that provide the framework for design and implementation. Phase 2 will conclude with the development of RTD's Blueprint and FTA Plan, two documents that position RTD to begin taking steps to meet its 2050 goal. The following subsections summarize the purpose and associated reports of each phase.

2.1.1 Phase 1 – Fuels/Technologies Screening

Phase 1 focused on providing RTD with a general understanding of the impact of transitioning its existing (predominant) fuel, diesel, to five low- and no-emission fuels/technologies: renewable diesel, diesel-hybrid, battery-electric, compressed natural gas (CNG), and hydrogen. Each potential fuel/technology was assessed with special consideration of RTD's existing and proposed fixed-route service and operations and is documented in subject-specific reports, summarized as follows (each report is available in its entirety in an appendix):

- **Fleet Report (Appendix A):** Assessed the impact that each evaluated fuel/technology would have on RTD's service and fleet.
- **Facilities Report (Appendix B):** Established the existing conditions for each RTD bus facility and identified opportunities and challenges to accommodate each evaluated fuel/technology.
- **Facility Siting Report (Appendix C):** Evaluated various RTD-owned parcels and their suitability to support future bus facilities.
- **Emissions Report (Appendix D):** Estimated RTD's Scope 1 and Scope 2 emissions across all facilities and identified strategies to reduce them.
- **Workforce and Training Report (Appendix E):** Identified the training requirements and impacts to personnel for each evaluated fuel/technology.
- **Costs Report (Appendix F):** Calculated the initial rough order of magnitude costs of a facility and fleet transition for each evaluated fuel/technology.

Between September 2023 and June 2024, the project team conducted technical analyses to inform the development of the Phase 1 reports referenced previously. The project team delivered Phase 1 technical reports to RTD between April and July 2024. Workshops with the project team and RTD staff preceded each report submission. Workshops focused on the methods and general findings of each analysis. On June 26, 2024, a Fuel/Technology Screening Workshop was held to summarize the Phase 1 findings and provide staff with a forum to ask questions and offer comments, ultimately informing a collective recommendation on the fuels/technologies most viable to meet RTD's goals.

The fuels/technologies that were selected will be advanced into Phase 2, where more detailed plans will be developed. Phase 1 concludes with a comprehensive **Fuel/Technology Screening Report** (this report) summarizing the technical reports, fuel/technology selection process, and fuels/technologies that will be advanced to meet RTD's goal.

2.1.2 Phase 2 – Facilities and Fleet Transition Plan

In Phase 2, the project team will refine technical reports from Phase 1 into specific plans that inform the Blueprint and FTA Plan. Phase 2 plans will be summarized and collated to develop RTD's Blueprint, which will be a living document that RTD will continually update as market factors, funding, and directions change. The FTA Plan will be largely derived from the Blueprint and focus on the six FTA-required ZE Transition Plan elements. The FTA Plan will position RTD to immediately begin to apply for various federal grants to support facility and fleet low- and no-emission upgrades. The following plans will be developed in Phase 2:

- **Facilities Plan:** Provides conceptual plans for RTD's facilities, along with construction and phasing plans.
- **Design Criteria:** Establishes the design criteria for the Facilities Plan.

- **Fleet Procurement Plan:** Presents a procurement strategy that aligns with the Facilities Plan and RTD's 2050 goal.
- **Workforce and Training Plan:** Refines the Workforce and Training Report from Phase 1 based on the two selected fuels/technologies.
- **Lifecycle Costs and Funding Plan:** Details lifecycle costs for the future fleet, including estimated capital, operations and maintenance, and monetized environmental costs associated with the transition. This plan also assesses funding opportunities that should be pursued.

2.2 Report Purpose and Structure

This report summarizes the technical analyses, including the approach, existing conditions, and findings of each respective report developed in Phase 1. It also provides an overview of the processes that were taken to determine the preferred fuels/technologies, ultimately concluding Phase 1. The following summarizes each subsequent section and what it provides.

- **Introduction:** Project background and report goals.
- **Existing Conditions:** Current service and fleet information.
- **Approach:** Overview of the alternative fuels/technologies considered and the inputs and assumptions used in the technical analyses.
- **Findings:** Comparison of scale of impacts associated with each alternative fuel/technology.
- **Fuel/Technology Screening:** Review of inputs received from the Fuel/Technology Screening Workshop and recommendations formed.

3. Existing Conditions

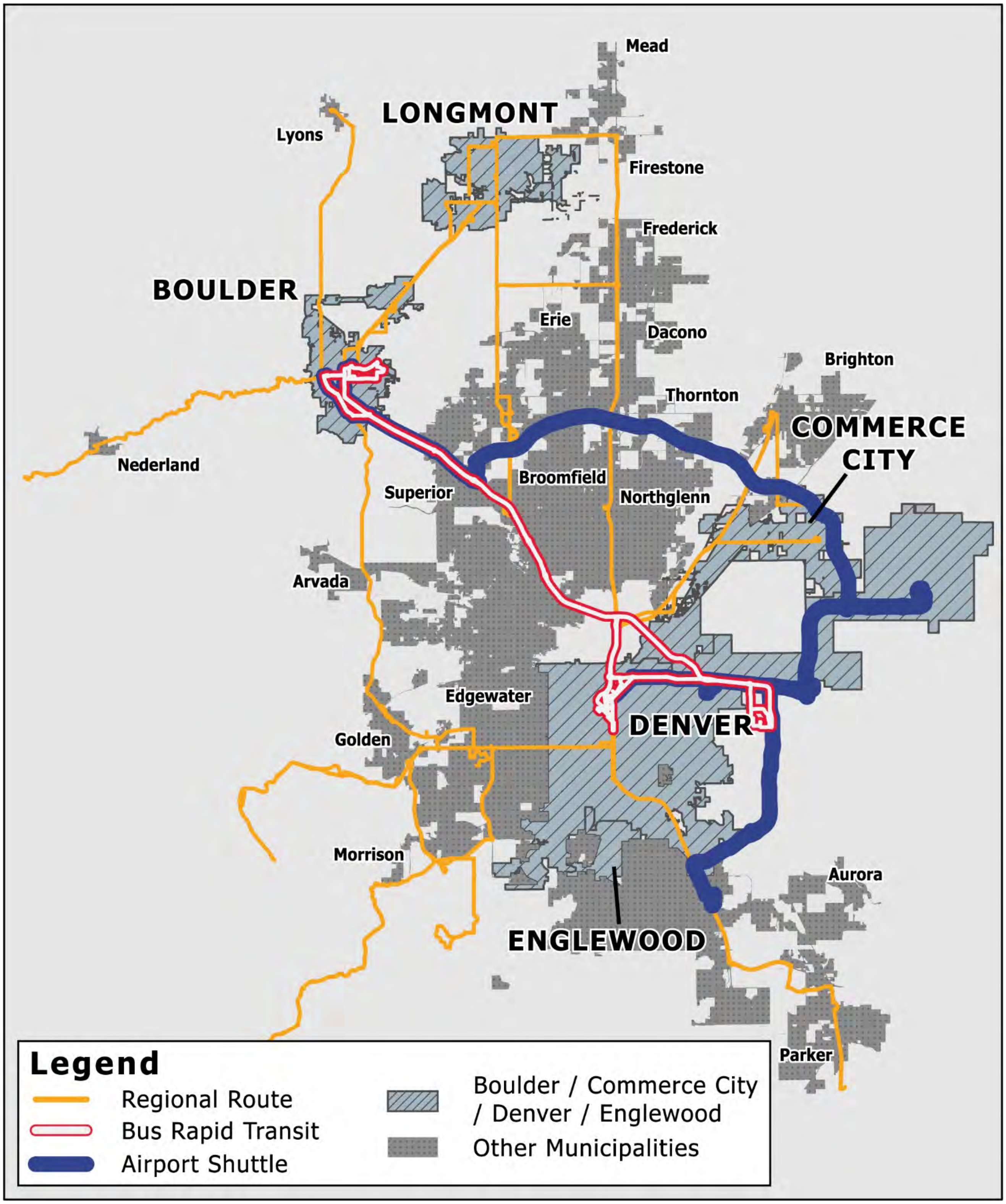
- The following chapter summarizes the existing conditions used as the baseline for Phase 1 analyses.

3.1 Service

Excluding the BEBs used for the MallRide service, RTD's current service is operated with diesel buses; therefore, diesel buses were used as a baseline for comparison with the evaluated fuels/technologies. Low-/no-emission bus fuels/technologies are subject to different consumption rates, and because some have limitations on onboard fuel/energy capacity, they have less range than that of diesel buses. When transitioning to these technologies, it is important to understand current service conditions and to determine the extent of infeasibility (due to range limitations) and the mitigation measures to achieve feasibility.

RTD provides public bus and rail transit service to one of the largest transit service areas in the United States (see **Figure 3-1**). With a service area of more than 2,342 square miles, the District serves a population of over 3 million within 40 municipalities in 6 counties, plus 2 city/county jurisdictions. The size of the service area, population density, and nature of the roadway network have led to the creation of a transit system with a wide range of service types intended to serve this large and diverse region most effectively. This study focuses on weekday fixed-route bus service and excludes specialized services (such as FlexRides) and rail, which is already completely electrified.

