Zero Emission Bus Transition Plan

Transit Authority of River City
October 2022

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ES. EXECUTIVE SUMMARY

This Zero Emission Bus (ZEB) Transition Plan provides a roadmap for the conversion of the Transit Authority of River City (TARC) bus fleet to zero-emission vehicles over the next 15 to 20 years. This transition plan evaluated both FCEB (fuel cell electric bus) and BEB (battery electric bus) technology for adoption at TARC and proposes several scenarios for transitioning to these technologies. Therefore, this Transition Plan identifies a path forward in terms of recommended types of ZEBs, what infrastructure is needed to support ZEBs, how ZEBs can be phased in, and what the implications are in terms of capital and operating costs.

ZEB TECHNOLOGIES

Two ZEB technologies were analyzed for the Transition Plan:

- Battery Electric Buses (BEBs)
- Fuel Cell Electric Buses (FCEBs, or hydrogen buses)

BATTERY ELECTRIC BUSES (BEBS)

BEBs are currently the most common type of ZEB in service and procurement today. These are a simple first step towards ZEB operations, however, they do come with a set of challenges that require consideration. BEBs have most of the same components as a typical transit bus, however, the engine block and fuel tank are replaced with a high-voltage battery pack and electric traction motors. The on-board battery pack powers the propulsion system, HVAC and other high-voltage systems, and distributes power to the 12-volt battery pack and systems on board the vehicle.

BEB performance is heavily influenced by heating, ventilation, and air conditioning usage, topography, and driver behavior, so TARC may achieve ranges from 130 to 200 miles per day depending on conditions.

There are different charging equipment and technology options for charging BEBs:

- Depot charging – charging stations typically located at the bus garage, providing a full charge when buses are not in operations, usually during overnight hours. Charging takes several hours per bus.
- Opportunity charging – Fast charging facilities typically located on-route at layover locations, providing enough energy to avoid replacing the bus to maintain the route and vehicle schedule.

There are also three different types of charging dispensers:

- Conductive – inverted overhead pantograph
- Conductive – plug-in
- Inductive – wireless charging

Operating a BEB system is an energy intensive activity; as such, energy tariffs play a key role in its practicality. Tariff structures imposed by utilities on energy consumption play a crucial role in managing the cost of BEB transit networks, with underlying price structures that can include use, capacity, and energy-based fees. To ensure a sustainable business case for both utility companies and transit agencies, efficient, electric vehicle-centric tariffs may be required. Energy-based tariffs, for instance, might be negotiated with incentives for off-peak consumption, resulting in lower costs.

FUEL CELL ELECTRIC BUSES (FCEBS)

FCEBs are a relatively nascent ZEB technology that is quickly gaining traction with the transit market. FCEBs do not experience the same range limitations as BEBs, however, they come at greater expense and require more space for fueling infrastructure. FCEBs are electric vehicles that use on-board fuel cells to generate electricity. The fuel cell runs pure hydrogen through an oxidizing membrane, which produces electricity and water. Energy from the fuel cell is supplied to onboard batteries to power propulsion and other systems. Hydrogen behaves differently from gasoline or diesel, but if applied correctly, it is about as safe as gasoline. The majority of transit agencies using FCEBs do not produce their own hydrogen but have fuel delivery contracts with large scale production companies.

The supply, storage, and fueling for FCEBs have their own infrastructure challenges that must be carefully planned for. When planning for an FCEB system, options for the transportation of fuel or, alternatively, on-site hydrogen re-formation, as well as storage, must be weighed against space requirements, costs, power requirements, and environmental factors.

Hydrogen fuel is typically stored in liquid form in large storage tanks. The supply, storage, and fueling for FCEBs have their own infrastructure challenges that must be carefully planned for. When planning for an FCEB system, options for the transportation of fuel or, alternatively, on-site hydrogen re-formation, as well as storage, must be weighed against space requirements, costs, power requirements, and environmental factors. Because of its volatility, safety consideration mandate significant buffers surrounding a hydrogen fueling facility. These requirements may impact the ability of a transit agency to partly, or fully, transition to an FCEB fleet.

FLEET REPLACEMENT

The existing TARC fixed-route fleet is comprised of 236 standard buses. Of these, 210 are in active operation while the remaining 26 are inactive. Inactive vehicles include buses that are awaiting disposal. The fleet consists of 206 40-foot buses and 30 30- and 35-foot models. While most of the fleet is diesel fueled, TARC also operates 28 hybrid diesel buses and 15 BEBs. TARC's existing service was analyzed to determine if ZEB technology could meet the duty cycles of the fixed route fleet. TARC's January 2022 pre-pandemic service statistics were used to model the agency's routes at full capacity.

Based on this analysis of TARC's pre-pandemic service, 234 blocks, representing 84% of service, run less than 180 miles per day and can be electrified without impeding existing operations. The longest 45 blocks are on routes 10, 18, 19, 28, 43, and 63. These blocks cannot be fully electrified today, but improvements in technology may allow them to be electrified in the future.

TARC currently has 14 2023 40-foot Gillig buses in production. In addition, six 2024 Nova LFSE and two 2024 40-foot Gillig buses are also on order. For years 2025 through 2036, 14 to 17 vehicles will need to be procured annually to maintain TARC's 174 peak-vehicle pull out. Most new bus purchases will be 40-foot vehicles with 35-foot procurements only in 2025 and 2034.

TARC FACILITIES ASSESSMENT

The assessment of the capabilities of TARC's operating and maintenance facilities is based on facility documentation provided by TARC, interviews and discussions with key TARC personnel, and an on-site visit conducted in March 2022. Both of TARC'S operating campuses were examined for adaptation to ZEB infrastructure: the "bus barn" located at TARC's main facility at 1000 West Broadway and the bus barn located at its 29th Street facility (2900 West Broadway).

BEB CAPABILITIES

Under a BEB transition scenario, TARC would convert its fleet of 205 40-foot vehicles using a charging level of 60 kW per vehicle, with the capability to intermittently provide increased charging rates as needed. Equipment required includes 60 kW dispensers, charging cabinets, and utility upgrades. It is likely that TARC can utilize a mixture of ground mounted and overhead plug-in dispensers. Using an all ground-mounted plug-in strategy, TARC may need to sacrifice some space inside its facility for charging lanes. Adding overhead plug-in dispensers will alleviate this space constraint. While TARC may have the height clearance in some parts of its facility to support overhead pantograph depot (in-garage) charging, the HVAC system may provide a height clearance problem in portions of the facility. As a result, this strategy is not recommended for depot charging. TARC will need to work with a designer to support 100% facility design activities to optimize the configuration of chargers, charging lanes, and vehicles.

FCEB CAPABILITIES

Hydrogen fuel is highly flammable; National Fire Protection Association (NFPA) codes requires buffer setbacks to separate bulk hydrogen storage. The distance from outdoor bulk hydrogen systems to various exposures is dependent on the operating pressure of the system, piping size, and type of exposure. Compressed hydrogen for use for FCEBs will range from 5,000 to 10,000 pounds per square inch (psi). “Exposure” is a measure of risk associated with objects and distances in range of a potential hydrogen accident.

Facilities for maintenance of hydrogen fueled vehicles need to be constructed to limit sources of ignition for flammable gas that may be accidentally released and to evacuate any such gas that is released. Facilities in which a combination of diesel, unleaded and lighter than air gas fueled vehicles may be maintained need to restrict ignition sources where flammable fumes may accumulate, both near the floor and near the ceiling.

Hydrogen is a colorless, odorless gas. Unlike compressed natural gas (CNG), which is odorized with mercaptan as a safety precaution so that leaking CNG can be detected by smell the same as natural gas used for comfort heating, hydrogen used in HFCBs is not odorized. Maintenance facilities require hydrogen gas sensors to detect and alert operators to the presence of the odorless, colorless, gas.

The facility at 1000 West Broadway has the capacity to fuel 50 vehicles with minimal space restrictions, and up to 100 vehicles with some impacts to the facility. The 1000 West Broadway repair facility is considered a minor repair garage while the 2900 West Broadway repair facility is considered a major repair garage. The 2900 West Broadway facility currently contains automatic fire suppression sprinklers. Both storage and maintenance facilities require modifications to fuel, store, and maintain FCEBs. TARC’s existing facility does not have space for onsite production, and few utility scale electrolysis plants exist, though more are currently planned or under construction.

To accommodate FCEBs and hydrogen fueling, the following actions and infrastructure modifications and improvements to TARC’s operating and maintenance facilities with regard to implications of utilizing FCEBs vehicles include:

1000 West Broadway:

- The minor repair garage (1000 West Broadway) maintenance bay ventilation systems be evaluated to ensure compliance with the mechanical code requirement exhaust rate not less than 0.75 cfm/ ft^2.
- Safety equipment should be on emergency power.
- Any conduits routed up to roof mounted equipment (MAUs, EFs etc.) need to be suitable for a classified environment if the space does not have continuous ventilation.

2900 West Broadway:

- Install a new hydrogen gas detection system in the major repair garage.
- Provide continuous ventilation at a rate not less than 1 cfm/ft^2 in where FCEBs will be repaired.
- Install automatic or self-closing man doors between the repair bays and the machine shop area.
  Isolate adjoining areas such the steam clean component room. Safety equipment should be on emergency power.
- Remove the existing infrared radiant tube heating system (Co-ray-vac) serving the major repair garage (29th & Broadway) maintenance bays.

- Do not conduct hot work near FCEBs
- Any conduits routed up to roof mounted equipment (MAUs, EFs, etc.) need to be suitable for a classified environment if the space does not have continuous ventilation.

RESILIENCE AND SOLAR POWER

Both BEB and FCEB technologies will require some level of resilience in the face of a power outage to TARC's facility, or fuel delivery interruption. To provide resilience to FCEB service, fuel storage tanks and fuel delivery schedules may be optimized to maintain fuel reserves in the event of a delivery interruption. Resiliency for BEB service can be more difficult. A combination of on-site generators, solar power, and battery storage may help offset TARC's electricity needs in case of an outage.

The rooftop of the 1000 W. Broadway facility has the space to install a 2500 kW DC solar array. Power output of the solar array fluctuates depending on the season, with greater consumption in the summer. The amount of power theoretically produced accounts for roughly one-tenth of that used to charge a 100% BEB fleet.

TECHNOLOGY AND FACILITIES ASSESSMENT CONCLUSIONS

The primary constraint of achieving a 100% zero emission fleet is the physical limitation of TARC's existing operating and maintenance facilities. A full conversion to BEBs is possible; however a full conversion using FCEBs is not.

Both facilities are in areas where expansion is either limited or unlikely given the surrounding built environment. TARC does not currently have the wherewithal to replace its facilities with a new facility that would accommodate the existing fleet, provide the flexibility to allow for an expanded fleet, and allow for full conversion from diesel to ZEV, either employing all BEBs, all FCEBs, or a combination of both.

While there is potential to use the 2900 West Broadway facility, this would require moving buses between 1000 West Broadway and 2900 West Broadway at least once a day, and possible more than once, the refuel and/or recharge. This would result in an onerous operating situation in terms of time and operating cost (labor) and it is not recommended. Should TARC choose to re-establish 2900 West Broadway as a full operating division in the future, a major overhaul would be necessary given the current configuration and ceiling height, which provides insufficient space for overhead charging units. It is possible to accommodate 60 floor-mounted dispensers, but this would also require a significant reconfiguration of the space along with two 2 megawatt (MW) feeders from Louisville Gas & Electric (LG&E).

Therefore, based on the current situation, given available space and facilities constraints, the following scenarios are possible at TARC:

SCENARIO 1: ALL BEB

TARC's facility can likely support a full fleet conversion to BEB technology. The majority of TARC's routes can also be covered by existing BEB technology, and the 1000 West Broadway facility could be configured to serve the existing fleet without use of the 2900 facility for overnight charging and storage.

SCENARIO 2: PARTIAL FCEB

TARC's facility can accommodate the fueling infrastructure for 50 FCEBs without much constraint, and up to 100 FCEBs with some design constraints to the facility. Additional land would be required to install fueling infrastructure for the entire fleet. To reach 100% ZEB, half of TARC's fleet would be converted to BEB.

RECCOMENDATION

It is recommended that TARC pursue a 100% BEB technology strategy to achieve a ZEB fleet.

Although both scenarios are viable, the majority of TARC's existing service can be electrified with today's BEB technology, and battery capacity is expected to improve in the coming years to support the remainder of TARC's service. TARC can convert fully to ZEB technology with minimal constraints to its facilities with this technology.