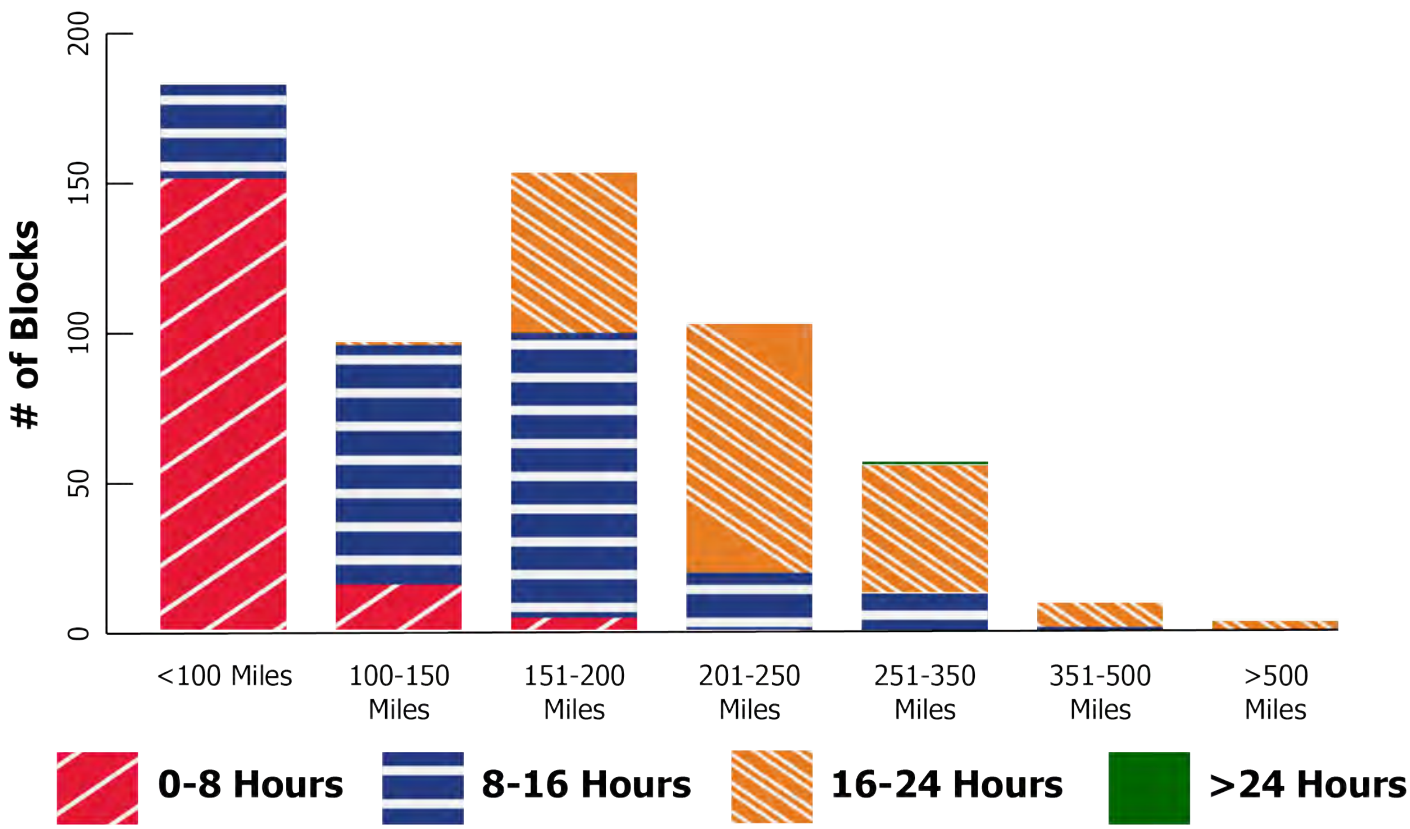
Figure 3-1. RTD Bus System Map



Source: RTD, WSP USA, Inc.

The study evaluated RTD's current runboard at the time of project initiation—the September 2023 runboard. The runboard included 594 service blocks for weekday service. RTD's service blocks represent sequences of trips assigned to each single bus. Service blocks vary by length, duration, and number of stops and facilities served. A substantial number of service blocks are relatively long, both in terms of duration (hours) and accumulated mileage. Fifty-four percent of service blocks are longer than 150 miles, and 58 percent operate for more than 12 hours (**Figure 3-2**). Virtually all existing service blocks can be operated by a diesel bus without refueling. However, BEBs in the market now have approximately up to a 150-mile range. Thus, even without detailed service modeling, it is already apparent that a single BEB cannot operate many of RTD's current service blocks without adding energy (charging) during service. It is also apparent that some current service blocks are also too long to be operated by a CNG bus (350-400 miles in range) or an FCEB (approximately 300 miles in range) without refueling.

Figure 3-2. RTD Current Service – Service Block Duration and Distance



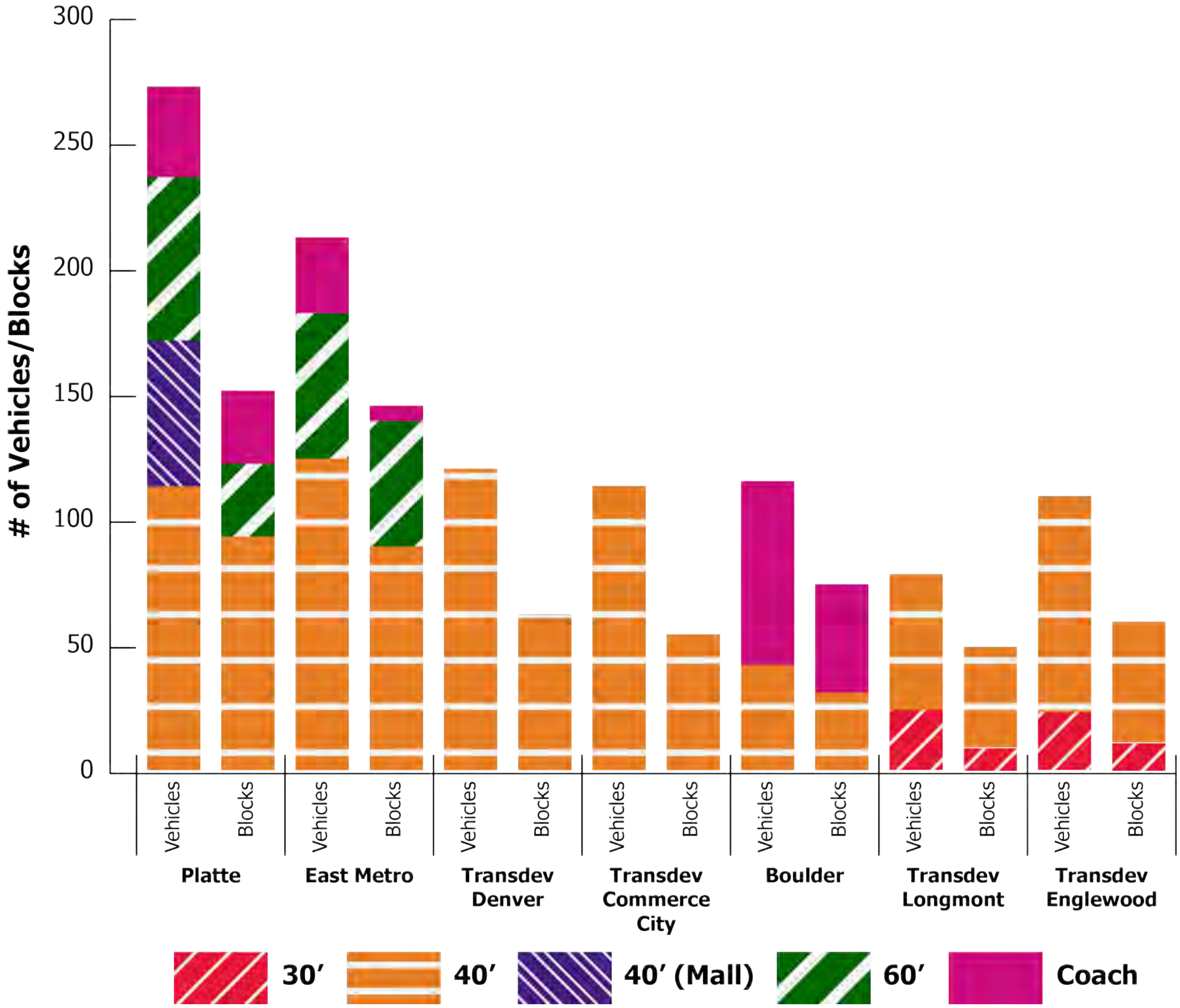
Source: RTD, September 2023

The relatively long service block lengths, both in time and distance, result in a relatively flat daily service profile. A flat daily service profile means that most buses do not return to the facility mid-day; they typically operate for the vast majority of a service day. This type of service offers limited opportunities for mid-day refueling/charging at the facilities, which may be necessary for some alternative fuel vehicles, especially BEBs. The **Fleet Report (Appendix A)** examines the existing RTD services and block features.

3.2 Fleet

The current fixed-route fleet comprises 30-foot, 40-foot, and 60-foot diesel transit buses; 45-foot diesel coach buses; and 45-foot BEBs used exclusively for the downtown MallRide. **Figure 3-3** shows the number of assigned buses and service blocks operated by bus type (length) at each facility. Not all assigned vehicles are currently in active use, largely due to service contraction during the COVID pandemic and RTD's plan to right-size the fleet to align with System Optimization Plan (SOP) service. Currently, the fleet consists of 1,019 buses, and with the implementation of the SOP, the fleet will eventually be reduced to accommodate the levels of service included in the SOP. Note that not all of RTD's vehicle types are currently available for each fleet technology, and for some that are, such as battery-electric coaches, there are impacts to undercarriage storage capacity on the vehicle.

Figure 3-3. Number of Vehicles and Service Blocks by Facility



Source: RTD, September 2023

3.3 Facilities

RTD operates fixed-route service out of seven bus facilities. Transdev is contracted to operate service out of four of the seven facilities, operating approximately 38 percent of the service blocks as of September 2023. **Table 3-1** summarizes RTD's bus facilities (and service blocks). The **Facilities Report (Appendix B)** provides a comprehensive review of each RTD bus facility.

Table 3-1. Summary of RTD's Bus Facilities

Facility	Operator	Address	# of Service Blocks
Boulder	RTD	1707 Exposition Drive, Boulder, CO 80301	74
Platte	RTD	333 Ringsby Court, Denver, CO 80216	151
East Metro	RTD	14100 East Colfax Avenue, Aurora, CO 80011	145
Commerce City	Transdev	6345 Colorado Boulevard, Commerce City, CO 80022	54
Broadway	Transdev	6345 Broadway Avenue, Denver, CO 80216	62
Longmont	Transdev	811 S. Sherman Street, Longmont, CO 80501	49
Englewood	Transdev	2775 S. Vallejo Street, Englewood, CO 80110	59

Source: RTD, September 2023

3.4 Emissions

Collectively, tailpipe emissions from RTD's diesel and gasoline fleet generate 95,564 tons of carbon dioxide (CO_2), making up 55 percent of RTD's total CO_2 emissions. The majority results from the diesel fleet: transit, articulated, and intercity coaches account for 73 percent of the total non-electric vehicle (EV) fleet and 86 percent of fleet emissions. FlexRide and paratransit vehicles (cutaways) account for 27 percent of the total non-EV fleet and 14 percent of fleet emissions (**Table 3-2**). Charging electricity emissions from RTD's 36 mall buses are included under Platte Division's facility emissions. RTD buses represent less than 2 percent of overall greenhouse gas (GHG) emissions in RTD's service area and have a significant, positive impact on the surrounding environment by replacing single-occupancy vehicle trips with transit trips.

Table 3-2. Fleet Emissions

Fleet	No. of Vehicles	Annual Fuel Use (Gallons)	Fuel Type	Annual Petroleum Use (Barrels)	Annual CO_2 Emissions (Tons)	Annual CO_2 Emissions (%)
Transit, Articulated, Coach	983	5,950,073[1]	Diesel	148,031	81,915	86%
Cutaway	370	1,155,309[2]	Gasoline	23,937	13,649	14%
—	—	—	—	**Total**	**95,564**	**100%**

1. Monthly average values from October 2022 to September 2023
2. Paratransit and FlexRide average monthly values from January 2023 to December 2023

Source: RTD, AFLEET Outputs

All facilities account for 17 percent of RTD's emissions: 7.4 percent are Scope 1 emissions[1] from natural gas use, and 9.3 percent are Scope 2 emissions[2] from electricity and steam use. Seven facilities—East Metro Division, District Shops, Commuter Rail Maintenance Facility (CRMF), Platte Division, Denver Union Station (DUS) Bus Concourse, Boulder Division, and Elati Rail—collectively account for 84 percent of total facility emissions. This, coupled with the site assessments, suggests that these facilities offer the most significant potential for energy savings. Maintenance facilities with large indoor bus areas—East Metro Division, Platte Division, and Boulder Division—have the highest overall emissions compared to other facility types due to their size and high natural gas consumption.

The remaining 28 percent of emissions result from commuter rail vehicles and light rail vehicles. The **Emissions Report (Appendix D)** provides more details on GHG emissions at the site level and identifies opportunities for emission reduction.

3.5 Workforce

Operations and Maintenance are the main roles affected by a transition to alternative fuels/technologies roles. Collectively, RTD and Transdev have 1,387 Bus Operators and 225 General Repair Mechanics. **Table 3-3** summarizes the current staffing levels for these and other critical roles under Operations and Maintenance functions.

Table 3-3: Staff Numbers for Selected Critical Roles

Staff Role	# of Staff (RTD and Transdev)
Bus Operators (Full-time + Part-time)	1,387
Street Supervisors	65
Dispatchers	42
Station Starters	4
Division Supervisors	24
General Repair Mechanics	225
Facilities Maintenance Technician	67

Source: RTD and Transdev Organizational Charts and Staffing Spreadsheets

[1] Scope 1 emissions refer to direct GHG emissions from sources that are controlled or owned by an organization, such as fleet tailpipe emissions and natural gas use at facilities.
[2] Scope 2 emissions refer to indirect GHG emissions resulting from the generation of purchased energy, including electricity and steam use at facilities and electricity use by rail vehicles.

Table 3-4 shows the current initial and promotional training that the aforementioned roles receive.[3] Note that Transdev training information was not available when this report was developed.

Table 3-4: Current Initial and Promotional Training for Selected Critical Roles

Staff Role	Initial Training (days)	Promotional Training (days)
Bus Operators (Full-time + Part-time)	60	—
Operator Trainers	60	—
Street Supervisors	—	25
Dispatchers	—	30
Station Starters	—	30
Division Supervisors	—	13
Lead Division Supervisors	—	13
General Repair Mechanics	75	—
Facilities Maintenance Technician	—	—

Source: RTD documents, Discussions with RTD staff

The **Workforce and Training Report (Appendix E)** further explains the staff levels, training, and roles.

Assessing the staffing levels and training needed for a successful transition requires a sufficient understanding of current operations. The following are considered items worthy of note:

- Virtually all buses are diesel powered except the MallRide, which uses BEBs operated from Platte. The reliability of the BEB buses is a known issue.
- Operators drop off buses after service. Maintenance personnel carry out all "back-office" operations, including fare box, cleaning, servicing, refueling, maintenance, and repair.
- Current RTD training:
    - Operations training is delivered in-house and is well-organized. RTD Bus Operators receive 12 weeks of training. Many other operational roles require new recruits to have been a Bus Operator.
    - 50 to 52 days of in-house Mechanic training but this training is inconsistently tracked. An apprenticeship is being developed with the Amalgamated Transit Union (ATU) for mechanics as a start and eventually will expand to other bus and rail functions.
    - There is no competence framework or formal training for Facilities Maintenance Technicians.

[3] Initial training includes training activities that develop core competences in new hires, while promotional training includes training activities that develop core competences in RTD employees who are promoted to other roles (e.g., a Bus Operator promoted to a Street Supervisor).

- Most bus original equipment manufacturers (OEMs) provide "train the trainer" training. Some provide maintenance services and take responsibility for corrective maintenance during warranty periods (as is the case for the Mall BEBs). Local institutions also offer trade-focused training and online training courses that allow RTD staff easy access for familiarization. RTD Transit Police have a capability to "push" training content.
- The current three-year RTD Collective Bargaining Agreement (CBA) is in effect through December 31, 2024. New negotiations are underway with ATU as of summer 2024. Three separate CBAs are in place for contracted service operators between Transdev and ATU.

3.6 Costs

RTD's current financial resources are an important consideration as the agency evaluates pathways to net ZEs by 2050. RTD currently has limited financial capacity to fund a new capital project of the magnitude of a facility and fleet transition. The bulk of existing fund balances controlled by RTD is either committed to operations and maintenance and maintaining a state of good repair on existing service or restricted by the Board in such a manner that funds cannot currently be used on a bus facility and fleet transition. For example, the FasTracks Internal Savings Account is a restricted fund that can be used only on projects that are part of the voter-approved FasTracks plan. Furthermore, RTD has no additional bonding authority and would require voter approval to change that. Due to a lack of available internal funding, implementation of any new bus technology will be dependent on acquiring reliable external funding to pay for a facility and fleet transition.

4. Approach

- The following chapter summarizes the inputs, assumptions, and approach used for each Phase 1 screening analysis (and report).

4.1 Overview

Phase 1 focused on providing RTD with an understanding of how five alternative fuels/technologies—renewable diesel, diesel hybrid electric buses, compressed natural gas, battery electric, and fuel cell electric—would impact existing fixed-route service and operating conditions. The following summarizes each evaluated fuel/technology:

- **Hydrogenation-derived renewable diesel (HDRD, or renewable diesel):** A drop-in replacement for diesel with no impacts on facility upgrades, operations, performance, and workforce. It offers a significant reduction in life cycle GHG emissions (62 percent less than ultra-low sulfur diesel) by using biomass feedstock rather than fossil fuels. The main challenge is the limited fuel availability in the United States, which also leads to a 34 percent increase in fuel costs compared to that of diesel. It is important to note that renewable diesel is chemically different from biodiesel but chemically the same as petroleum-derived diesel.
- **Diesel hybrid electric bus (DHEB):** DHEBs have a diesel engine and a small energy storage system that stores energy from regenerative braking, offering up to a 20 percent increase in range over diesel buses. The improved fuel economy means less fuel consumption, resulting in a reduction in fuel costs and environmental impacts. DHEBs can use either conventional diesel or renewable diesel, with environmental and cost implications depending on the preferred type. The capital cost is higher than that of conventional diesel buses, with minimal facility upgrades and workforce training required. The bus OEMs using diesel hybrid propulsion systems in North America are New Flyer and Gillig, with diesel hybrid options available on 35-foot, 40-foot, and 60-foot transit buses.
- **Compressed natural gas (CNG) bus:** CNG buses use a natural gas-fueled engine and high-pressure natural gas storage cylinders (opposed to liquid diesel fuel tanks), requiring a high-pressure fueling station for refueling. CNG buses can operate on either natural gas or biomass-derived renewable natural gas (RNG). They have a slightly shorter range than diesel buses, which could impact operations, and require significant facility upgrades, along with moderate workforce training. Capital costs are higher than those of diesel buses, but fuel prices are slightly lower. GHG reductions vary widely depending on the production method, but tailpipe emissions such as nitrogen oxides (NOx) and particulate matter (PM) 2.5 are significantly reduced. Currently, several CNG bus manufacturers are popular among U.S. agencies, such as New Flyer and Gillig.
- **Battery-electric bus (BEB):** BEBs replace traditional combustion engines with electric motors and batteries. Instead of a fuel tank, the battery acts as the power source for the motor, requiring periodic recharging with charging times varying by charger type. Due to limitations in onboard battery size, BEBs currently have significantly shorter ranges compared to conventional diesel buses. Mitigation strategies, such as strategic phasing for transition, service modifications, on-route charging installation, or diesel auxiliary heaters installation, could be considered to extend their

range and ensure service completion. Given the emerging nature of BEB technology, strategic phasing plays a crucial role in achieving service completion. It involves prioritizing the electrification of services that are most readily adaptable to electrification, allowing the technology to evolve and, consequently, provide better range and reliability in the future. The report also finds that adding diesel auxiliary heaters is crucial to improving completion rates during extreme winter conditions. Transitioning to BEB technology also requires significant facility upgrades and workforce training and is still substantially more expensive than that of conventional diesel. However, BEBs offer notable benefits, including eliminating tailpipe emissions and lower operational fuel costs compared to diesel buses. The GHG emissions reductions are impacted by the grid mix. Today's grid carbon intensity would result in BEBs having 60 percent lower carbon emissions than petroleum diesel. As Xcel's grid decarbonizes, there will be greater reductions in carbon emissions. Four bus manufacturers currently offer 35-foot and larger BEBs in the United States: BYD Motors (not Buy America compliant), Gillig LLC, GreenPower Motor Company Inc., and New Flyer of America Inc.

- **Fuel cell electric bus (FCEB):** The FCEB propulsion system consists of hydrogen fuel storage, a fuel cell, an electric motor, and an auxiliary battery pack. Hydrogen, a lighter-than-air gas, is stored in high-pressure storage cylinders on the vehicle, similar to CNG buses but at higher operating pressures. The fuel cell converts hydrogen fuel into electrical energy, powering the bus's propulsion via its motor and other ancillary systems. FCEBs are fully a ZE technology, emitting only water and heat as byproducts. However, the extent of GHG reductions depends on the hydrogen fuel's production method. Currently, FCEBs have an estimated 37 percent reduction in range compared to that of diesel buses, which may impact service completion.[4] They also require significant facility upgrades and workforce training and are substantially more expensive than diesel buses, both in terms of capital and fuel costs. FCEBs' primary advantages include their ZE capability and a better range than BEBs, which translates to less operational impact. However, hydrogen fuel is not currently available within Colorado. At this time, New Flyer is the only OEM that produces FCEBs in the U.S. market, offering two vehicle sizes: 40-foot and 60-foot.

Currently, RTD's fleet is mostly diesel buses; therefore, an all-diesel fleet was established as the baseline for analyses. A 100 percent conversion of each respective fuel/technology at each bus facility was assumed to clearly distinguish the required physical and operational changes and the extent of change to the diesel baseline.

Five distinct reports capture the impacts of change from the baseline to each analyzed respective fuel/technology: **Fleet Report** (**Appendix A**), **Facilities Report** (**Appendix B**), **Emissions Report** (**Appendix D**), **Workforce and Training Report** (**Appendix E**), **and Costs Report** (**Appendix F**). A technology-neutral **Facility Siting Report** (**Appendix C**) also evaluated existing RTD-owned parcels for their viability to support future bus facilities.

[4] Assuming a 475-mile range for a 40-foot diesel bus and a 300-mile range for a 40-foot FCEB.

Various stakeholders and data sources developed and informed each Phase 1 report. Internal stakeholders included the Steering Committee (SC) and the Working Group (WG). The SC, comprising RTD project managers and WSP project managers and task leads, monitored project status; identified barriers, challenges, issues, and opportunities for upcoming project tasks; and provided guidance for progression. The WG, made up of 50+ RTD staff members, represented all departments throughout the agency, including Finance, Bus Operations, Capital Programs, IT, Legal, Planning, Safety, and Service Development.

Together, the SC and WG provided data, insight, and general guidance to the project team task leads for each respective Phase 1 report/analysis—and will continue to do so in Phase 2. The following subsections summarize the approach for the report/analysis conducted in Phase 1.

4.2 Fleet Report

The **Fleet Report (Appendix A)** evaluated each alternative fuel/technology's impact on RTD's ability to meet service obligations and fleet requirements.

The ability to maintain existing—or planned—service without any impacts to the fleet is an essential consideration in selecting the optimal fuel/technology mix for the bus fleet. With that consideration, RTD identified two parameters to be factored into the fleet's transition plan. The first is to maintain a 1:1 vehicle replacement ratio when replacing existing diesel buses with alternative fuels/technologies. The second parameter is to ensure that the analysis aligns with the fleet needs of the near-term SOP and Denver Regional Council of Governments Regional Transportation Plan.