IMPLEMENTATION TIMELINE

The transition timeline is divided up into three components: Utilities, Facilities and Vehicles. Utility and Facility Development would prepare TARC to accept BEBs and infrastructure through their transition period. Utilities application, design, and construction can take up to 36 months, though this timeline is shorter or longer depending on LG&E and power required. The facilities timeline is based upon a design-bid-build strategy. The lengths of time required for each stage of this process depends heavily on TARC's internal procurement and design procedures, but the assumptions below give a rough estimate based off experience with other agencies. The facility build itself is divided into three "phases" to allow partial fleet relocation during construction.

Timeline activities and assumptions are shown in the following table. They take into account a preliminary procurement schedule, and two rounds of bus production extending into 2025. It is assumed that TARC will not go out for bid in successive years for vehicles, but instead, exercise options off a procurement contract for several years before going out for bid. It is also assumed that chargers will be purchased with vehicles and electrified by infrastructure installed in the bus barn.

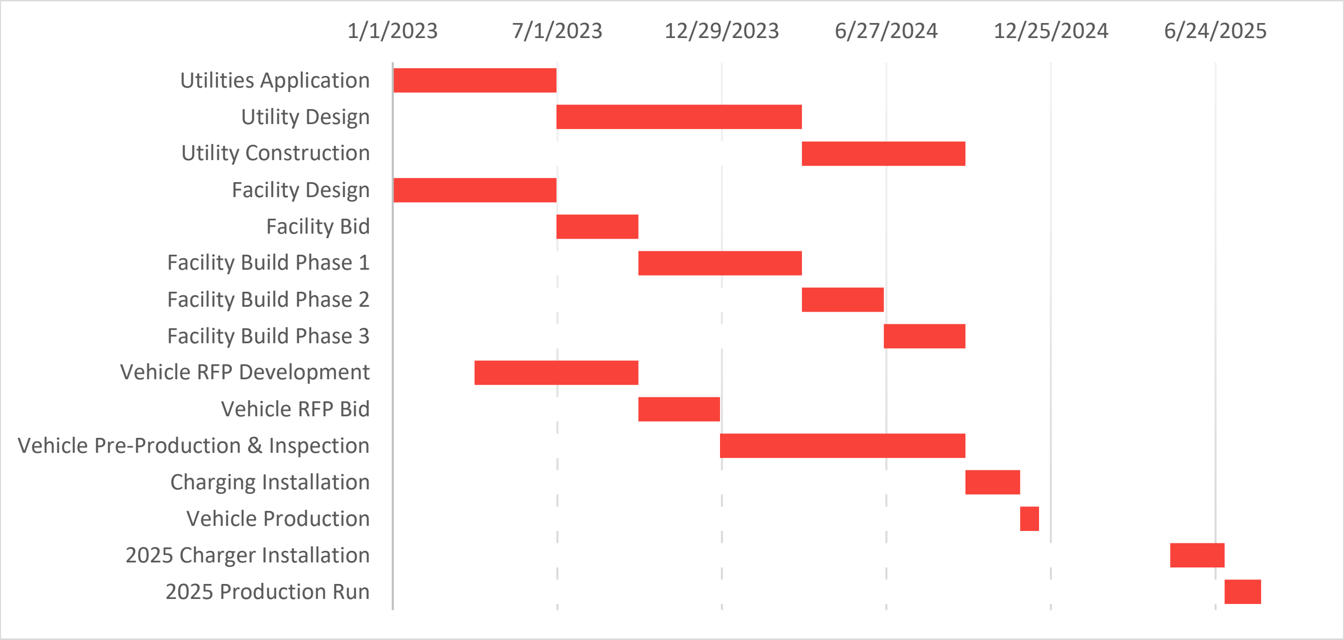
ES Table 0-1: Transition Timeline Activities & Assumptions

ACTIVITY	START DATE	DURATION (DAYS)
Utilities Application	1/1/2023	180
Utility Design	6/30/2023	270
Utility Construction	3/26/2024	180
Facility Design	1/1/2023	180
Facility Bid	6/30/2023	90
Facility Build Phase 1	9/28/2023	180
Facility Build Phase 2	3/26/2024	90
Facility Build Phase 3	6/24/2024	90
Vehicle RFP Development	4/1/2023	180
Vehicle RFP Bid	9/28/2023	90
Vehicle Pre-Production & Inspection	12/27/2023	270
Charging Installation	9/22/2024	60
Vehicle Production	11/21/2024	21

SOURCE: WSP

It is paramount that TARC complete infrastructure to support vehicles before vehicles arrive onsite. The schedule in the following figure includes utility and facility design, as well as the first two procurements in 2024 and 2025. Due to 2024 being a relatively small procurement year, only six vehicles, it may be possible to support those vehicles with existing utility service and extend this timeline to prepare the bus barn for the 2025 procurement year.

ES Figure 0-1: Sample Transition Timeline, 2023-2025



SOURCE: WSP

PROCUREMENT & TRAINING CONSIDERATIONS

Work with transitioning agencies around the country has resulted in a variety of lessons learned for both procurement and incorporation of ZEB technology into a fleet. The following considerations should be made in developing TARC's full fleet transition:

- Facility construction and infrastructure installation should complete before buses arrive onsite.
- Training is typically, and should be, provided by bus original equipment manufacturers (OEMs) and coincide with bus pre-production activities.
- TARC may consider "evergreen battery warranties" to ensure performance for the lifetime of a vehicle.
- TARC should engage a facility designer to perform 100% designs.

LIFECYCLE COST ANALYSIS

The purpose of the lifecycle cost analysis is to provide in-depth analyses on the lifecycle costs for TARC's fleet transition effort. The lifecycle cost estimation includes cash and non-cash costs. Cash costs consist of vehicle and infrastructure capital costs, operating and maintenance costs, and disposal costs. Non-cash costs consist of environmental costs and benefits.

Compared to conventional diesel, gasoline, and CNG vehicles, ZEBs incur different capital and operating costs. For example, in the case of BEBs, the cost to install and maintain utility and charging infrastructure will differ in both the magnitude and the types of resources required in comparison to existing diesel storage and fueling facilities. Other examples include FCEB infrastructure and operating requirements, battery replacement schedules, vehicle components requiring mid-life overhaul, and disposal values for the vehicles and batteries.

The lifecycle costs are assessed over the vehicles' operating years to account for their full operating costs over 15 years for buses. BEBs and FCEBs and required facilities may offer the opportunity for TARC to lower some operations and maintenance costs; however, other costs will increase. Similar to conventionally fueled vehicles, BEB and FCEB operations and maintenance costs are highly dependent on the size and complexity of the vehicle fleet. Additionally, an electrification strategy would shift TARC's primary fuel source for core bus operations from diesel to electric power, which would subject the agency to very different energy pricing structures and exposure to energy price volatility.

VEHICLE PROCUREMENT SCHEDULE

Two main factors are considered with vehicle procurement: timing and quantity. The number of vehicles being procured is determined by how many vehicles can be accommodated at each facility and the quantity needed to maintain services. The procurement timeline needs to align with facility enhancements and is subject to considerations such as the useful life of the vehicles and any established procurement goals. The lifecycle model assumes that buses will be retired 15 years after their acceptance date. The following vehicle procurement schedule was developed by the WSP team in alignment of TARC's transition schedule.

ES Table 0-3: Build and No Build Scenario Vehicle Replacement Schedule

VEHICLE TYPE	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
NO BUILD SCENARIO														
35ft Diesel	-	-	6	-	-	-	-	-	-	-	-	7	-	-
40ft Diesel	14	-	10	5	14	16	5	14	14	15	16	10	17	17
40ft HYB	-	8	-	10	-	-	11	-	1	-	-	-	-	8
BUILD SCENARIO 1: 100% BEB														
35ft BEB	-	-	6	-	-	-	-	-	-	-	-	7	-	-
40ft BEB	14	8	10	15	14	16	16	14	15	15	16	10	17	17
BUILD SCENARIO 2: MIXED BEB/FCEB														
35ft BEB	-	-	6	-	-	-	-	-	-	-	-	7	-	-
40ft BEB	14	8	10	-	-	-	-	-	-	5	16	10	17	17
40ft FCEB	-	-	-	15	14	16	16	14	15	10	-	-	-	-

SOURCE: WSP

CAPITAL COST

Bus capital costs are based on standard vehicle purchase prices, after-market equipment, allowances for contingency, and charging infrastructure. Charging and fueling infrastructure requirements are a key consideration for BEBs and FCEBs. Costs are based on the number of operating vehicles per facility and their expected lifespan, to estimate the total infrastructure costs per bus.

Charging and fueling infrastructure includes the supporting equipment and facility construction to support the operations and maintenance of buses. Charging infrastructure conceptual estimates are developed by a WSP cost estimator based on the equipment and construction needs to host battery electric buses at TARC facility. Hydrogen costs are based on infrastructure to support hydrogen delivery, as well as mitigation of "lighter than air" flammable gas risk. Hydrogen facility improvements are anticipated to happen in two stages with each stage supporting the acquisition of 50 FCEBs. For the FCEB/BEB scenario, BEB facility costs are based on estimates developed for the full BEB scenario, with adjustments made to account for the smaller size of the fleet based on a cost per bus value derived from the full BEB scenario and applied to the number of BEBs in the FCEB/BEB scenario. For the No Build case the costs are based on assumed future replacements of underground storage tanks, pumps, and dispensers. The next major tank replacement is assumed to occur in 2033.

The following table shows the overall capital investment costs assumed for each of the scenarios.

ES Table 0-4: Facility Improvement Costs by Scenario (2021 dollars)

SCENARIO	DIESEL FUELING INFRASTRUCTURE	BEB IINFRASTRUCTURE	FCEB INFRASTRUCTURE	TOTAL
No Build	$1,530,000	$-	$-	$1,530,000
1: BEB	$-	$18,600,000	$-	$18,600,000
2: BEB/FCEB	$-	$9,700,000	$22,000,000	$31,700,000

SOURCE: WSP COST ESTIMATOR

OPERATING AND MAINTENANCE COSTS

Vehicle operations and maintenance (O&M) costs include general vehicle maintenance costs, tire service costs, fueling infrastructure annual maintenance costs, fuel or energy costs, and bus disposal and retirement costs. Vehicle O&M costs are specific to the vehicle types and the length of the vehicles. Overall O&M costs are influenced by the operating costs per mile of each vehicle and annual mileage, both direct inputs into the lifecycle cost model.

ES Table 0-5: TARC – O&M Costs for Build and No Build Scenarios (2021 $/mile)

COST CATEGORY	DIESEL 35'	DIESEL 40'	HYBRID 40'	BEB 35'	BEB 40'	FCEB 40'
Maintenance Cost ($/mi)	0.81	0.81	1.19	1.84	1.84	1.09
Tires ($/mi)	0.065	0.065	0.065	0.072	0.072	0.065
Fueling Unit/Charger ($/year/bus)	100	100	100	2,000	2,000	1,200

SOURCE: TARC AND PEER AGENCY

FUEL AND ENERGY COSTS

Fuel costs are based on average 2022 prices through June, escalated using the U.S. Department of Energy, Energy Information Administration (USEIA) 2022 Annual Energy Outlook Reference Case Scenario price forecast. The USEIA price forecast is referenced as annual percent increases which are applied to the 2021 price baseline. Prices for electric vehicles are based on LG&E and USEIA's five-year historical utility rates. The following table summarizes the energy cost assumptions. Demand charges are rounded to the nearest thousands. Hydrogen prices of $8.00 per kg are based on delivered costs for other agencies currently using hydrogen vehicles.

ES Table 0-6: TARC – Fuel/Energy Cost per Bus (2022 $ Values)

	ELECTRICITY		DIESEL	HYBRID		HYDROGEN
Fuel/Energy Cost	$0.03/kWh		$2.70/gal	$2.70/gal		$8.00/kg
Demand Charges ($/kW)	$25.61		N/A	N/A		N/A
Vehicle Type	*35'*	*40'*	*35'*	*40'*	*40'*	*40'*
Vehicle Fuel Efficiency Diesel Equivalent (mpdge)	-	-	5.52	4.90	5.58	8.86
Vehicle Fuel	1.88	2.40		-	-	-

	ELECTRICITY		DIESEL	HYBRID		HYDROGEN
Efficiency (kWh/mi)						
Average Annual Miles	50,252	58,222	50,252	58,222	58,222	58,222
Total Fuel/Energy Costs per Year per Bus	**$21,613**	**$23,135**	**$24,570**	**$32,069**	**$28,161**	**$52,571**

SOURCE: VARIOUS ENERGY PROVIDERS AND USEIA ESCALATION

LIFECYCLE COST ANALYSIS RESULTS

The lifecycle cost analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs. Additionally, a non-cash cost of environmental benefits and costs, which the lifecycle model monetizes to account for a holistic comparative cost and benefit, is assessed. Results in both 2021 $s and YOE $s, along with the overall estimated capital cost, in year of expenditure (YOE) $, are shown in the tables on the next three pages.