4.2.1 Service Modeling Analysis

The project team used its energy model and RTD-provided scheduling data (from the September 2023 runboard) and inputs to determine the portion of RTD's service that could be supported with alternative fuels/technologies. The service modeling analysis focused on service blocks, which are sequences of trips assigned to a single bus. The initial phase of the analysis involved estimating the amount of fuel/energy required to complete each service block (measured in gallons for diesel, kilowatts [kW] for BEBs, kilograms [kg] of hydrogen for FCEBs, and standard cubic feet [scf] of natural gas for CNG buses). Understanding this fuel/energy demand is vital to determining the number of service blocks a single BEB, FCEB, or CNG bus can complete on one charging or fueling session, taking into account the capacity of the battery or fuel tank. Currently, diesel buses (and DHEBs) have no range impacts; therefore, mitigation measures are not required to maintain a 1:1 replacement ratio.

Service Completion Rate

For any failing/incomplete service block due to insufficient range, the analysis determined the extent of the fuel/energy shortfall and proposed preliminary solutions. Depending on the specific reasons preventing service completion, various mitigation strategies can be considered to ensure that RTD maintains its service level and can effectively adapt to the operational changes necessitated by the introduction of different fuel/technology types.

The service completion analysis considered many factors that impact fuel/energy use on a given service block: the length and duration of the service block; heating, ventilation, and air conditioning (HVAC) usage; route elevations; stop frequency; and regenerative braking. The project team analyzed BEBs, whose total energy is significantly impacted by HVAC demands, under two scenarios (extreme summer and winter temperature conditions) to assess the highest energy requirements for cooling and heating, respectively. The team based the selected temperatures on previous historical data of extreme weather conditions in RTD's service area. It was assumed that the ambient temperature is a constant (remains the same for the duration of the service blocks); thereby, providing a fairly conservative outlook on potential block completion.

In contrast, FCEBs and CNG buses use excess heat from their engine systems for cabin warming, and their net energy use is less impacted by cold winter temperatures. Therefore, the analysis for FCEBs and CNG buses focused on the summer extreme scenario, with results extrapolated from the BEB modeling, adjusted for fuel energy content and differences in system efficiency.

Assumptions used in the service modeling analysis for BEB, FCEB, and CNG buses were based on models currently available on the market. Usable fuel and battery capacities and the effects of regenerative braking are based on industry experience, while battery degradation impacts were aligned with OEM standard warranties. While DHEBs, BEBs, and FCEBs are equipped with regenerative braking from their electric motors, CNG buses are not. As a result, net energy reductions from regenerative braking were not included in CNG service modeling. To provide conservative estimates, it was assumed buses operate at maximum load (captured by Gross Vehicle Weight Rating/GVWR), resulting in higher energy consumption rates.

Currently, limited bus sizes are available in the market for BEBs and FCEBs. Therefore, blocks currently assigned to unavailable bus sizes were reassigned to available vehicle sizes. For BEBs, the 30-foot blocks were assigned to 35-foot BEBs, while for FCEBs, the 30-foot and 45-foot coach bus blocks were assigned to 40-foot FCEBs. Additionally, given the rapid development of BEB technology, a future technology service analysis assumed a 30 percent improvement in battery capacity and range by 2030, which is a conservative estimate based on current trends.

Mitigation Strategies

Various mitigation strategies are available to address service blocks that cannot be completed by a given fuel/technology. Strategies include strategic phasing (timing of bus procurements and infrastructure construction), service modifications, fleet expansion, and specifically for BEBs, integration of mid-day and on-route charging, and use of diesel auxiliary heaters in cold weather. Given the emerging nature of BEB technology, strategic phasing plays a crucial role in achieving service completion. It involves prioritizing the electrification of services that are most readily adaptable to electrification, allowing the technology to evolve and, consequently, provide better range and reliability in the future.

The BEB service modeling analysis, therefore, included further evaluations of these mitigation strategies. It included an analysis using increased battery capacity by 2030 to explore potential improvements in range and reliability. The impact of implementing on-route charging infrastructure on service completion was examined to understand potential benefits. The analysis also considered the effectiveness of diesel auxiliary heaters in ensuring service reliability under extreme winter conditions. The following subsections elaborate on the methodologies used in these analyses:

- **On-Route Charging Analysis:** On-route charging (sometimes referred to as opportunity charging) is a mitigation strategy that RTD may consider for improving service block completion for BEBs. On-route charging involves strategically installing fast chargers within the transit system, enabling BEBs to recharge in-service. This capability extends the BEBs' daily operational range and potentially increases the number of completed service blocks. Typically, these chargers are located at layover locations. Bus trips include scheduled stops at these locations for various purposes, including giving the operators a rest period, allowing schedule recovery if buses are delayed, or allowing field relief operator changes. Layover locations are usually at transit centers, which can be ideally suited to accommodate buses recharging while in service. The extent of energy a bus can replenish during a layover is directly influenced by the layover's duration and installed charging infrastructure. This preliminary analysis identified realistic opportunities for, and benefits of, on-route charging and involved several key steps. Additional analyses will be conducted in Phase 2.
- **Diesel Auxiliary Heaters:** Diesel auxiliary heaters can improve the service completion rate for BEBs by mitigating the HVAC system's energy demand during winter. Consequently, in this winter-extreme scenario, the energy consumption attributed to HVAC was excluded from the service model calculations, and the service completion rate was recalculated based on the revised total energy consumption. Given that this approach eliminated the HVAC load from the battery energy consumption, the service modeling showed better results when compared to the summer-extreme scenario, where the HVAC system was still required to cool the cabin.

Vehicle Replacement Ratio

The vehicle replacement ratio indicates the number of buses estimated to be required to replace a single diesel bus due to the range limitations of current technology. This metric is crucial for RTD's future fleet planning, encompassing financial, utility, space, and timing considerations. The baseline for this calculation is the current number of diesel buses necessary to cover the modeled service blocks (Peak Vehicle Requirement/PVR), with an additional 5 percent buffer to account for buses temporarily unavailable due to maintenance, cleaning, inspections, or other reasons (the PVR is not inclusive of RTD's 20 percent spare ratio). The PVR in this analysis was calculated for each vehicle type, such as 30-foot bus, 40-foot bus, etc., at each facility, with the 5 percent buffer added to each vehicle type, and then those were all summed to produce the overall PVR. The team calculated the number of additional vehicles by summing the estimated energy shortfall from all failing service blocks (service block completion analysis). The team then translated this total energy shortfall into the equivalent number of additional buses required, factoring in each bus's usable battery capacity or fuel tank size. This high-level planning approach may yield an optimistic ratio, and it relied on inputs and assumptions that, if changed, would likely change these exact predictions. A more detailed service planning exercise would likely entail reblocking service and other considerations.

4.3 Facilities Report and Facility Siting Report

The facility analysis, represented by the **Facilities Report (Appendix B)** and the **Facility Siting Report (Appendix C)**, evaluated existing bus facilities to understand the difficulty in implementing changes to each site necessitated by each evaluated fuel/technology. In addition, the team evaluated parcels and other sites that RTD can explore for future development to support transition.

4.3.1 Facilities Report

To determine the viability of adopting new fuels/technologies at each bus facility, the project team took the following three general steps as part of the **Facilities Report (Appendix B)**. They first established the existing conditions of each of the eight evaluated facilities (one being District Shops, RTD's maintenance facility). The previous Reimagine RTD project and the site visits conducted between February 5 and February 9, 2024, informed existing conditions. The project team then developed a basis of design for each assessed fuel/technology. The basis of design established the specific strategy and parameters used for each assessed fuel/technology at each facility (for example, assuming delivered hydrogen opposed to on-site generation). In the last step, the project team considered and applied various international and local codes to ensure that each assumed concept was not only technically viable but in compliance with regulations.

This assessment assumed a 100 percent conversion of each respective fuel/technology at each bus facility to clearly distinguish, and to what extent, the required physical and operational changes may be required if a fuel/technology was selected. Since RTD plans to operate a mixed fleet (up to two fuels/technologies), the resulting findings of this report are considered conservative. The specific fleet mix and more detailed site considerations will be determined in the Phase 2 Facilities Plan and Design Criteria.

The team compared facilities against each other to gain an approximate idea of the degree of difficulty to implement infrastructure to support fueling/charging infrastructure at each facility. This comparison involved four major categories:

- **Occupancy/Fire Resistance Rating Changes**: This category provides an understanding of the level of difficulty to upgrade an existing structure to accommodate a more stringent construction type/fire resistance rating. It directly results from the new 2024 International Building Code and International Fire Code requirements. This category has the largest impact on facilities that store and support BEBs and FCEBs.

- **Impacts of Defining Major/Minor Repair Bays**: While the National Fire Protection Association codes require Major and Minor Repair Bays to be defined, there are no significant code impacts unless CNG and Hydrogen (H2) fueled vehicles are involved. These modifications can be broadly summarized as physical separation of Major Repair Bays from other spaces, and independent mechanical ventilation tied to gas detection sensors. Meeting these requirements is easier to accomplish at certain facilities.
- **Difficulty in Locating Fueling Infrastructure**: This category summarizes the difficulties of placing the various fueling/charging infrastructures on the site, with consideration of 1) code restrictions, 2) infrastructure requirements, and 3) respecting on-site operational flow/circulation to avoid more drastic site construction issues.
- **Mechanical Ventilation and Electrical Zones**: This category summarizes the code-required mechanical ventilation needs, potential electrical hazard zones, and difficulty in implementing them at a given site.

4.3.2 Facility Siting Report

As RTD plans for the transition to alternative fuels/technologies, RTD has the opportunity to evaluate and optimize other aspects of its service and operations to better prepare for future demands. Given that RTD does not own four of the seven bus operating facilities, meeting the 2050 goal depends on the ability and willingness of other entities to adhere to and adopt RTD's vision. Because this represents a potential risk to meeting the goal, it is essential that RTD evaluates the possibility of building new bus facilities that they would own and operate.

The team completed the facility siting analysis, and the **Facility Siting Report (Appendix C)** presents the initial findings of parcels/properties that RTD can consider for future development. In Phase 2, parcels identified in this report will be further refined and evaluated with additional criteria. The evaluation will result in a "shortlist" of properties that RTD can explore further in the near future. These properties will be selected with consideration of RTD-vetted criteria, including deadhead distance, environmental justice and Title VI impacts, utility availability, road access, and environmental impacts. It should be noted that the properties identified in this report and subsequent reports are not prescriptive.

4.4 Emissions Report

The **Emissions Report (Appendix D)** evaluated all RTD facilities and fleet to determine the organization's Scope 1 and Scope 2 emissions. These metrics will be essential in estimating the reductions that each proposed strategy will have, a key factor in assessing RTD's ability to meet the 2050 goal.