The full lifecycle cash cost of a transition to BEBs and FCEBs is higher than the continued reliance on internal combustion (diesel). While the initial capital and operating costs are higher for ZEBs, there are opportunities for some savings in fuel costs. Additionally, operating cost benefits are highly dependent on factors that are continually evolving as battery-electric and hydrogen buses deploy in transit services. The analysis also shows that the No-Build scenario would result in a large emission generation over the lifecycle of diesel operations in comparison to the Build scenarios. The large vehicle emission difference between the two replacement scenarios was expected, as the technology in the battery electric buses are aimed to reduce GHG emissions, particularly for carbon emissions. These costs are inclusive of ZEB purchases, charging/fueling infrastructure, additional options and charges, or vehicles and battery extended warranties.

ES Table 0-7: Lifecycle Cost Analysis Results for TARC (2021 $ Millions)

		STANDARD SCENARIO ("NO BUILD")	**BUILD SCENARIO 1: 100% BEB**	**BUILD SCENARIO 2: MIXED BEB/FCEB**
Capital	VEHICLE PURCHASE PRICE	$84.0	$164.0	$171.4
	MODIFICATIONS & CONTINGENCY	$13.5	$27.6	$28.2
	CHARGING/FUELING INFRASTRUCTURE	$1.5	$18.6	$31.7
	TOTAL CAPITAL COSTS	*$99.0*	*$210.2*	*$231.3*
Operating	VEHICLE MAINTENANCE	$63.1	$128.0	$103.5
	VEHICLE TIRES	$4.8	$5.3	$5.2
	VEHICLE FUEL COSTS	$38.1	$21.2	$36.7
	CHARGING/FUELING INFRASTRUCTURE	$0.0	$12.2	$5.8
	TOTAL OPERATING COSTS	*$106.0*	*$169.2*	*$152.5*
Disposal	BATTERY DISPOSAL	$0.0	$0.0	$0.0
	BUS DISPOSAL	-$0.3	-$0.3	-$0.4
	TOTAL DISPOSAL COSTS	*-$0.3*	*-$0.3*	*-$0.4*
Total Cash Costs		**$204.8**	**$379.1**	**$383.4**
Comparison to Base	DOLLARS	$0.0	$174.3	$179
	PERCENT	-	85%	87%
Total Cash Cost per Mile		**$1.13**	**$2.08**	**$2.11**
Environmental	EMISSIONS - VEHICLE	$2.0	$1.2	$1.2
	EMISSIONS - REFINING/UTILITY	$12.3	$6.8	$3.4
	NOISE	$4.8	$3.8	$4.3
	TOTAL ENVIRONMENTAL COSTS	*$19.0*	*$11.8*	*$8.9*
Total Cash and Non-Cash Costs		**$223.8**	**$390.9**	**$392.2**
Comparison to Base	DOLLARS	$0.0	$167.0	$168
	PERCENT	-	75%	75%
Total Cash and Non-Cash Costs per Mile		**$1.23**	**$2.15**	**$2.16**
Total Mileage (million miles)		182	182	182

SOURCE: WSP

ES Table 0-8: Lifecycle Cost Analysis Results for TARC (YOE $ Millions)

		STANDARD SCENARIO ("NO BUILD")	BUILD SCENARIO 1: 100% BEB	BUILD SCENARIO 2: MIXED BEB/FCEB
Capital	VEHICLE PURCHASE PRICE	$164	$331	$344
	MODIFICATIONS & CONTINGENCY	$27	$56	$57
	CHARGING/FUELING INFRASTRUCTURE	$2	$20	$36
	TOTAL CAPITAL COSTS	*$192*	*$406*	*$436*
Operating	VEHICLE MAINTENANCE	$254	$549	$444
	VEHICLE TIRES	$19	$21	$21
	VEHICLE FUEL COSTS	$161	$79	$136
	CHARGING/FUELING INFRASTRUCTURE	$0	$10	$5
	TOTAL OPERATING COSTS	*$434*	*$671*	*$612*
Disposal	BATTERY DISPOSAL	$0	$0	$0
	BUS DISPOSAL	-$2.2	-$2.7	-$3
	TOTAL DISPOSAL COSTS	*-$2*	*-$3*	*-$3*
Total Cash Costs		$624	$1,075	$1,045
Comparison to Base	DOLLARS	$0	$452	$422
	PERCENT	-	72%	68%
Total Cash Cost per Mile		$3.43	$5.91	$5.75
Environmental	EMISSIONS - VEHICLES	$7.9	$4.7	$5
	EMISSIONS - REFINING/UTILITY	$45.0	$28.0	$15
	NOISE	$19.0	$15.0	$17
	TOTAL ENVIRONMENTAL COSTS	*$72*	*$48*	*$37*
Total Cash and Non-Cash Costs		$696	$1,123	$1,082
Comparison to Base	DOLLARS	$0	$427	$386
	PERCENT	-	61%	56%
Total Cash and Non-Cash Costs per Mile		$3.83	$6.18	$5.95
Total Mileage (million miles)		*182*	*182*	*182*

Source: WSP

ES Table 0-9: Estimated Overall Capital Costs by Scenario by Year (all amounts in millions of YOE $)

YEAR	NO-BUILD	BUILD SCENARIO 1: 100% BEB	BUILD SCENARIO 2: MIXED BEB/FCEB
2022	$8.76	$20.67	$21.38
2023	$9.77	$12.60	$13.04
2024	$11.02	$24.50	$25.34
2025	$16.69	$25.36	$28.40
2026	$10.39	$24.52	$27.46
2027	$12.30	$29.03	$32.51
2028	$20.01	$30.08	$33.68
2029	$11.55	$27.26	$30.53
2030	$13.53	$30.26	$33.89
2031	$13.28	$31.35	$34.21
2032	$14.68	$34.64	$35.83
2033	$16.10	$35.57	$36.79
2034	$16.77	$39.58	$40.93
2035	$17.39	$41.04	$42.44
Total	**$192.27**	**$406.47**	**$436.44**

SOURCE: WSP

FEDERAL FUNDING OPPORTUNITIES

The 2021 Infrastructure Investment and Jobs Act (IIJA or “Act”), now formally known as the Bipartisan Infrastructure Law (BIL), reauthorizes surface transportation programs for five years and provides new investments in transportation, energy, water, buildings, and other programs to improve America’s infrastructure.

BIL contains $550 billion in new spending over five years. It provides new federal funding to support roads and bridges, public transit, freight and passenger rail, ports, and airports; investment in broadband infrastructure; water systems; modernizing the power sector; and improving climate resilience. In addition to authorizing these programs, BIL also provides $113.3 billion in advance general fund appropriations to allow agencies to begin funding infrastructure improvements before the fiscal year (FY) 2022 appropriations process is completed.

The following list summarizes the primary programs for TARC’s consideration regarding funding for ZEB purchases, ZEB charging/fueling infrastructure, and associated maintenance facility investments:

- Federal Transit Administration (FTA) Section 5307 Urbanized Area Formula Funding
- FTA Section 5339 (a) Buses & Bus Facilities Formula Funding
- FTA Section 5339 (b) Buses & Bus Facilities Discretionary Grant Program
- FTA Section 5339 (c) Low or No Emission Vehicles Discretionary Grant Program
- Federal Highway Administration (FHWA) Congestion Mitigation/Air Quality (CMAQ) Formula Funding
- FHWA SMART Discretionary Grant Program
- FHWA Carbon Reduction Program
- FHWA Charging and Refueling Infrastructure Program
- U.S. Department of Transportation (USDOT) RAISE Discretionary Grant Program
- USDOT/USDOE National Electric Vehicle Formula Program
- USDOE State Energy Program

1 INTRODUCTION

This Zero Emission Bus (ZEB) Transition Plan provides a roadmap for the conversion of the Transit Authority of River City (TARC) bus fleet to zero-emission vehicles over the next 15 to 20 years. This transition plan evaluated both FCEB (fuel cell electric bus) and BEB (battery electric bus) technology for adoption at TARC and proposes several scenarios for transitioning to these technologies.

Louisville Metro Government has committed to a goal of "100% clean energy by 2035." Kentucky's Governor Andy Beshear empaneled a Hydrogen Hub Workgroup early in 2022. The Kentucky Transportation Cabinet (KYTC) has created an Electric Vehicle Infrastructure Deployment Plan. However, there are no local or statewide mandates or incentives to push or help the Commonwealth's transits make the switch to zero-emission buses. Therefore, while some of the incremental costs will be offset through various federal, state, and local incentives, remaining incremental costs will be borne directly by TARC through conventional funding sources.

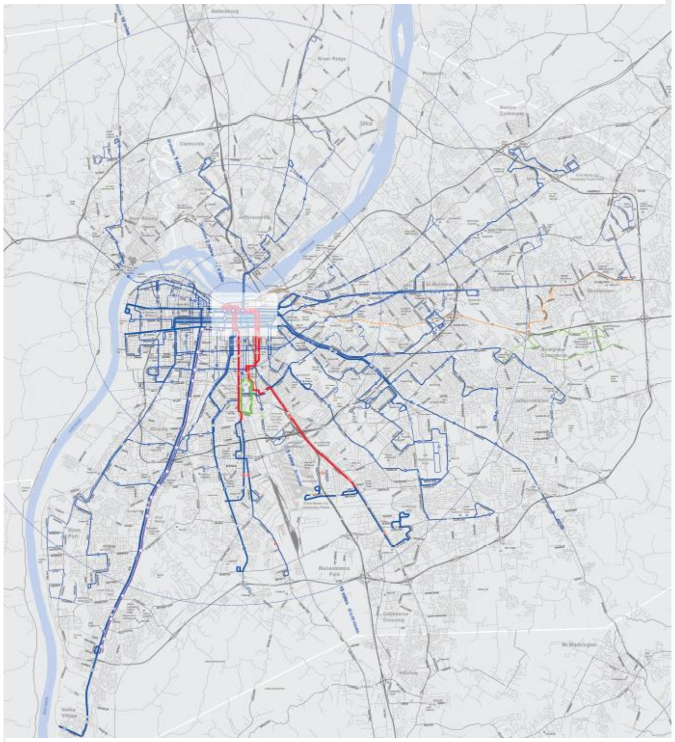
1.1 BACKGROUND

TARC delivers safe and accessible transportation services to the Greater Louisville area. With close to 50 years of history serving this community, TARC and its 580 employees and contractors connect residents and visitors to the region with 209 buses, operating 31 routes, providing more than 6 million miles of service throughout Greater Louisville, including Southern Indiana. Figure 1-1 displays a map of the fixed route

TARC provides service in Jefferson County in Kentucky, and Clark and Floyd counties in Indiana. TARC's service area includes Kentucky Congressional District 3, as well as Indiana's 9th district. According to the 2010 U.S. Census the population of the Louisville Metro urbanized area is 1,285,439; the population of Louisville alone is 782,969. TARC's service area encompasses an area of 357 square miles with a population of 806,893.

TARC provides extensive bus service in and from the vast majority of the Environmental Justice (EJ) zones in the Louisville Urbanized Area. Those zones are where our region's highest density of minority, low-income, disadvantaged, and elderly citizens depend on TARC to get to work, school, shopping, medical care, and other essential services.

Figure 1-1: TARC Fixed Route System



SOURCE: TRANSIT AUTHORITY OF RIVER CITY, 2021

1.2 PROJECT GOALS

TARC is seeking to determine if and how it can transition from a primarily diesel bus fleet to a zero-emission bus (ZEB) fleet, either using battery electric buses (BEBs), fuel cell electric buses (FCEBs, also referred to as hydrogen fuel cell buses, or HFCBs), a combination of both, or a mix of ZEBs and diesel buses. As is the case with many transit agencies, TARC faces fiscal constraints. Although federal policy is focusing on ZEBs, with significant grant funding available under the 2021 infrastructure law, securing local match can be a challenge, especially for major capital improvements.

TARC also faces several physical constraints, primarily regarding its operating and maintenance facilities. It currently has two major facilities, both located on Broadway, relatively close to downtown which serves as the hub of most fixed routes. Both are in densely developed urban settings with tightly developed campuses that offer little room for expansion and that are hemmed in by other development. These physical constraints are major factors in the determination of what directions TARC should take to achieve a zero-emission fleet.

Therefore, this Transition Plan identifies a path forward in terms of recommended types of ZEBs, what infrastructure is needed to support ZEBs, how ZEBs can be phased in, and what the implications are in terms of capital and operating costs.

1.3 EXPERIENCE WITH LOW- OR ZERO-EMISSION VEHICLES

Greater Louisville is a region with long-standing air quality issues. According to National Ambient Air Quality Standards (NAAQS), Louisville's status for ozone is Nonattainment. The community also sometimes struggles to remain below the annual standard for particulate matter (especially PM 2.5). Both pollutants create significant health risks, and diesel exhaust is a significant contributor to these pollutants locally.

TARC has for years worked to reduce those diesel emissions. It first placed hybrid buses in service in 2004, and over the following 10 years acquired a total of 32 hybrid diesel-electric buses. TARC was the first fleet in the region to switch to ultra-low diesel fuel, making that switch three years before the U.S. Environmental Protection Agency (EPA) mandated the change. In 2015, TARC made its first foray into the world of full battery electric buses. To date, TARC's experience with charging BEBs is limited to on-route, fast charge systems, as shown in **Error! Reference source not found.**. However, the experience gained has taught the agency about the complexities associated with operating, maintaining, and planning service with range-limited vehicles. TARC is currently, though modestly, expanding its BEB fleets.

Figure 1-2: TARC BEB Previously in Downtown Service

SOURCE: LOUISVILLE COURIER-JOURNAL

TARC recognizes that current decisions about whether and how much to invest in BEB and/or FCEB technology is largely based on existing infrastructure, system design, and cost. TARC also recognizes that BEB and FCEB technologies are still developing. It is highly likely that the strategies that TARC will adopt today will need to be revised in the future. The guidance presented in this Transition Plan is intended to start TARC down the road toward a zero-emission vehicle future.

2 ZERO EMISSION TECHNOLOGIES

The following section provides an overview of ZEB and infrastructure technology.

2.1 BATTERY ELECTRIC BUSES

Battery electric buses (BEBs) are currently the most common type of ZEB in service and procurement today. These are a simple first step towards ZEB operations, however, they do come with a set of challenges that require consideration.

Vehicles

BEBs have most of the same components as a typical transit bus, however, the engine block and fuel tank are replaced with a high-voltage battery pack and electric traction motors. The on-board battery pack powers the propulsion system, HVAC and other high-voltage systems, and distributes power to the 12-volt battery pack and systems on board the vehicle.

Today's battery technology is not as energy dense as conventional fuel; A battery pack that weighs the same as a full diesel tank contains less energy, reducing the range capabilities of the BEB. Increasing the battery's capacity (kilowatt hours [kWh]) increases the gross vehicle weight, which risks exceeding state or federal weight limitations. Battery energy density, however, has improved over time due to technological breakthroughs and experimentation with different chemistries and orientations. BEB performance is heavily influenced by heating, ventilation, and air conditioning usage, topography, and driver behavior, so TARC may achieve ranges from 130 to 200 miles per day depending on conditions.[1]

Charging Strategies

There are two primary charging strategies that agencies can consider implementing to meet operational requirements: depot and opportunity charging.

DEPOT CHARGING

Depot charging consists of an array of charging stations in the bus parking area. BEBs are charged when not in service, overnight or between AM and PM trips. Charging stations are rated between 150 – 180 kW, and typically have two or three dispensers to charge multiple BEBs. Total charge time per bus depends on the number of BEBs plugged into a single charging station but is conservatively estimated at 2.5 hours per vehicle or up to 7 hours for multiple vehicles charging together from the same box. To support a depot charging strategy, adequate space (for equipment) and power (from the electrical utility) is required.

OPPORTUNITY CHARGING

Opportunity charging, or "fast charging" employs high-voltage chargers (over 450 kW) at vehicle layover locations (typically at transit centers or stops). This enables BEBs to charge while in-service, effectively maintaining or increasing its range throughout the day. Although layovers are typically brief (5-15 minutes), the higher charge rating allows the BEB to

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[1] This range assumes a 525 kWh battery pack with a 20% safety buffer, and efficiencies of 2.1 to 3.36 kWh/mi that represent a range of operating conditions

replenish a sizable amount of energy (as compared to depot charging) in a fairly short period of time. Opportunity charging is often necessary to extend range from overnight charging to avoid midday bus replacements.

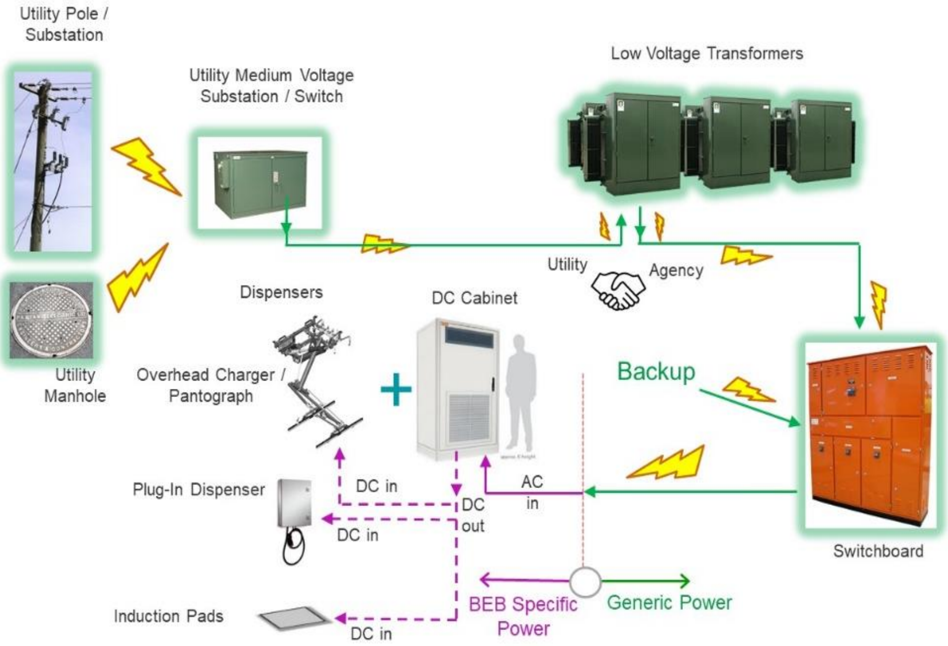
Charging Dispensers

Currently, there three technologies (charging type and orientation) that are used in the US market to transfer energy to a BEB's on-board batteries:

- Conductive – Inverted overhead pantograph
- Conductive – Plug-in
- Inductive – Wireless charging

Each of these charging technologies are described in greater detail, below. Figure 2-1 gives an overview of how these dispensing methods fit into overall BEB charging systems.

Figure 2-1: Charging System Components



SOURCE: WSP

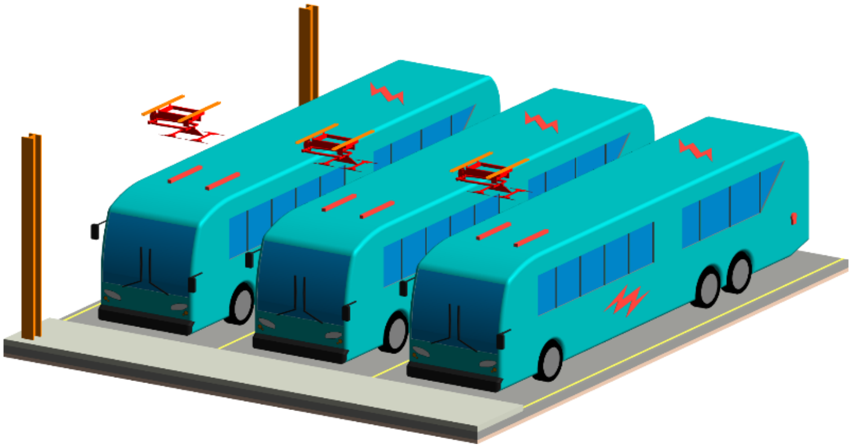
CONDUCTIVE - INVERTED OVERHEAD PANTOGRAPH

The inverted overhead pantograph is an infrastructure-mounted, retractable device that has electrical contacts that engage a contact bar on the roof of the bus. The operator uses visual indicators, such as lighting or painted markings to ensure that the BEB is aligned with the pantograph. Then, the operator lowers the pantograph from a switch on the bus (using RFID or wireless technology) – the charge automatically starts once the pantograph has engaged the contacts on the bus. This charging strategy automates the initiation of charging which reduces the risk of user error.

Inverted Overhead Pantograph charging can be used for both opportunity and depot charging. Depot pantographs can be connected as dispensers in 2:1 or 3:1 configuration to a single depot charging station. Pantographs are also used, more typically, as high voltage opportunity chargers.

The inverted overhead pantograph strategy does require overhead clearance, depending on the preferred mast and mounting orientation. An example of an inverted overhead pantograph is illustrated in Figure 2-2.

Figure 2-2: Inverted Overhead Pantograph Chargers in Depot Charging

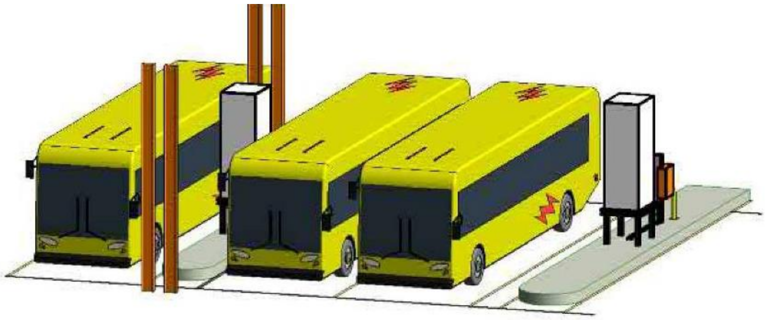


SOURCE: WSP

CONDUCTIVE – PLUG-IN

The plug-in charger consists of cables and a standardized plug which can be manually inserted into a BEB charging port. Plug-in charging is typically used in bus depot applications. Plugs are connected as dispensers in 2:1 or 3:1 configuration to a single depot charging station. Plug-in charging can be ground mounted, or cords can be hung overhead from retractable pulley systems. The ground mounted plug-in concept is illustrated in Figure 2-3. Plug-in charging is easy to implement and plug standardization across manufacturers has allowed for easy adoption. However, plugs are subject to misalignment errors and mismanaged cables are subject to damage because of their proximity to bus lanes. Overhead retractable cords do help alleviate this problem but require some overhead clearance.

Figure 2-3: Plug-in Charging



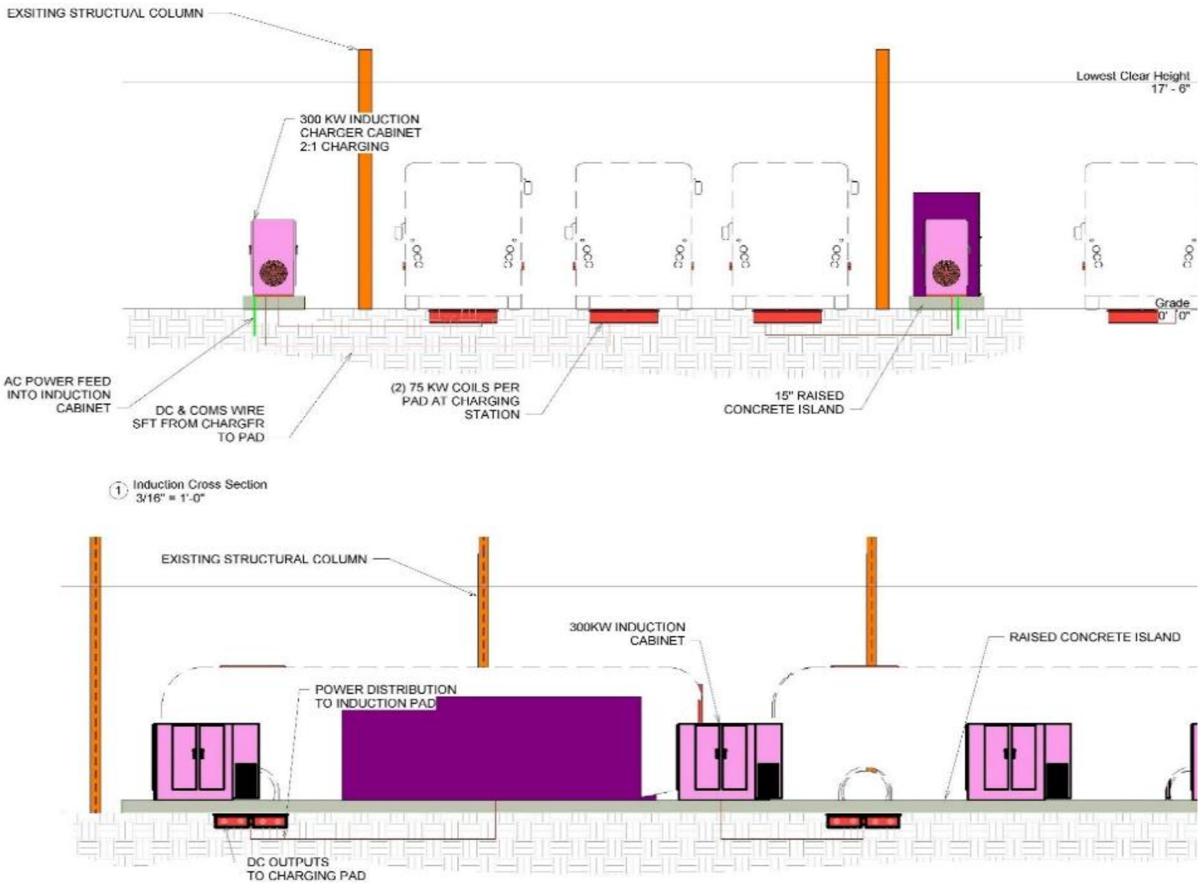
SOURCE: WSP

INDUCTIVE - WIRELESS CHARGING

Inductive chargers rely on inductive charging pads, one installed in the ground, and the other on the BEB. Powering the induction coil in the ground-mounted pad create an alternating electromagnetic field which induces current in the induction coil on the BEB, which charges the battery. The induction charger system brings some important advantages to the charging operation. Foremost is that no system connections are exposed, reducing corrosion from water or the salt and chemicals used to de-ice roads. In addition, the system needs no physical plug and unplug activity, thereby eliminating issues related to wear and tear. It requires no labor for external connections and requires no loose electrical cords. Buses equipped for induction charging have visual indicators to provide the vehicle operator with visual cues to precisely align the induction charging plates for efficient charging. More sophisticated (and expensive) systems provide steering assist for the driver to align charging surfaces.