The anticipated environmental impact resulting from transitioning to alternative fuels/technologies mostly depends on the chemical characteristics, fuel/energy generation, and vehicle performance of each corresponding fuel/technology. The **Emissions Report (Appendix D)** provided a comprehensive emissions analysis for current emissions, as well as estimates under each fuel/technology scenario. The team conducted site visits and collaborated with RTD and contractor facility operators to collect facilities and fleet data. While the fleet currently accounts for most of RTD's emissions—similar to the majority of transit agencies—the potential amount of fleet emissions that can be reduced (or eliminated) will be determined by the specific vehicle fuels/technologies selected at the conclusion of Phase 1. For this reason, the Emissions Report focused on emissions from facility operations, which also form a significant portion of RTD's GHG footprint. Phase 2 will provide estimates of the energy and cost savings potential of each strategy.

4.5 Workforce and Training Report

The **Workforce and Training Report (Appendix E)** aimed to determine the required staffing levels and training requirements for each evaluated fuel/technology.

To determine these metrics, the team developed a baseline understanding of existing workforce, roles, competences, and training by interviewing RTD staff and assessing relevant data on the subject. For each evaluated fuel/technology, the team identified affected roles and defined new required competences. Any net increase in staffing levels was assessed, being driven by changes in either working practices or volume of work (larger fleet size, more blocks, more platform miles).

The team used both the changes in competencies for existing staff and the changes in staff numbers (including for attrition) to aggregate the total training required to switch to each fuel/technology type.

The Workforce and Training analysis started with the project team understanding the current organization and training undertaken based on reviewing the data provided and supplemented by interviews with RTD staff from 14 departments/functions such as operations, dispatch, fleet, planning, and IT.

For each fuel/technology scenario, the project team assessed the likely change in workload for the affected roles and, therefore, the probable change in staffing levels. In each fuel/technology type scenario, the project team analyzed four dimensions of staffing changes:

- Changes in operational drivers (such as fleet platform hours) due to changing fleet size
- Vacancies left behind by attrition from employees who do not want to retrain (or from those who might be promoted into more senior roles)
- Inefficiencies from staff being involved in retraining/learning new skills
- Workload changes to reflect the change in role-based activities

In Phase 2, this analysis will be refined to align with the preferred technologies and fleet mix.

4.6 Costs Report

The **Costs Report (Appendix F)** provided lifecycle cost estimates for each alternative fuel/technology and a review of potential grant funding options to support RTD's transition to alternative fuels/technologies. The following subsections detail the approach to lifecycle costs analysis and funding opportunities review, respectively.

4.6.1 Lifecycle Costs Analysis

A critical consideration in any transition process is understanding the attributed cash costs. Attributed cash costs include 1) the direct costs incurred by acquiring capital, 2) the cost operating, maintaining, and disposing of the fleet and associated facilities, and 3) the non-cash costs or "benefits" associated with reduced emissions and other environmental factors. The team first developed lifecycle costs for a baseline "no-build" scenario, which assumes that RTD continues to procure and operate diesel buses. After the no-build scenario cost estimate was developed, costs associated with the seven build scenarios were modeled. Lifecycle cost model inputs included fleet size, fuel/technology type, annual vehicle mileage, vehicle efficiency, required facility improvements, fueling or charging strategies, and fuel and utility price structure. The project team captured and considered information and data from fuel providers, agencies operating zero emission buses (ZEBs), and vehicle manufacturers (OEMs) to ensure that the model reflected cost trends in the industry. The values presented are subject to change and based on the most current information. All costs are estimated in 2023 dollars.

For purposes of the Phase 1 evaluation, the lifecycle cost analysis covers a 12-year period to align with the FTA assumed minimum useful replacement cycle for large buses[5] and the current maximum length of an extended warranty on batteries for BEB options. The Phase 2 analysis will further refine assumptions on vehicle and major component life by technology.

4.6.2 Funding Opportunities Review

The WSP team set out with the goal to create a menu encompassing a full range of potential grant funding options for RTD's transition to alternative fuels/technologies. As a starting point, the WSP team drew on its previous work supporting transitions for similar entities, such as Fairfax County, Virginia; Placer and Solano counties in California; and Washington Metropolitan Area Transit Authority. This scan of previous research yielded many of the most common federal programs for funding bus acquisitions, maintenance, and infrastructure.

To ensure the federal funding options list was comprehensive and up to date, WSP's Climate Finance team conducted a search of its proprietary Climate Fund Navigator system. This tool contains a comprehensive database mapping out the programs detailed in the Infrastructure Investment and Jobs Act, the Inflation Reduction Act, and several legacy infrastructure funding programs. The team screened programs with the

[5] Federal Transit Administration, Circular FTA C 5010.1D. November 1, 2008. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/C_5010_1D_Finalpub.pdf

following themes: Transportation – Electric Charging & Vehicles; Transportation – Alternative Fuels & Vehicles; Transportation – Buses & Light Rail; and Transportation – Public. By contrast, the team excluded programs centered on maritime and aviation, those requiring that charging infrastructure be public, and those programs administered by regional authorities of which Colorado is not a part. Individual due diligence was conducted on the remaining programs to ensure their eligibility.

Finally, to ensure state government opportunities were reflected, the WSP team drew on a search of government agency websites, relevant journalism, and state appropriations documents. Key parameters collected for each program included funding agency, name of program, type of program (formula vs. discretionary vs. incentive program), status (open vs. closed), key dates, program description, and any stated points of contact. Additionally, WSP aimed to assess RTD's likelihood of attaining funding from each source, if pursued. Programs were classified as being high, moderate, or low potential based on a three-point scale. The criteria underlying these scores were:

- The ability of RTD's potential uses (i.e., bus acquisition, infrastructure buildout, maintenance) to meet the grant's minimum eligibility standard
- Clear alignment of the grant's notice of funding opportunity (NOFO) or funding opportunity announcement (FOA) with the goal of emissions reduction
- Historical competitiveness of the grant, with a threshold of 25 percent successful applicants for programs to be deemed "less competitive

5. Findings

- The following chapter summarizes the findings of each Phase 1 technical analysis (and report).

5.1 Overview

To create a consistent and intuitive comparison among technologies, the team developed a tiered scale diagram for results visualization. While each Phase 1 analysis report has refined quantitative modeling results at the facility level, the Fuel/Technology Screening Report focuses on the differences of using each alternative fuel/technology at the system level. By using this approach, the team can assess and display the significance of the impacts to RTD's current operations in five tiers ranging from no/minor changes to significant impacts. The following sections summarize the findings of each analysis by significance of impact for each fuel/technology.

5.2 Fleet Report

5.2.1 Market Availability

With respect to fuel sourcing, diesel fuel, CNG, and electricity are already mature fuels/technologies and readily available for RTD. Renewable diesel has limited availability at the national and local levels and is thus considered to have medium impacts. There is also the intention of using renewable diesel in DHEBs to capture as many environmental benefits as possible, thus DHEB receives the same assessment as renewable diesel in fuel availability. Hydrogen gas for FCEBs is considered the most challenging fuel to acquire, requiring a significant effort to produce on-site (at scale) or delivery (there are currently no hydrogen production plants within the state).

For the vehicle market, limited Buy America-compliant OEMs are available in the U.S. market, and they all face long delivery schedules (18–24 months) due to production capacity limitations as more U.S. agencies are needing to procure ZEBs.

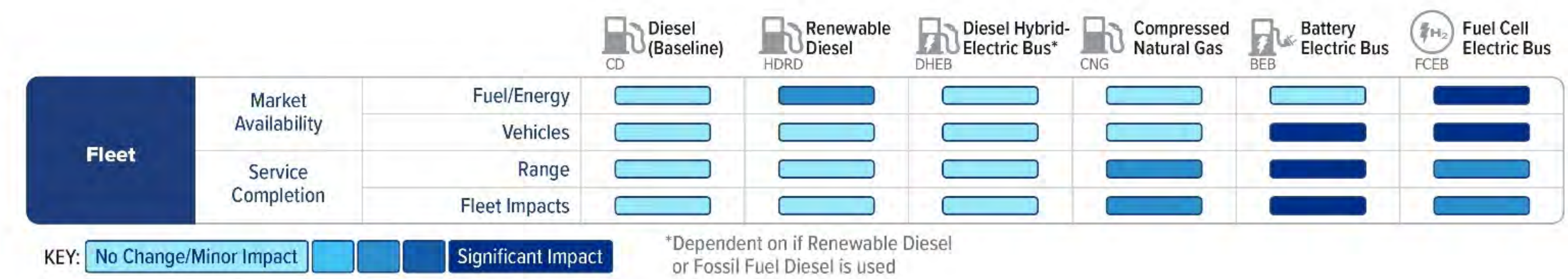
5.2.2 Service Completion

Based on the analysis, no additional buses are needed if renewable diesel or DHEB is adopted. If CNG and/or FCEB are adopted, a slight increase to the fleet size would be necessary—approximately, six (1 percent) and eight (1 percent) additional buses, respectively. The additional buses would primarily be required to maintain services originating from the Boulder and East Metro facilities.

In contrast, the adoption of BEB technology could significantly impact the fleet size, contingent on the mitigation strategies that RTD employs. For example, if on-route charging and diesel auxiliary heaters are implemented, a 1:1 replacement could potentially be achieved depending on the number (and power output) of on-route chargers. However, without these mitigation measures, RTD may need as many as **two** BEBs for every diesel bus.

Figure 5-1 presents the fleet impacts in regard to market availability and service completion for the baseline and alternative fuels/technologies.

Figure 5-1. Fuel/Technology Screening – Fleet Impacts



Source: WSP USA, Inc.

5.3 Facilities Report

Using renewable diesel creates virtually no impact to current RTD operations as it is a drop-in fuel and requires no upgrades. While individual sites vary, these technologies generally require no major upgrades to repair bays with the exception of BEBs and FCEBs.

DHEB operates similarly in many ways to diesel buses; however, the on-board battery features may trigger additional building requirements related to the fire resistance rating of the structure.

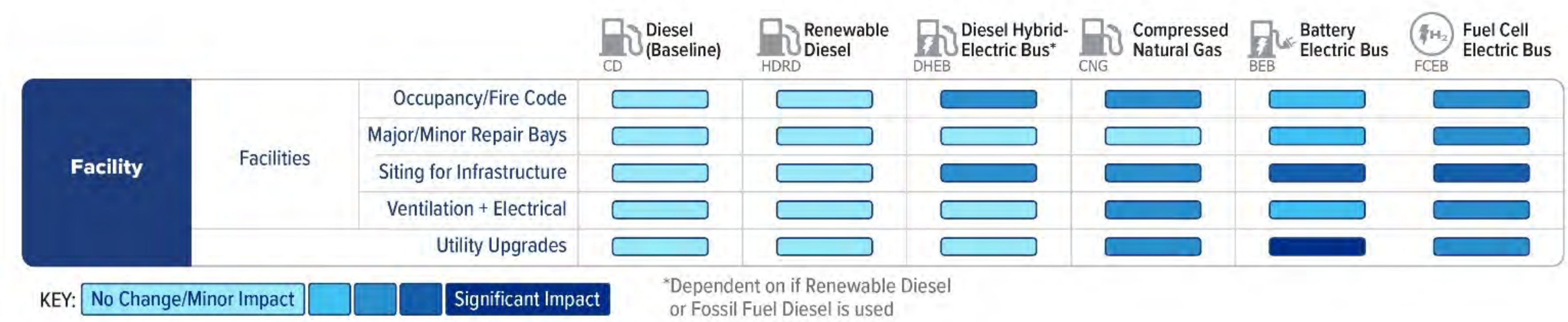
CNG buses are used widely in the United States with mature technology available for implementation. Because CNG is still a flammable gas, upgrades to current RTD facilities would be required for fuel storage, dispensing, safety, electrical. It may also be necessary to connect to a local natural gas pipeline, which brings significant utility upgrade costs.