Induction plate technology involves a substantial capital investment, and currently, only two manufactures provide equipment. Electrical feeders between the DC charger and the streetside induction plate are subsurface, requiring extensive excavation. In addition, electric buses must be specially equipped with matching induction coils and supporting electronics to be compatible with this charging method. It is the most expensive installed alternative. However, once installed, is the most flexible and, operationally, the least labor intensive of the three different types of charging. Induction charging can be used for both opportunity and depot charging. The concept is illustrated in Figure 2-4.

Figure 2-4: Induction Charging in Depot



SOURCE: WSP

Electricity Rates and Charging Structures

Typically, existing facilities are not supported by enough power for electrifying a fleet of buses. Power enhancements, including new circuits and upgrades to transformers and switchboards, are usually required by the utility. This additional infrastructure, as well as any resilience measures – such as backup power generation systems or on-site energy storage - can lead to challenges at spatially constrained sites. Additionally, power must be subsequently distributed to each vehicle, requiring elaborate electrical conduit and cable runs for charging infrastructure that must be carefully designed to limit negative impacts on transit operations and allow for efficient maintenance and repairs. These cables are typically trenched under exterior bus parking lots, garage floor slabs, or suspended from canopies or roof structures.

Operating a BEB system is an energy intensive activity; as such, energy tariffs play a key role in its practicality. Energy tariffs are aimed at balancing consumption through the day/year in order to match consumption with production and achieve a stable energy system. However, designing a tariff is a complicated task, with multiple factors influencing its structure, including regulations, politics, consumer behavior, and future developments. Tariff structures imposed by utilities on energy consumption play a crucial role in managing the cost of BEB transit networks, with underlying price structures that can include use, capacity, and energy-based fees. To ensure a sustainable business case for both utility companies and transit agencies, efficient, electric vehicle-centric tariffs may be required. Energy-based tariffs, for instance, might be negotiated with incentives for off-peak consumption, resulting in lower costs.

2.2 FUEL CELL ELECTRIC BUSES

Fuel cell electric buses (FCEBs) are a relatively nascent ZEB technology that is quickly gaining traction with the transit market. FCEBs do not experience the same range limitations as BEBs, however, they come at greater expense and require more space for fueling infrastructure.

Vehicles

FCEBs are electric vehicles that use on-board fuel cells to generate electricity. The fuel cell runs pure hydrogen through an oxidizing membrane, which produces electricity and water. Energy from the fuel cell is supplied to onboard batteries to power propulsion and other systems. Water is emitted from the tailpipe. Hydrogen is stored onboard the vehicle to operate the fuel cell in the same manner liquid fuels are stored in more conventional vehicles with internal combustion engines. Hydrogen behaves differently from gasoline or diesel, but if applied correctly, it is about as safe as gasoline. The volume and density of a gas changes with temperature and pressure but mass stays the same. For this reason, quantities of hydrogen are usually given in kg. A typical 40-foot FCEB can store approximately 38 kg of hydrogen with an expected range of up to 250 miles.

Fuel Production

There are two methods of producing hydrogen: steam methane reformation (SMR) and electrolysis. The method and location of hydrogen production has direct implications for the cost and greenhouse gases (GHG) emitted.

The most prevalent way to produce hydrogen (most hydrogen is produced this way), SMR, involves running methane (natural gas) through a reformer, and extracting hydrogen - the byproduct of this process is carbon monoxide. The overall cost and emissions of SMR depend on the source of the natural gas (renewable or fossil), as well as the proximity of the SMR facility to its end use. Small scale SMR equipment can be deployed onsite, and several small transit agencies have pursued this option. The majority of transit agencies using FCEBs have fuel delivery contracts with large scale SMR production companies. While utility scale hydrogen production is relatively inexpensive, providers typically pass the cost of delivery to the consumer at several dollars per kg of hydrogen. The delivery of hydrogen is typically via a diesel truck, which also can be problematic in terms of potential GHG goals.

Electrolysis is a process which splits hydrogen from water molecules using electricity. The cost per kg of hydrogen is dependent on the cost of electricity and water at the production location, and if produced onsite, the cost of infrastructure installation.

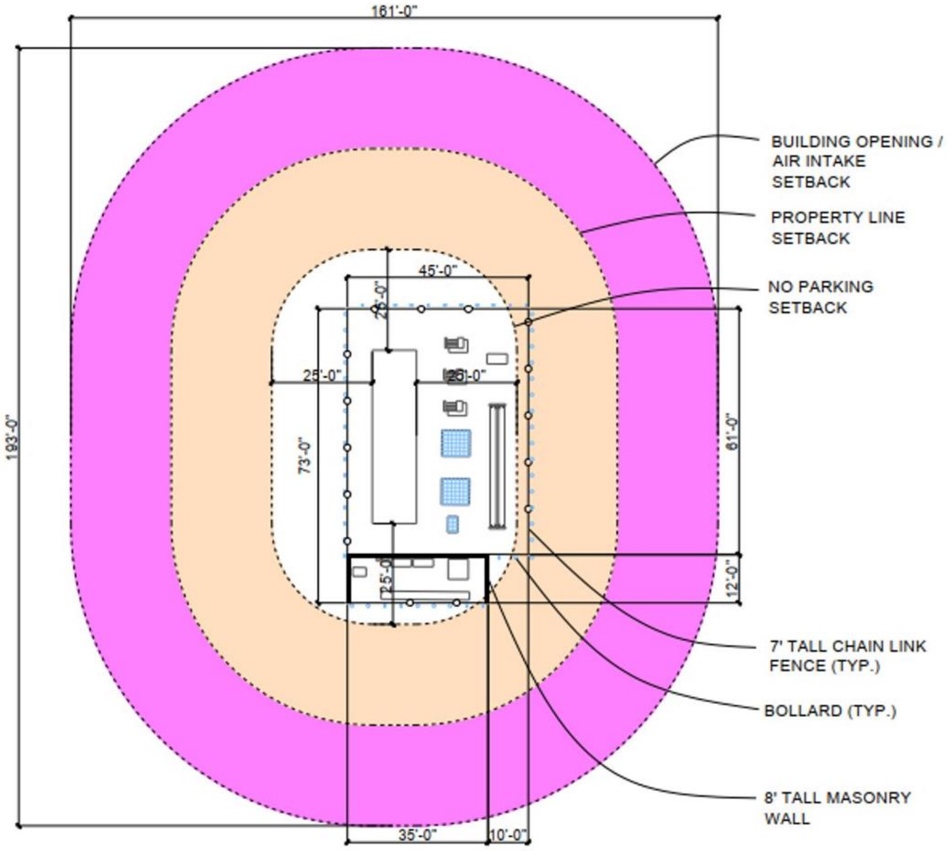
Infrastructure

The supply, storage, and fueling for FCEBs have their own infrastructure challenges that must be carefully planned for. When planning for an FCEB system, options for the transportation of fuel or, alternatively, on-site hydrogen re-formation, as well as storage, must be weighed against space requirements, costs, power requirements, and environmental factors.

OUTDOOR ABOVEGROUND STORAGE

Hydrogen fuel is typically stored in liquid form in large storage tanks. Figure 2-5 displays a hydrogen fuel storage tank capable of fueling 50 vehicles, as well as setbacks required by the NFPA. The NFPA required distance from outdoor bulk hydrogen systems to various exposures is dependent on the operating pressure of the system, piping size, and type of exposure. These distances are discussed further in Section 4.2 as well as Appendix C.

Figure 2-5: Liquid Hydrogen Storage with Setbacks



Source: WSP

3 CURRENT FLEET REPLACEMENT PLAN

3.1 EXISTING FLEET

The existing TARC fixed-route fleet is comprised of 236 standard buses. Of these, 210 are in active operation while the remaining 26 are inactive. Inactive vehicles include buses that are awaiting disposal. The fleet consists of 206 40-foot buses and 30 30- and 35-foot models.

While most of the fleet is diesel fueled, TARC also operates 28 hybrid diesel buses and 15 BEBs. A summary of the current fleet as of June 2022 is shown in Table 3-1 with a detailed inventory in Appendix A.

Table 3-1: Current Fleet Summary

YEAR	MAKE	LENGTH	TYPE	QUANTITY
2004	Gillig	40-foot	Hybrid Diesel	**4**
2005	Gillig	40-foot	Diesel	**16**
2007	Gillig	35-foot	Diesel	**6**
2007	Gillig	40-foot	Hybrid Diesel	**4**
2007	Gillig	40-foot	Diesel	**2**
2008	Gillig	40-foot	Diesel	**4**
2008	Gillig	40-foot	Hybrid Diesel	**2**
2009	Gillig	30-foot	Diesel	**3**
2009	Gillig	40-foot	Hybrid Diesel	**3**
2009	Gillig	40-foot	Diesel	**17**
2010	Gillig	40-foot	Hybrid Diesel	**7**
2010	Gillig	40-foot	Diesel	**2**
2013	Gillig	40-foot	Diesel	**14**
2013	Gillig	40-foot Commuter	Diesel	**21**
2013	Gillig	40-foot	Hybrid Diesel	**11**
2013	Proterra	35-foot	Electric	**2**
2014	Gillig	40-foot	Diesel	**14**

YEAR	MAKE	LENGTH	TYPE	QUANTITY
2014	Proterra	35-foot	Electric	**7**
2016	Gillig	40-foot	Diesel	**23**
2016	Gillig	40-foot	Hybrid Diesel	**1**
2016	Proterra	Catalyst	Electric	**6**
2017	Gillig	35-foot	Diesel	**2**
2017	Gillig	40-foot	Diesel	**2**
2019	Gillig	40-foot	Diesel	**8**
2019	Gillig	40-foot Commuter	Diesel	**8**
2021	Gillig	35-foot	Diesel	**4**
2021	Gillig	40-foot	Diesel	**41**
2021	Gillig	40-foot Commuter	Diesel	**2**
Total Fleet				**236**

3.2 BEB RANGE ANALYSIS

TARC's existing service was analyzed to determine if ZEB technology could meet the duty cycles of the fixed route fleet. TARC's January 2022 pre-pandemic service statistics were used to model the agency's routes at full capacity. A bus's daily service is divided into "blocks". Buses may travel one or more route blocks per day. TARC's service comprises 279 weekday blocks, 80 of which are all day blocks and the remaining 199 are partial day blocks.

To determine the ability of BEBs to meet TARC's existing service, a high-level analysis was performed. Existing BEBs in service today can achieve a range between 150 and 180 miles on a single charge. This broad range in capability is the result of cold weather, topography, driver operating behavior, and technology nascence. The benchmark range of 180 miles was applied to TARC's service blocks to ascertain the feasibility of converting the fleet to BEB. A more in-depth analysis may be performed with routes that partially exceed this benchmark or for routes that make good candidates for on route charging.

Based on this analysis of TARC's pre-pandemic service, 234 blocks, representing 84% of service, run less than 180 miles per day and can be electrified without impeding existing operations. The longest 45 blocks are on routes 10, 18, 19, 28, 43, and 63. These blocks cannot be fully electrified today, but improvements in technology may allow them to be electrified in the future. The detailed blocking analysis table, listing BEB-eligible blocks, is shown in Appendix B.

Of note, TARC had yet to return to pre-pandemic service levels. As of January 2020, the peak vehicle requirement was 174, whereas of June 2022, the peak vehicle requirement was 141 vehicles, representing a 19% reduction.

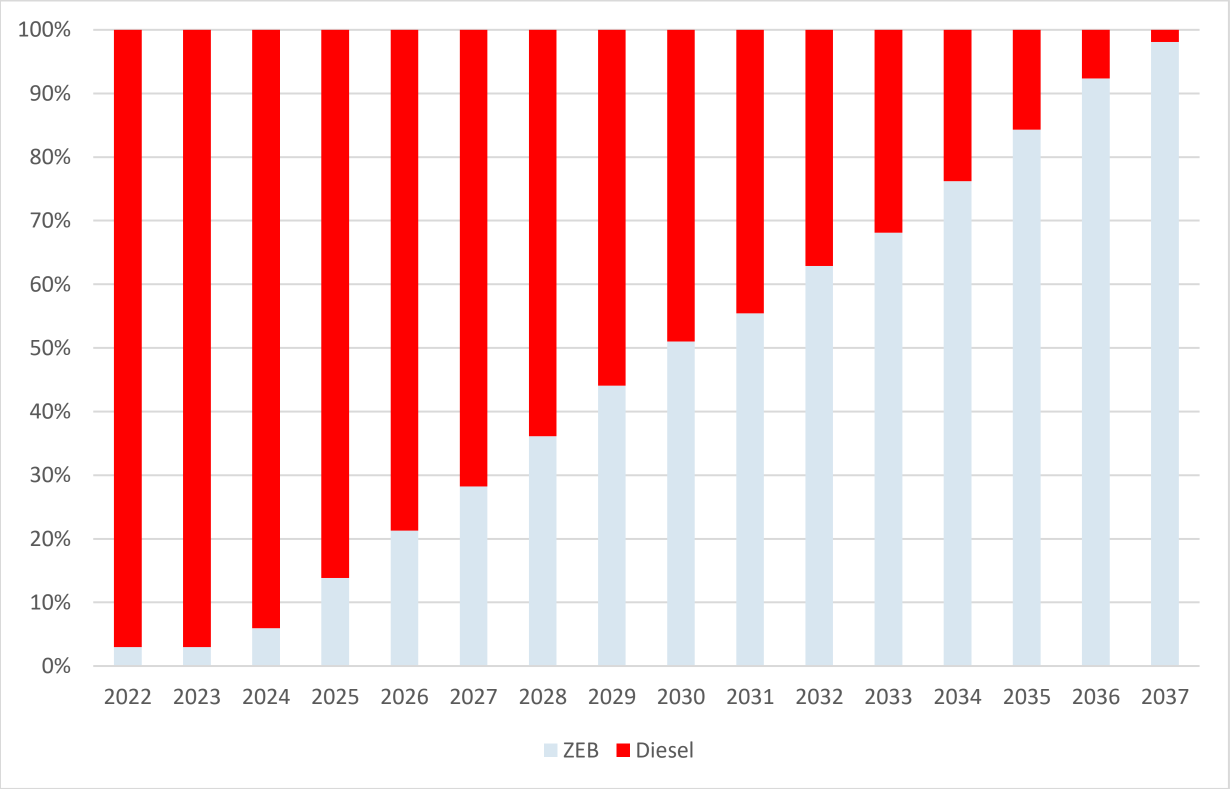
3.3 TARC FLEET REPLACEMENT SCHEDULE

The fleet replacement plan outlines TARC's projected vehicle retirements and purchases through 2036, as shown in Figure 3-1. The plan does not consider a transition to ZEBs but identifies how many buses are due for replacement in any given year based on completion of their expected useful life. While procurement and deliveries through 2024 have already been programmed, subsequent years provide TARC with the flexibility to plan for increased ZEV deployment as maintenance infrastructure is also expanded. By 2036, based on the useful lives of the existing bus fleet, all the fleet will have been replaced.

For the purposes of this analysis, a peak vehicle requirement of 174 buses is assumed (based on pre-COVID service). With consideration to the Federal Transit Administration's (FTA's) 20% spare ratio constraint, the maximum fleet requirement is projected to be maintained at 210 buses.

TARC currently has 14 2023 40-foot Gillig buses in production. In addition, six 2024 Nova LFSE and two 2024 40-foot Gillig buses are also on order. For years 2025 through 2036, 14 to 17 vehicles will need to be procured annually to maintain TARC's 174 peak-vehicle pull out. Most new bus purchases will be 40-foot vehicles with 35-foot procurements only in 2025 and 2034.

Figure 3-1: TARC Fleet Replacement Timeline



SOURCE: NELSON\NYGAARD BASED ON TARC DATA, 2022
SHADED INVENTORY IS ELIGIBLE FOR RETIREMENT BASED ON AGE

4 ZEB TECHNOLOGY & FACILITIES ASSESSMENT

The assessment of the capabilities of TARC's operating and maintenance facilities is based on facility documentation provided by TARC, interviews and discussions with key TARC personnel, and an on-site visit conducted in March 2022.

4.1 METHODOLOGY

To assess TARC's operating and maintenance facilities, the project team conducted the following:

- Reviewed plans, drawings, and other documentation provided by TARC.
- Conducted a two-day site visit in March 2022 of TARC's two operating and maintenance facilities.
- Analyzed surrounding area land uses as part of the site visit and by using Google Earth.
- Interviewed key TARC operations, maintenance, and planning staff during the site visit.
- Conducted several follow-up conversations with TARC staff.
- Researched facility and power requirements of BEB and FCEB technologies.
- Obtained information on existing power systems and capacity from LG&E, TARC's utility provider.

4.2 BEB CAPABILITIES

The following section details ZEB conversion challenges and recommendations for TARC's fleet, facilities, and transition timeline.

Facility Capabilities

Both of TARC'S operating campuses were examined for adaptation to electrical bus infrastructure: the "bus barn" located at TARC's main facility at 1000 West Broadway and the bus barn located at its 29th Street facility (2900 West Broadway). Although both facilities have the capacity to be converted for use by BEBs, each has limitations, including insufficient electrical service suitable for extensive bus charging.

TARC's fixed route fleet currently berths at the bus barn at the main 1000 West Broadway facility. The main bus barn provides approximately 185,000 sq. ft. of raw storage area, including continuous main circulation lanes on the west and east side of the building. Buses enter at the northwest corner and exit at the northeast corner of the facility. According to record drawings, the main bus barn facility incorporates two 600kW bi-fuel generators connected in parallel and distributed to three emergency feeder circuits: the T&O Building, Union Station, and the bus barn. Main electrical utility service is provided by LG&E.

The bus barn at the 2900 West Broadway facility is used for storage of out-of-service rolling stock and temporary storage for vehicles awaiting service at the adjacent repair facility located south of the bus barn (and facing Broadway). It contains approximately 75,000 sq. ft. and is located adjacent to a TARC repair facility across a paved yard to accommodate bus traffic between buildings and the entrance at 30th Street. The 2900 West Broadway facility has been modified to house two paint facilities, leaving a usable bus storage of approximately 55,000 sq. ft. It is served by a small aerial feeder from the adjacent maintenance facility for general lighting and electrical, and a larger service through a pad transformer on 30th Street for a new paint booth in the west end of the facility. LG&E serves the maintenance facility from West Broadway.

Accommodating BEBs at TARC

Under a BEB transition scenario, TARC would convert its fleet of 205 40-foot vehicles using a charging level of 60 kW per vehicle, with the capability to intermittently provide increased charging rates as needed. Equipment required, including 60 kW dispensers, charging cabinets, and utility upgrades is shown in Table 4-1. Of note, 60 kW dispensers are recommended; it is likely that TARC can utilize a mixture of ground mounted and overhead plug-in dispensers. Using an all ground-mounted plug-in strategy, TARC may need to sacrifice some space inside its facility for charging lanes. Adding overhead plug-in dispensers will alleviate this space constraint. While TARC may have the height clearance in some parts of its facility to support overhead pantograph depot (in-garage) charging, the HVAC system may provide a height clearance problem in portions of the facility. As a result, this strategy is not recommended for depot charging. TARC will need to work with a designer to support 100% facility design activities to optimize the configuration of chargers, charging lanes, and vehicles.

Table 4-1: Proposed Charging Equipment

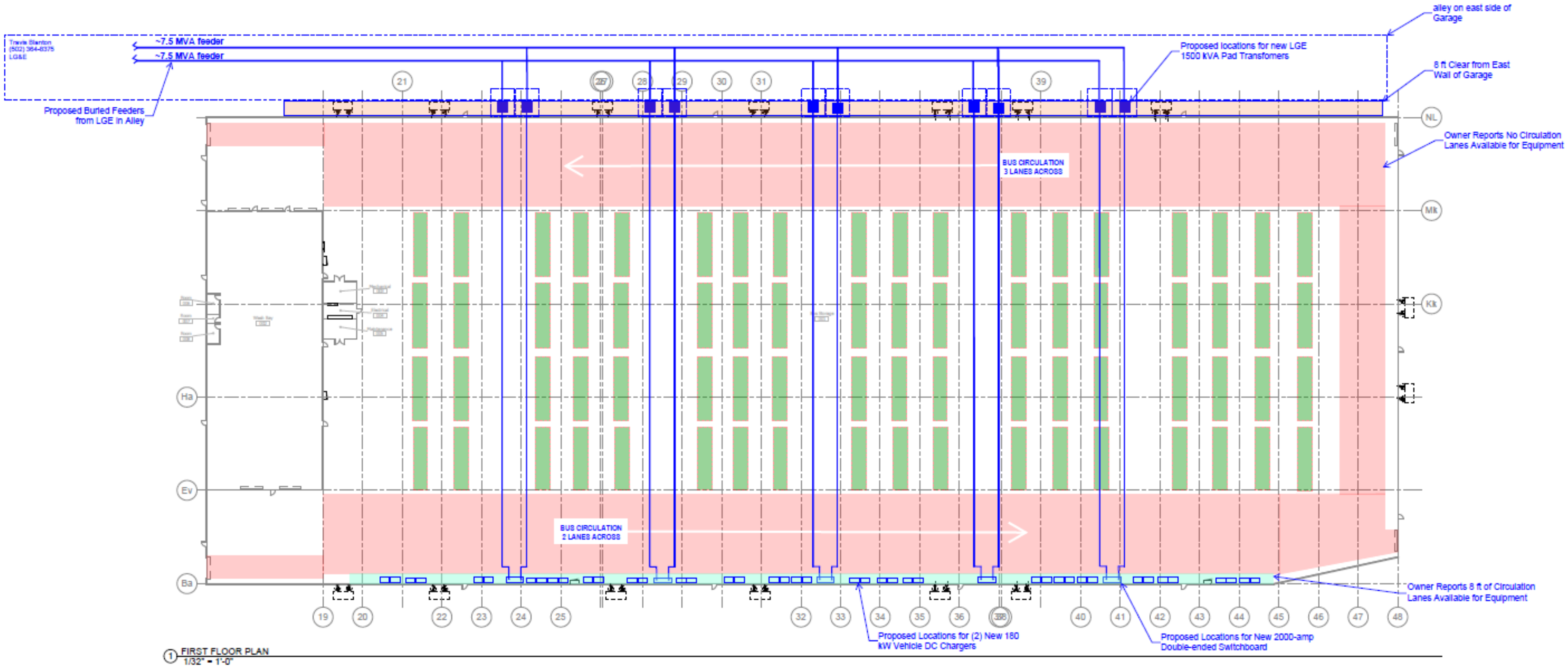
QUANTITY	DESCRIPTION
200	60kW charger dispensers, ground mounted and overhead plug-in
34	360kW charger cabinets
5	2000 amp, 480/277 Volt double-ended switchboard
10	1500kVA pad transformers
2	7.5 MVA utility feeders

A word of caution regarding utility demand: The existing LG&E tariff is heavily weighted so that instantaneous demand could asymmetrically affect monthly electrical charges. Despite the proposed system's capability, discretion should be exercised to limit instantaneous demand with a strategy of scheduling daily charging operation over a wider schedule window to consume the same energy with lower demand.