Because BEBs come with bigger batteries, the potential need for facility upgrades is greater. The charging infrastructure at the facility would most likely require significant utility upgrades.

FCEB infrastructure, on the other hand, is "extremely difficult" to integrate into many facilities due to roof upgrades (for ventilation) and setback requirements that in some cases reduce parking.

Figure 5-2 presents the facility impact evaluations for the baseline and alternative fuels/technologies.

Figure 5-2. Fuel/Technology Screening – Facility Impacts



Source: WSP USA, Inc.

5.4 Emissions Report

5.4.1 Renewable Diesel

The local air pollutant (tailpipe) emissions of conventional and renewable diesel during operations are nearly identical to those of the diesel baseline. The main difference between the two fuels is the GHG emitted during fuel production. Compared to conventional diesel produced from petroleum, renewable diesel would provide an average of 60 percent net reduction in lifecycle GHG emissions, primarily due to the recycling of GHG compounds into the bio-feedstocks as they grow. The actual reduction would depend on the feedstock and production pathway. For example, renewable diesel produced from recycled animal fats is less carbon-intensive than renewable diesel produced from growing oil crops. There is also a risk that the cultivation of renewable diesel feedstock(s) could negatively impact land use and water resources. Although, as noted, the local tailpipe emissions from burning conventional and renewable diesel are nearly the same, there is limited evidence of marginal reductions in particulates and aromatic hydrocarbons from burning renewable fuels.

5.4.2 Diesel Hybrid-Electric Bus

Due to their greater per-mile fuel efficiency, if using conventional diesel fuel, there would be an estimated 15–30 percent reduction in GHG emissions for DHEBs compared to those of current RTD diesel buses. If using renewable diesel in DHEBs, there would be an average 70 percent reduction in GHG emissions compared to current operations. DHEBs also reduce the local air quality impacts of bus operations. Recent improvements have enabled DHEBs to operate with the conventional engine off for up to 3 miles at a time and up to one-third of daily miles. Selective use of electric-only mode could allow RTD to prioritize specific areas and populations for zero bus emissions.

5.4.3 Compressed Natural Gas Bus

Natural gas engines are less efficient than diesel engines, since CNG engines use more input fuel energy per mile. However, natural gas emits about 25 percent fewer GHGs than conventional diesel fuel. Depending on service characteristics, GHG emissions from CNG buses would typically be 0–10 percent lower than the emissions from diesel buses. Criteria pollutant emissions are also lower. Based on U.S. Environmental Protection Agency (EPA) emissions certification testing, new CNG bus engines would have 95 percent lower NOx and 80 percent lower PM emissions than new diesel bus engines.[6]

5.4.4 Battery Electric Bus

One key benefit of BEBs is the reduction in lifecycle GHG emissions. While BEBs do not emit any local tailpipe emissions, GHG is typically emitted during electricity production. Based on the current grid mix for electricity generation in Colorado, net lifecycle GHG emissions of BEBs operated in RTD service would be nearly 60 percent lower than lifecycle GHG emissions of current diesel buses.[7] BEBs also have no tailpipe emissions of NOx or PM. Compared to continued use of diesel buses, BEBs would reduce exposure of Denver residents and RTD

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[6] California Air Resources Board, New Vehicle and Engine Certification: Executive Orders for MY2023 Medium-Duty and Heavy-Duty Engines; A-021-0773, A-021-0767.

[7] According to Xcel Energy, their carbon dioxide (CO2) emissions from electricity generation in Colorado average 925 pounds per MWh. Based on estimated average BEB energy use of 3 kWh/mile, this equates to 1,259 g CO2/mile for BEBs, compared to 2,995 g CO2/mile for RTD diesel buses (4.9 miles per gallon).

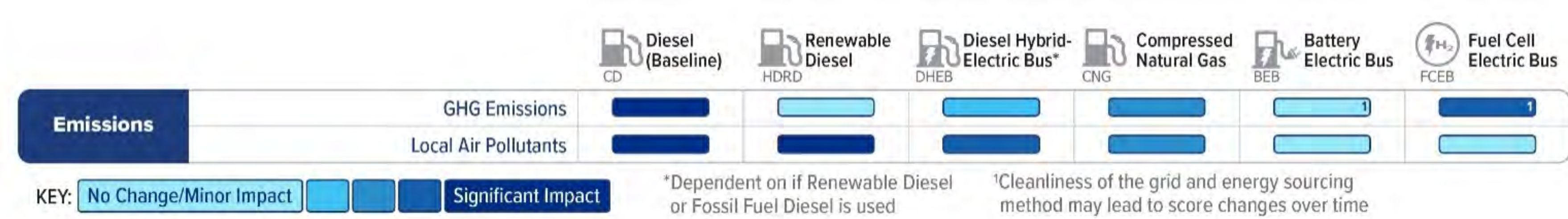
riders and employees to negative health impacts from these vehicle emissions. Although BEBs do not produce tailpipe emissions, they do create PM from braking and tire wear.

5.4.5 Fuel Cell Electric Bus

While FCEBs have zero tailpipe emissions, upstream emissions vary depending on the hydrogen production method used. The two methods of generating hydrogen fuel are steam methane reforming (SMR) and electrolysis, and both have off-site and on-site production options. The hydrogen gas (H_2) produced via these methods is generally categorized as brown, gray, blue, or green, with each signifying a different degree of upstream emissions. Lifecycle GHG emissions of hydrogen depend on the production and delivery method. Compared to lifecycle GHG emissions from diesel fuel, emissions from hydrogen production vary from one percent more via SMR to a complete elimination via electrolysis using renewable energy. Local air pollutants would see a 100 percent reduction, except for the PM emitted from brake and tire wear. Noise pollution would be reduced, as the vehicles would be virtually silent/vibration free.

Figure 5-3 presents the emission impact evaluations for the baseline and alternative fuels/technologies.

Figure 5-3. Fuel/Technology Screening – Emission Impacts



Source: WSP USA, Inc.

5.5 Workforce and Training Report

5.5.1 Staffing

Based on the analysis, renewable diesel would have minor impacts to staffing as it is considered a “drop in” fuel. Diesel hybrid, CNG, and FCEB would each require fewer than five additional staff (less than a 1 percent increase) based on the assumption that the maintenance of the new facility infrastructure would be outsourced.

In contrast, the adoption of BEB technology could require the largest staffing increase, contingent on the infrastructure and strategy that RTD employs. For example, if on-route charging and diesel auxiliary heaters are implemented, staffing would increase by approximately 30 people. However, if only overnight charging is used—in conjunction with not using diesel auxiliary heaters—the staff increase could be as many as 264 people.

It is important to note that the demand for training is not driven by net increases in staff but by total recruitment demand inclusive of promotions, attrition, and relevant "uplift" training associated with the new fuels/technologies. Assumed attrition rates are declared in each fuel/technology-specific section of this report. The analysis also considered these changes and estimated the remaining staff.

5.5.2 Training

To support these additional roles and the selected fuel/technology, RTD would have to prepare the workforce with new training and resources to support operations. Similar to staffing requirements, any new fuel/technology, except for renewable diesel, would have an impact to existing training requirements, ranging from approximately 6,400 to 34,000 additional training hours.

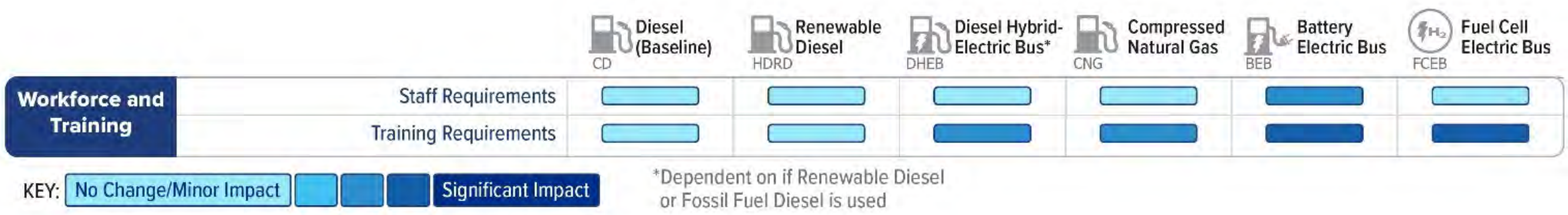
The fuel/technology with the lowest training demand is diesel hybrid with just 6,400 training days, requiring around 0.5 FTE trainers over 12 years. CNG, fuel cell electric, and battery-electric (with on-route charging) would require 19,000, 22,000, and 23,000 training days, respectively. The latter would require approximately 1.8 FTE trainers over 12 years.

The fuel/technology with the highest training demand is battery-electric (with overnight charging) with approximately 34,000 training days. However, it should be noted that this is skewed due to the estimated number of additional buses (and Operators) required for the service's longer blocks. It is likely that RTD would opt for other solutions (in practice) before additional buses are purchased.

The increase in training requirements is skewed by two critical roles: Bus Operators and General Repair Mechanics. Across all scenarios, training for Bus Operators and General Mechanics would account for an average of 62 percent and 28 percent of all training, respectively. While the specific demands would vary (slightly) by fuel/technology, it is evident that prioritizing Operators' and Mechanics' training would be beneficial for a more seamless transition. When further assessed, it was found that the majority of the required training would be driven by the demand for new hires. Each additional staff member would require both initial training and the uplift training to convert to the new fuel/technology. Therefore, enacting an engagement plan/communications strategy that minimizes attrition would be key to retaining staff and keeping the training demand relatively low.

Figure 5-4 presents the workforce and training impact evaluations for the baseline and alternative fuels/technologies.

Figure 5-4. Fuel/Technology Screening – Workforce and Training Impacts



Source: WSP USA, Inc.