Switchboard: If the fleet is to transition to solely BEBs, new charging capacity should be supplied using a 2000-amp, 480/277-volt, three-phase, four-wire, double-ended switchboard that makes use of molded-case breaker technology. The "double-ended" switchboard is characterized by two independent main buses, each with its own main breaker. The switchboard architecture would feature an interconnecting bus with a normally open breaker that would close automatically in the event either incoming feeder is interrupted. In addition, the main breaker affected by the outage would open. This "automatic throwover" mechanism would permit any one of the chargers on the affected buses to continue operation, although at half capacity. When power is restored, automatic mechanisms reverse the sequence to restore breakers to normal—isolated—operation. It is expected that each incoming feeder (two per switchboard) will be separately metered, and LG&E will impose its secondary power tariff.

A 1500 kVA is the maximum readily available pad transformer that can be supplied by LG&E. each 1500 kVA transformer circuit is conservatively capable of serving four Heliox 360 chargers or eight Heliox 180 chargers. It would be expected that LG&E can and does furnish higher-rated transformers; however, making use of inventory units that are readily available will permit LG&E to streamline installation schedule and quickly address damaged transformers should the need arise. Each switchboard would be served by two transformers, each transformer served by one of two nearby LG&E medium voltage feeders, so that no switchboard is served by the same LG&E circuit.

Figure 4-1: Potential BEB Charging and Storage Layout at 1000 West Broadway



Major Components

Qty	Description
200	60kW charger dispensers
67	180kW charger cabinets
5	2000 amp, 480/277 Volt double-ended switchboard
10	1500 kVA pad transformers
2	7.5 MVA utility feeders

SOURCE: WSP

4.3 FCEB CAPABILITIES

TARC'S two operating campuses were examined for adaptation to hydrogen infrastructure: the main facility at 1000 West Broadway and the secondary facility located at 2900 West Broadway.

Hydrogen Requirements

OUTDOOR ABOVEGROUND STORAGE

Hydrogen fuel is highly flammable; NFPA codes requires buffer setbacks to separate bulk hydrogen storage. The distance from outdoor bulk hydrogen systems to various exposures is dependent on the operating pressure of the system, piping size, and type of exposure. Compressed hydrogen for use for FCEBs will range from 5,000 to 10,000 psi. "Exposure" is a measure of risk associated with objects and distances in range of a potential hydrogen accident. Exposures are categorized in three groups as follows:

Exposures Group 1

- Lot lines
- Air intakes (HVAC, compressors, other)
- Operable openings in buildings and structures
- Ignition sources such as open flames and welding

Exposures Group 2

- Exposed persons other than those servicing the system
- Parked cars

Exposures Group 3

- Buildings of non-combustible non-fire-rated construction
- Buildings of combustible construction
- Flammable gas storage systems above or below ground
- Hazardous materials storage systems above or below ground
- Heavy timber, coal, or other slow-burning combustible solids
- Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas
- Unopenable openings in building and structures
- Encroachment by overhead utilities (horizontal distance from the vertical plane Below the nearest overhead electrical wire of building service)
- Piping containing other hazardous materials
- Flammable gas metering and regulating stations such as natural gas or propane

Due to the storage pressure for FCEBs, the minimum distance from a gaseous hydrogen system located outdoors to specified exposures shall be in accordance with NFPA 2, Table 7.3.2.3.1.1(A)(c), excerpts of which are included in the Appendix.

Except for distances to air intakes, the distances to Group 1 and 2 exposures may be reduced by one-half and shall not apply to Group 3 exposures where fire barrier walls are located between the system and the exposure.

MAINTENANCE AND REPAIR FACILITIES

Facilities for maintenance of hydrogen fueled vehicles need to be constructed to limit sources of ignition for flammable gas that may be accidentally released and to evacuate any such gas that is released. Facilities in which a combination of diesel, unleaded and lighter than air gas fueled vehicles may be maintained need to restrict ignition sources where flammable fumes may accumulate, both near the floor and near the ceiling.

Hydrogen is a colorless, odorless gas. Unlike CNG, which is odorized with mercaptan as a safety precaution so that leaking CNG can be detected by smell the same as natural gas used for comfort heating, hydrogen used in HFCBs is not odorized. Maintenance facilities require hydrogen gas sensors to detect and alert operators to the presence of the odorless, colorless, gas.

FCEB Capabilities

The facility at 1000 West Broadway has the capacity to fuel 50 vehicles with minimal space restrictions, and up to 100 vehicles with some impacts to the facility. Based on field observations and discussions with TARC personnel, it is WSP's understanding the 1000 West Broadway repair facility is considered a minor repair garage while the 2900 West Broadway repair facility is considered a major repair garage. The 2900 West Broadway facility currently contains automatic fire suppression sprinklers. Both storage and maintenance facilities require modifications to fuel, store, and maintain FCEBs. TARC's existing facility does not have space for onsite production, and few utility scale electrolysis plants exist, though more are currently planned or under construction.

Accommodating FCEBs at TARC

To accommodate FCEBs and hydrogen fueling, the following actions and infrastructure modifications and improvements to TARC's operating and maintenance facilities with regard to implications of utilizing FCEBs vehicles include:

1000 West Broadway:

- **The minor repair garage (1000 West Broadway) maintenance bay ventilation systems be evaluated to ensure compliance with the mechanical code requirement exhaust rate not less than 0.75 cfm/ft^2.** Existing Co-ray-vac heating systems would need to be evaluated for their compliance with NFPA code.
- **Safety equipment should be on emergency power.** This includes the major repair garage maintenance bay ventilation system equipment, designated overhead door operators and proposed gas detection system.
- **Any conduits routed up to roof mounted equipment (MAUs, EFs etc.) need to be suitable for a classified environment if the space does not have continuous ventilation.**

2900 West Broadway:

- **Install a new hydrogen gas detection system in the major repair garage.** In addition to improving safety in the facility and automatically controlling ventilation and ignition sources, the gas detection system provides a means of detecting problems with vehicle or maintenance systems by identifying the location of a gas release if one should occur and to notify building occupants of a potential increased hazard. The gas detection system should be able to log faults and gas detection at individual detectors and should allow for calibration of sensors.
- **Provide continuous ventilation at a rate not less than 1 cfm/ft^2 in where FCEBs will be repaired.** The ventilation will mitigate the need to electrically classify the area within 18" below the roof deck. The existing make-up air units and exhaust fans should be evaluated to determine the airflow capabilities.
- **Install automatic or self-closing man doors between the repair bays and the machine shop area.**
Isolate adjoining areas such the steam clean component room. To prevent fugitive hydrogen from migrating from areas designed for FCEB operations and reduce the amount of ventilation airflow in the major repair garage (29th &

Broadway) maintenance bays, the adjoining areas such as the steam clean component room should be effectively isolated by walls that extend to the roof deck.

- **Safety equipment should be on emergency power.** This includes the major repair garage maintenance bay ventilation system equipment, designated overhead door operators and proposed gas detection system.
- **Remove the existing infrared radiant tube heating system (Co-ray-vac) serving the major repair garage (29th & Broadway) maintenance bays.** The infrared heating system has surface temperatures exceeding 750°F which is a potential ignition source of flammable concentrations of gas.
- **Do not conduct hot work near FCEBs.** Any of the major repair garage (2900 West Broadway) maintenance bays may have work done using a welder and/or torch. Since these are ignition sources, FCEBs should not be in the garage when hot work is being done or the CNG bus shall be defueled if remaining in the garage during hot work.
- **Any conduits routed up to roof mounted equipment (MAUs, EFs etc.) need to be suitable for a classified environment if the space does not have continuous ventilation.**

To reduce the impact of the recommendations above, a number of major repair bays could be effectively isolated from others for specific usage of FCEB repair work. An "isolated" maintenance bay would require walls extending up to the ceiling, and fireproof doors between the isolated bay and the remainder of the maintenance garage. A working relationship with local fire marshals can help guide TARC's process if Hydrogen is pursued as the ZE technology of choice. Additional resources providing guidance for conversion to FCEBs are listed in Appendix C.

4.4 RESILIENCE & SOLAR POWER

Both BEB and FCEB technologies will require some level of resilience in the face of a power outage to TARC's facility, or fuel delivery interruption. To provide resilience to FCEB service, fuel storage tanks and fuel delivery schedules may be optimized to maintain fuel reserves in the event of a delivery interruption. Resiliency for BEB service can be more difficult. A combination of on-site generators, solar power, and battery storage may help offset TARC's electricity needs in case of an outage.

TARC's facility at 1000 Broadway was analyzed for solar production using the PVWatts online tool. The rooftop of this facility has the space to install a 2500 kW DC solar array. Table 4-2 provides the estimated monthly output of this solar array in MWh. Power output of the solar array fluctuates depending on the season, with greater consumption in the summer. The amount of power theoretically produced accounts for roughly one-tenth of that used to charge a 100% BEB fleet.

Table 4-2: Monthly Output of Rooftop Solar Array

MONTH	DC ARRAY OUTPUT (MWh)
Jan	203
Feb	220
Mar	299
Apr	337
May	370
Jun	369
Jul	367
Aug	361
Sept	311
Oct	288
Nov	215
Dec	184
TOTAL	3,528

4.5 TECHNOLOGY AND FACILITIES ASSESSMENT CONCLUSIONS

The primary constraint of achieving a 100% zero emission fleet is the physical limitation of TARC's existing operating and maintenance facilities. A full conversion to BEBs is possible; however, a full conversion using FCEBs is not. Both facilities are located in areas where expansion is either limited or unlikely given the surrounding built environment. TARC does not currently have the wherewithal to replace its facilities with a new facility that would accommodate the existing fleet, provide the flexibility to allow for an expanded fleet, and allow for full conversion from diesel to ZEB, either employing all BEBs, all FCEBs, or a combination of both.

While there is potential to use the 2900 West Broadway facility, this would require moving buses between 1000 West Broadway and 2900 West Broadway at least once a day, and possible more than once, the refuel and/or recharge. This would result in an onerous operating situation in terms of time and operating cost (labor) and it is not recommended. Should TARC choose to re-establish 2900 West Broadway as a full operating division in the future, a major overhaul would be necessary given the current configuration and ceiling height, which provides insufficient space for overhead charging units. It is possible to accommodate 60 floor-mounted dispensers, but this would also require a significant reconfiguration of the space along with two 2 megawatt (MW) feeders from LG&E.

Therefore, based on the current situation, given available space and facilities constraints, the following scenarios are possible at TARC:

SCENARIO 1: ALL BEB

TARC's facility can likely support a full fleet conversion to BEB technology. The majority of TARC's routes can also be covered by existing BEB technology, and the 1000 West Broadway facility could be configured to serve the existing fleet without use of the 2900 facility for overnight charging and storage.

SCENARIO 2: PARTIAL FCEB

TARC's facility can accommodate the fueling infrastructure for 50 FCEBs without much constraint, and up to 100 FCEBs with some design constraints to the facility. Additional land would be required to install fueling infrastructure for the entire fleet. To reach 100% ZEB, half of TARC's fleet would be converted to BEB.

RECCOMENDATION

It is recommended that TARC pursue a 100% BEB technology strategy to achieve a ZEB fleet. Although both scenarios are viable, the majority of TARC's existing service can be electrified with today's BEB technology, and battery capacity is expected to improve in the coming years to support the remainder of TARC's service. TARC can convert fully to ZEB technology with minimal constraints to its facilities with this technology.

4.6 TRANSITION TIMELINE

WSP has developed a sample schedule for TARC's transition based on assumptions listed in Table 4-3. These assumptions are based off of experience developing transition schedules for a variety of public transit agencies and may differ based on TARC's unique needs. This schedule was developed to support the procurement schedule in Section 3 of this report, which has TARC's next procurement of ZEBs arriving in 2024, while also allowing TARC as much time as possible to work with designers as well as LG&E.

The transition timeline is divided up into three components: Utilities, Facilities and Vehicles. Utility and Facility Development would prepare TARC to accept BEBs and infrastructure through their transition period. Utilities application, design, and construction can take up to 36 months, though this timeline is shorter or longer depending on LG&E and power required. The facilities timeline is based upon a design-bid-build strategy. The lengths of time required for each stage of this process depends heavily on TARC's internal procurement and design procedures, but the assumptions below give a rough estimate based off experience with other agencies. The facility build itself is divided into three "phases" to allow partial fleet relocation during construction.

These assumptions take into account a preliminary procurement schedule, and two rounds of bus production extending into 2025. It is assumed that TARC will not go out for bid in successive years for vehicles, but instead, exercise options off a procurement contract for several years before going out for bid. It is also assumed that chargers will be purchased with vehicles and electrified by infrastructure installed in the bus barn.