5.6 Costs Report

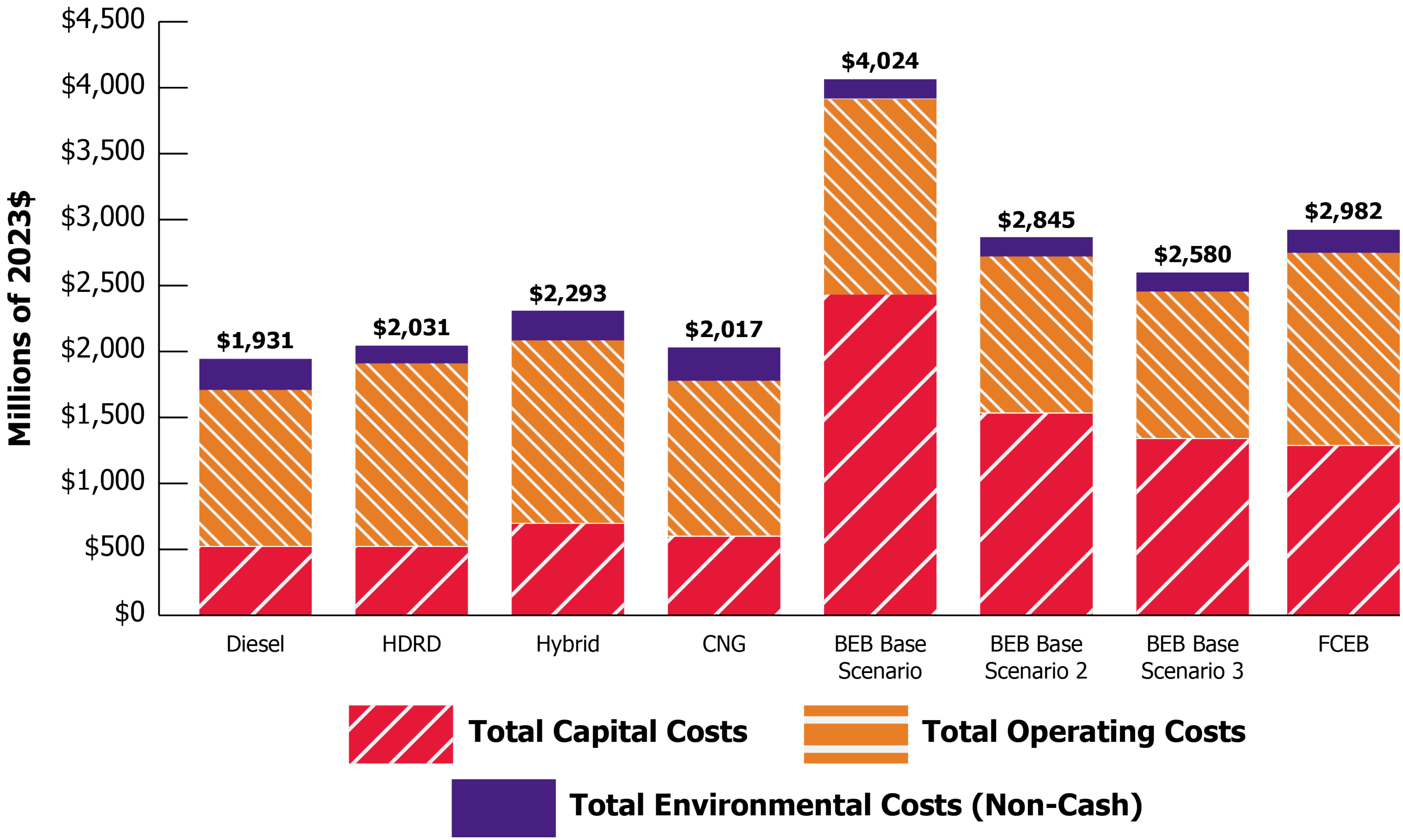
For each scenario, the team calculated comprehensive lifecycle costs, including capital, operating, and environmental costs. Below is a summary of findings:

- Continued operation of diesel buses through 2036 would cost $1.9 billion.
- The most expensive transition would be the BEB Base Scenario, resulting in an additional cost of $2.1 billion compared to the baseline.
- The least expensive transitions would be renewable diesel, diesel hybrid, or CNG, none of which would exceed $362 million over the diesel baseline over the same time period.
- For the ZE fuels/technologies, the largest driver of costs for BEBs, regardless of scenario, would be capital costs, whereas FCEB's largest driver would be operating costs.

The lifecycle costs include the cost of additional staff required. Annual costs would range from $215 million for the BEB Base Scenario (no on-route charging or diesel auxiliary heaters) at the high end to lesser amounts for the other BEB scenarios and for the diesel hybrid, CNG, and FCEB scenarios.

Figure 5-5 presents a high-level summary of the lifecycle costs that RTD would incur under each scenario, including capital costs (vehicle purchases and facility modifications), operating costs (maintenance, fuel, and training), and non-cash environmental costs.

Figure 5-5. Lifecycle Costs by Scenario (2025–2036)



Source: WSP USA, Inc.

Note: BEB Base Scenario does not include on-route charging or electric heaters, BEB Scenario 2 does not have on-route charging but uses diesel auxiliary heaters, BEB Scenario 3 has on-route charging and diesel auxiliary heaters.

For comparison, the following scales are developed for each cost category.

5.6.1 Capital Costs

Renewable diesel would have the lowest impact in vehicle costs as it could be directly used in existing diesel buses. DHEB and CNG buses would be slightly more expensive than diesel buses, while BEB and FCEB prices would be significantly higher. The following pricing impact data are based on data from peer agencies and adjusted to RTD's baseline costs for diesel buses:

- The approximate capital cost for a DHEB would be 45 percent greater than that of conventional diesel buses.
- CNG buses would be more expensive than diesel buses, with an estimated 10 percent increase in bus capital costs compared to diesel buses. Virtually all transit bus OEMs that sell into the U.S. market offer CNG buses, including New Flyer and Gillig.
- Vehicle costs for BEBs are expected to increase 100 to 140 percent per vehicle. While the cost per vehicle would be high, BEBs are becoming more affordable and there are several incentive programs to help reduce the cost. Despite lower fuel costs for BEBs, it is expected (at least in the near term) that RTD would experience higher maintenance costs.
- Costs per FCEB are expected to be 100 to 160 percent greater than current diesel bus costs. National Renewable Energy Laboratory estimates this is where costs will remain for the near term for orders between 25–40 buses.

Regarding facility upgrade costs, both renewable diesel and DHEB scenarios would still require that fueling be done the same way as diesel buses and thus minor changes would incur. CNG would require significant facility upgrades. Since the technology is mature and standardized around CNG facilities, the cost for CNG adaptation would be deemed as medium impact. Infrastructure costs for FCEB would depend on the size. Hydrogen fueling station equipment and installation are estimated to be approximately $3 million for a station that can handle up to 80 buses (liquid delivery and storage). Maintenance facility upgrades would cost around $1 million per facility (similar to that of CNG facility upgrades). Lastly, costs associated with full BEB transition are estimated to be the highest as the potential grid upgrade and installation of charging infrastructure would represent a significant undertaking. **Figure 5-6** presents the capital costs impact evaluations for the baseline and alternative fuels/technologies.

5.6.2 Operating Costs

Operating costs comprise Operations & Maintenance (O&M), including vehicle and facility maintenance and labor costs, and costs to purchase fuel/energy.

Operations and Maintenance

Renewable diesel, as a drop-in fuel, does not require any changes in O&M practices. Consequently, adopting renewable diesel as the main fuel would not impact O&M costs. O&M costs for DHEBs are expected to be just over 20 percent higher than those of the diesel baseline. Without range improvement mitigation strategies, a 100 percent BEB transition would involve a great level of impact on O&M costs, specifically related to vehicle maintenance, incremental staff cost, and cost for maintaining the charging infrastructure. If on-route chargers and diesel auxiliary heaters are used, O&M costs for a BEB fleet could be largely reduced. FCEBs are also deemed to have moderate impact on O&M since the additional staff and training costs would be less intensive than BEB-related trainings. FCEB vehicle maintenance is also more comparable with the diesel baseline.

Fuel Costs

Renewable diesel and hydrogen are identified as the two most expensive fuels.

Renewable diesel is more expensive to purchase than conventional diesel, though cost estimates are currently subject to significant uncertainties. In October 2023, the U.S. Department of Energy's *Clean Cities Alternative Fuel Price Report* stated that renewable diesel is available only at publicly accessible fuel stations in California and Oregon. As a result, national averages are difficult to come by.[8] In addition, policies incentivizing renewable diesel's use may distort consumer prices: renewable diesel can generate credits under the Low Carbon Fuel Standard programs in California and Oregon, and credits typically subsidize part of the net cost to the user. The report estimates the retail price of renewable diesel to be $6.33 a gallon. Other estimates place the unsubsidized price at approximately $1.00 more per gallon than conventional diesel. This implies that, compared to the current per mile diesel fuel costs paid by RTD, the fuel costs of renewable diesel represent an increase of 35 to 110 percent. The price of buying in bulk may vary greatly depending on the ability to negotiate with distributors.[9]

The cost of gray hydrogen, delivered as a liquid from off-site suppliers, generally ranges between $8 and $10 per kg (equating to approximately an 80 percent increase in costs per mile). The cost of delivered green hydrogen is currently higher, typically varying between $13 and $14 per kg (approximately 190 percent increase per mile).

Environmental Benefits

Environmental costs estimate the cash value of vehicle emissions, upstream emissions, and vehicle noise. The CNG scenario would result in higher emission costs than diesel buses, and DHEBs provide only a nominal reduction in emission costs. The other technologies could also reduce emission costs significantly and are marked as no/minor impact to environmental benefits.

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[8] https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_october_2023.pdf
[9] "CLEAN CITIES Alternative Fuel Price Report." 2023. https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_october_2023.pdf?98eec8e8b8

Funding Opportunities

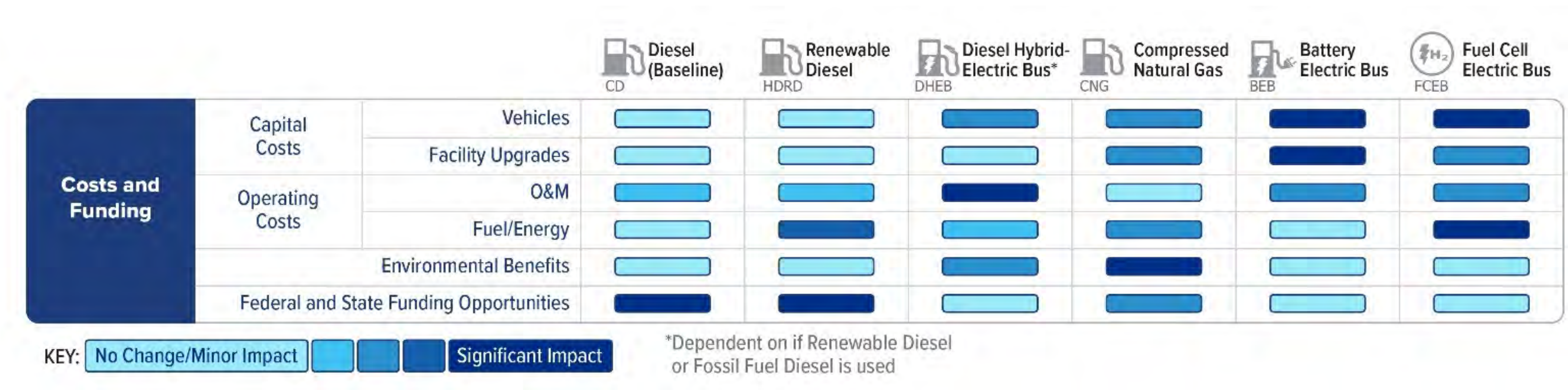
Data gathered from the review of federal and state funding programs established a broad list of possible opportunities to fund RTD's facilities and fleet transition. The review showed little differentiation according to clean energy technology, with broad support available for diesel hybrid, battery-electric, fuel cell electric, and CNG vehicles. Of the 24 discretionary programs highlighted, 3 were considered to have "high" funding potential:

- FTA Section 5339 (c): Low or No Emission Vehicle Program
- EPA Clean Heavy-Duty Vehicle Program
- EPA Community Change Grants Program

Thirteen other programs had "moderate" award potential, and 8 were considered "low" probability opportunities. WSP adopted a relatively high bar for attaining the top rating, and RTD should not disregard lower outlook opportunities solely based on this preliminary analysis. Data availability had a strong impact as only programs for which success rates were public could be identified as less competitive.

Figure 5-6 presents the costs and funding opportunities impact evaluations for the baseline and alternative fuels/technologies.

Figure 5-6. Fuel/Technology Screening – Costs and Funding Opportunities Impacts



Source: WSP USA, Inc.

6. Fuel/Technology Screening

- The following chapter summarizes the staff feedback received at the in-person Fuel/Technology Screening Workshop and the decision-making process that went into the formulation of the preferred fuels/technologies recommendations.

6.1 Engagement and Decision-Making

Since the project's inception, the Steering Committee (SC) and Working Group (WG) have held alternating bi-weekly meetings with the project team. These one-hour meetings focused on project progress and schedule updates. They have also served as a forum for information and data sharing. As previously mentioned, before each Phase 1 report was submitted to the WG members for review, the team first presented the approach and analysis findings to the SC (where initial comments and feedback were provided) and then to the WG—approximately one week later—to collect feedback from a larger share of RTD staff. This structure of engagement enabled all WG members to engage at several points throughout the process, ensuring that all voices were heard.

6.1.1 Fuel/Technology Screening Workshop

Once all Phase 1 reports were submitted (end of June), the project team hosted a one-day in-person workshop on June 26, 2024. Approximately 50 participants attended the workshop, including 31 RTD staff (primarily from the WG) and 15 representatives from the project team.

The workshop offered a critical opportunity to have staff from different operating functions sitting together and voicing their input on the analysis conducted in Phase 1. RTD attendees were provided a high-level overview of the technical work completed to date. The project team reviewed the current state of each fuel and technology considered, peer agency case studies, and findings of the analyses. The team also hosted discipline-focused (that is, fleet, facility, workforce and training, etc.) roundtable sessions to address subject-specific questions.

The goal of the workshop was for staff to voice their questions and concerns with each fuel/technology being reviewed and provide input regarding the best fuel/technology options for future RTD operations. The team used these inputs to select the preferred fuel/technology with the intent that no more than two types of fuels/technologies would be in the final recommended mix—a consideration for the ease of operations. The preferred fuels/technologies would be advanced into Phase 2 to guide the RTD toward its 2050 net ZE goal.

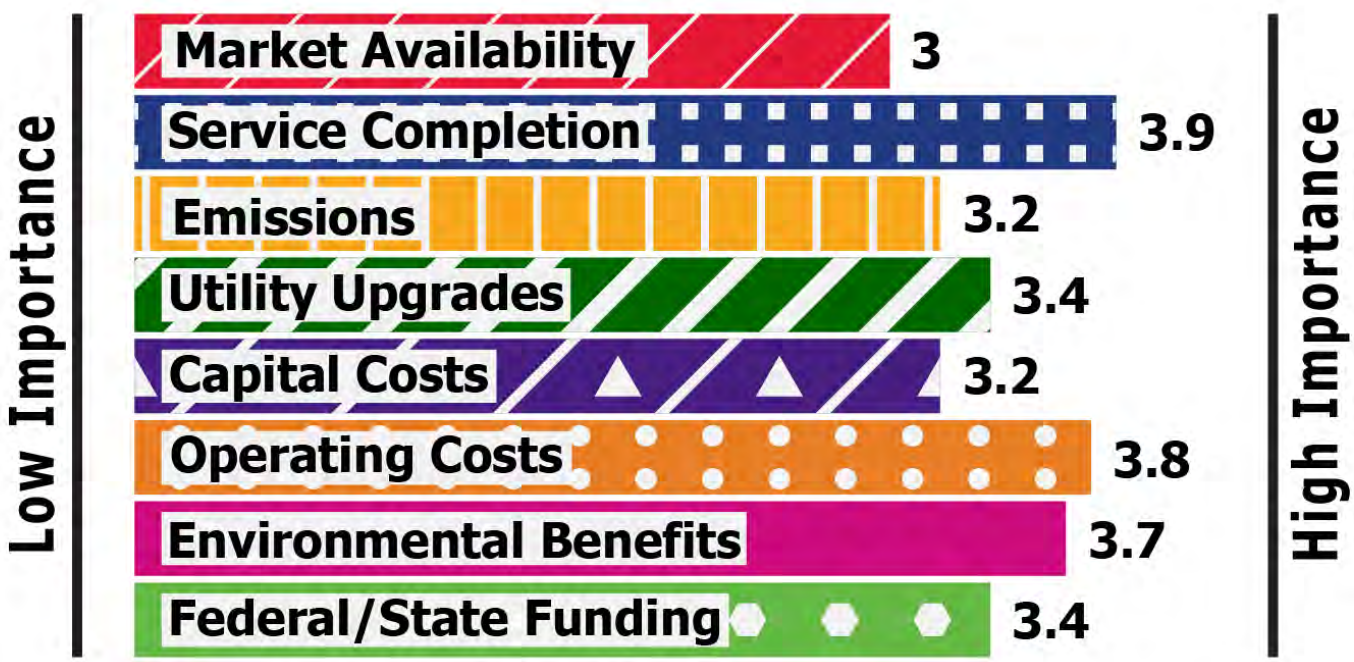
Staff Assessments

The project team used a real-time polling tool, Mentimeter, to assess staff's impression of different technologies and factors that should be prioritized when going through a transition. The team conducted several polls throughout the workshop to help facilitate each topic discussion.

Transition Factor Survey

Staff were asked to score between 1 (low importance) to 5 (high importance) each factor that should be considered to meet RTD's transition goals. The results show service completion, operating costs, and environmental benefits as the top 3 considerations (**Figure 6-1**).

Figure 6-1. Importance of Transition Factors – Poll Result



Source: WSP USA, Inc.

Fuel/Technology Preference Survey(s)

Staff then scored each technology in terms of how well it would support the transition goals. The first poll was taken after the project team presented the results of each fuel/technology, while the second poll was taken at the conclusion of the roundtable discussions. The second poll also disaggregated fuels/technologies by "short-term" (the next 5–10 years) and "long-term" (beyond the next decade) as the outlook on costs and availability of some fuels/technologies are forecasted to change over time.

The results indicate that during the first poll staff generally had more confidence in mature fuels/technologies, along with many concerns with how ZE technologies—battery electric and fuel cell electric—can support the services provided by RTD. After the roundtable discussions, staff suggested the consideration of a phased approach where renewable diesel (when/if available) and DEB are favored to realize short-term environmental benefits while creating low impacts to current operations, and in the long-term, more attention should be given to BEBs and FCEBs if and when those technologies become mature enough. **Table 6-1** presents the poll scores from before and after the roundtable discussions.

Table 6-1. Fuel/Technology Alignment with RTD Transition Goals – Poll Results

Fuel/Technology	Pre-Roundtable/ Discussion	Post-Roundtable Discussion Short-Term (5–10 years)	Post-Roundtable Discussion Long-Term (10+ years)
Renewable Diesel	5.6	4.0	2.1
Diesel Hybrid	5.2	3.8	3.1
Battery Electric	3.7	1.8	3.2
Fuel Cell Electric	4.0	1.4	3.4
Compressed Natural Gas	5.0	1.6	1.5

Source: WSP USA, Inc.

Fuels/Technologies Discussion

The following summarizes the key themes that emerged from the Fuel/Technology Screening Workshop:

- Renewable diesel is viewed as a bridging fuel that should be used as soon as possible if supply is available. It is also generally recognized as a short-term strategy due to its high cost and inability to eliminate localized emissions. There is also concern about its availability given that only one supplier has been identified (Wyoming).
- CNG is also viewed as a potential bridging fuel since it also emits local emissions. At the same time, Maintenance staff is concerned about maintenance practices, safety, and space limitations based on previous experience with CNG buses. The transition to CNG buses would also require significant changes to RTD's facilities, and staff felt the environmental benefit realized through the conversion to CNG buses was not great enough to warrant the level of effort needed to transition to the technology.
- Most consider DHEBs a short-term strategy to achieve some emission reductions while the technologies for BEB and FCEB continue to mature.
- FCEB is the only technology that is ZE **and** has limited impacts on service. However, this technology also has the most uncertainties as there is currently no hydrogen available in the state and where it is available, the upstream production emits a significant amount of GHGs. However, with the state and federal support for green hydrogen production, staff were optimistic that the market will improve.
- BEBs have demonstrated their advantage in emissions reduction, with a power source—electricity—that is readily available. However, staff were concerned about the costs and challenges on service scheduling. Staff raised concerns about being unable to meet a 1:1 replacement ratio, prompting several suggestions to pursue a mixed-technology fleet.

6.2 Recommendations

It is clear from the workshop discussions that a two-phased approach defining both short-term and long-term strategies is warranted given that the future of BEBs and especially FCEBs remains unclear and volatile. Recommendations for near-term actions and long-term considerations include:

Near-term (2025–2035): Focus on deploying BEBs where they make sense and use DHEBs to replace existing diesel buses. This involves:

- Providing annual updates to the FFTP to reflect any fuel/technology and market updates.
- Replacing existing diesel buses with DHEBs to claim some environmental benefits and integrate the use of renewable diesel, if feasible, when available.
- Increasing the BEB fleet to the maximum extent possible based on infrastructure and service requirements.
- Considering a FCEB pilot.
- Planning for and potentially acquiring properties for long-term goals(s).
- Exploring facility improvements that are implementable in the near term that facilitate emission reduction, such as on-route charging infrastructure and facility energy efficiency improvements.

Long-term (2036–2050): Consider BEB fleet and/or FCEB fleet. This involves:

- Providing annual updates to the FFTP to reflect any fuel/technology and market updates.
- Providing an expanded BEB fleet or a mixed BEB and FCEB fleet as the current goal for the future fleet.
- Replacing DHEBs with BEBs and/or FCEBs if the respective fuels/technologies have matured to an appropriate degree.
- Increasing the DHEB fleet if both technologies fail to mature at the expected rate.

6.3 Next Steps

This report marks the completion of Phase 1. The preferred fuels/technologies recommendations will be communicated to the WG.

The project team will then initiate Phase 2 work and develop a work plan that reflects the two-phase planning strategy. Anticipated work to be completed in Phase 2 includes:

- Refining the on-route charging analysis
- Conducting utility coordination
- Analyzing facilities, designing, and developing a concept that reflects the recommendations

- Developing the transition schedule and fleet procurement plan in alignment with the two transition phases
- Updating the Workforce and Training Plan
- Updating the Emissions Analysis
- Updating the Lifecycle Costs and Funding Plan
- Developing the final Facilities Transition Blueprint and FTA Fleet Transition Plan