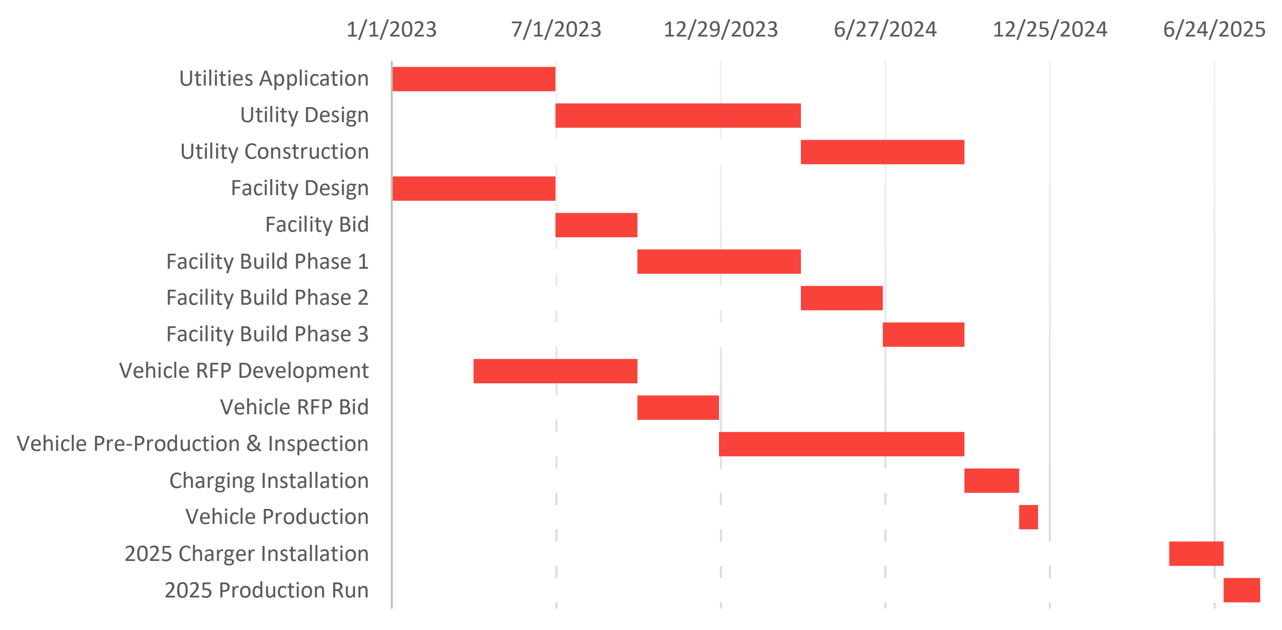
Table 4-3: Transition Timeline Activities & Assumptions

ACTIVITY	START DATE	DURATION (DAYS)
Utilities Application	1/1/2023	180
Utility Design	6/30/2023	270
Utility Construction	3/26/2024	180
Facility Design	1/1/2023	180
Facility Bid	6/30/2023	90
Facility Build Phase 1	9/28/2023	180
Facility Build Phase 2	3/26/2024	90
Facility Build Phase 3	6/24/2024	90
Vehicle RFP Development	4/1/2023	180
Vehicle RFP Bid	9/28/2023	90
Vehicle Pre-Production & Inspection	12/27/2023	270
Charging Installation	9/22/2024	60
Vehicle Production	11/21/2024	21

SOURCE: WSP

It is paramount that TARC complete infrastructure to support vehicles before vehicles arrive onsite. The schedule in Figure 4-2 includes utility and facility design, as well as the first two procurements in 2024 and 2025. Due to 2024 being a relatively small procurement year, only six vehicles, it may be possible to support those vehicles with existing utility service and extend this timeline to prepare the bus barn for the 2025 procurement year.

Figure 4-2: Sample Transition Timeline, 2023-2025



SOURCE: WSP

Procurement & Training Considerations

Work with transitioning agencies around the country has resulted in a variety of lessons learned for both procurement and incorporation of ZEB technology into a fleet. The following considerations should be made in developing TARC's full fleet transition:

- **Facility construction and infrastructure installation should complete before buses arrive onsite.** This will ensure that vehicles can be used when they arrive and prevent warranty delays.
- **Training is typically, and should be, provided by bus original equipment manufacturers (OEMs) and coincide with bus pre-production activities.** OEMs provide training for operators, mechanics, maintenance staff, and emergency responders. This training should focus on high voltage "lock out tag out" procedures and other safety considerations.
- **TARC may consider "evergreen battery warranties" to ensure performance for the lifetime of a vehicle.** Adding warranty language to bus contracts will allow TARC to maintain its fleet performance as batteries age.
- **TARC should engage a facility designer to perform 100% designs.** Regardless of technology choice, a facility designer will enable TARC to best optimize their facility to fit new technology with minimal impact to ongoing operations.

5 LIFECYCLE COST ANALYSIS

The purpose of the lifecycle cost analysis is to provide in-depth analyses on the lifecycle costs for TARC's fleet transition effort. The lifecycle cost estimation includes cash and non-cash costs. Cash costs consist of vehicle and infrastructure capital costs, operating and maintenance costs, and disposal costs. Non-cash costs consist of environmental costs and benefits. As previously described, the BEB compatible blocks are listed in Appendix B.

5.1 METHODOLOGY

The following section provides an overview of the inputs (data and assumptions), methodology, and outputs used to determine the viability of operating electric and hydrogen buses based on TARC's existing service schedules.

The WSP team is actively engaged with fuel providers, agencies operating zero-emission buses, and vehicle manufacturers to understand technology and cost trends in the industry. This information is utilized to inform assumptions on the availability and pricing of vehicles and supporting infrastructure. The values presented are subject to change and are based on the most current information available at the time of this analysis in mid-2022.

Compared to conventional diesel, gasoline, and CNG vehicles, ZEBs incur different capital and operating costs. For example, in the case of BEBs, the cost to install and maintain utility and charging infrastructure will differ in both the magnitude and the types of resources required in comparison to existing diesel storage and fueling facilities. Other examples include FCEB infrastructure and operating requirements, battery replacement schedules, vehicle components requiring mid-life overhaul, and disposal values for the vehicles and batteries.

The total cost of TARC's transition will be contingent upon its specific fleet size, bus acquisition plan, facility sizes, charging strategy, construction schedule, pursuit of applicable grant and funding programs, among other details.

The structure of the lifecycle cost modeling includes the assessment of capital, operating, disposal, and monetized environmental costs associated with the transition of TARC's existing vehicles under a No Build and Build Scenarios, defined as:

- **No Build Scenario** - Continued operation of TARC's current mix of clean diesel-fueled and hybrid vehicles with replacement by similar models at the end of the assumed vehicle service life
- **Scenario 1: 100% BEB Build Scenario** - Replacement of TARC's current clean diesel-fueled and hybrid vehicles with BEBs at the end of the assumed vehicle service life
- **Scenario 2: Mixed BEB/FCEB Build Scenario** - Replacement of TARC's current clean diesel-fueled and hybrid vehicles with 100 FCEB and 110 BEB vehicles at the end of the assumed vehicle service life

The lifecycle costs are assessed over the vehicles' operating years to account for their full operating costs over 15 years for buses.

BEBs and FCEBs and required facilities may offer the opportunity for TARC to lower some operations and maintenance costs; however, other costs will increase. Like conventionally fueled vehicles, BEB and FCEB operations and maintenance costs are highly dependent on the size and complexity of the vehicle fleet. Additionally, an electrification strategy would shift TARC's primary fuel source for core bus operations from diesel to electric power, which would subject the agency to very different energy pricing structures and exposure to energy price volatility. Table 5-1 outlines the major cost categories evaluated as part of the lifecycle analysis.

Table 5-1: Primary Cost Categories

TYPE	COST COMPNENTS ATTRIBUTED TO LIFECYCLE ANALYSIS
Capital	Vehicle Purchase Price
	Modifications & Contingency
	Charging or Fueling Infrastructure
Operating	Vehicle Maintenance, Vehicle Tools, Training and Equipment
	Vehicle Fuel/Energy Costs
	Tire Replacement Costs
	Battery Replacement Costs
	Fueling or Charging Operational Costs
Disposal	Battery Disposal Cost or Salvage Value
	Bus Disposal Cost or Salvage Value
Environmental	Vehicle Emissions
	Upstream Emissions
	Noise

SOURCE: WSP

5.2 GENERAL DATA, ASSUMPTIONS, AND LIMITATIONS

This section details the data inputs and sources, and operational assumptions underlying the lifecycle cost analysis and modeling for all the fleet operators.

General Data Sources

Lifecycle cost modeling utilizes various capital, operating, disposal and environmental assumptions. Wherever possible, agency-specific datapoints are used to inform the cost assumptions and when unavailable, peer agency data and WSP assumptions based on previous experience with other agencies are leveraged.

Capital Costs: Vehicles

Capital costs of vehicles are sourced from the base vehicle prices provided through the California State Buyboard for BEBs, the American Public Transportation Association (APTA) 2020 vehicle inventory and recent TARC experience for internal combustion (diesel and hybrid) vehicles. The additional cost of battery extended warranties were applied to the capital cost of BEBs. Vehicle costs represent the cost of replacing the existing vehicle fleet and do not consider incremental vehicle requirements due to potential range reductions from the transition to BEBs. Capital costs of vehicles are incurred based on the fleet replacement plan developed by WSP in support of Task 4. The fleet replacement plan is based on the current operations of TARC with the assumption that BEB and FCEB-related infrastructure costs will be incurred during the applicable vehicle transition timeframe. Vehicle purchases for BEB and FCEB conversion may not fully align with the current vehicle fleet due to other operational considerations. Additionally, capital costs of vehicles are incurred one year prior to operational start date to account for delivery lag and acceptance testing.

Capital Costs: Infrastructure

Capital costs for charging and fueling infrastructure are based on recent experiences of peer agencies to replace their existing fueling tanks for the No Build scenario. For the Build-BEB scenario, infrastructure cost estimates represent the cost to procure, design, and install BEB chargers. For the Build-FCEB/BEB scenario, infrastructure costs represent the price of delivered hydrogen. Cost assumptions were developed by a WSP cost estimator, or in the case of comparable cost estimates, by a contractor. The facility cost estimates prepared by WSP are based on a combination of facility improvements, vehicle charger units, and supporting utility infrastructure upgrades. Current costs for BEB chargers were used and applied to each facility based on the number of anticipated BEBs in operation. Facility improvements and utility upgrades are based on unit estimates and corresponding unit costs values. The analysis does not amortize the capital costs and assume costs will be incurred during the specified fleet replacement years or assumed construction period.

Operating And Maintenance Costs

Operating and maintenance costs are evaluated on a cost per mile basis and applied to the average vehicle mileage over the lifecycle of BEB, FCEB, diesel-electric hybrid, and internal combustion (diesel) vehicles. The operating life of the vehicles is assumed to be 15 years for transit buses. The average mileage of each vehicle type is determined based on the fleet odometer for each vehicle. Values on operating costs per mile are sourced from the operating experience of peer agencies. Fuel costs (electricity) are based on the utility tariffs of TARC's local utility, LG&E. Diesel fuel costs are based on five-year historical trends. Disposal costs are based on the current FTA guidance. Lastly, the environmental assumptions for tailpipe and lifecycle greenhouse gas (GHG) emissions are based on Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, Fuel Pathways by the California Air Resources Board (CARB), and the EPA Moves 2014b model.

General Inflation

The lifecycle cost model accounts for inflation using the historical Consumer Price Index for all Urban Consumers (CPI-U) and Producer Price Index (PPI) for Bus Chassis Manufacturing. The model accounts for the historic differential in growth rates based on the regional CPI-U. Table 5-2: National Consumer Price Index for all Urban Consumers (CPI-U) and National PPI for Bus Chassis Manufacturing Based on Historic Ratio is an overview of CPI-U values from 2021 through 2024, which is also the rate assumed through the remaining forecast horizon. The historical values through June 2022 are provided by federal Bureau of Labor Statistics and PPI for Bus Chassis Manufacturing. After June 2022, annual growth rates are based on anticipated lower cost increases in 2023 and a return to historical averages starting with the 2024 values. For example, a 40-foot BEB purchased in 2022 for $991,000 is assumed to cost $1,026,000 in 2025 after one year of escalation at 3.66% based on assumed increases in PPI. The resulting value is the year of expenditure (YOE) dollar amount that is presented in the lifecycle cost model output tables. For purposes of economic analysis of various technological alternatives and application to various federal benefit-cost analysis requirements for discretionary grants a discount rate is also considered.

Table 5-2: National Consumer Price Index for all Urban Consumers (CPI-U) and National PPI for Bus Chassis Manufacturing Based on Historic Ratio

FACTOR	2021	2022	2023	2024+
CPI-U	5.30%	9.06%	5.40%	2.30%
PPI Bus Chassis Manufacturing	6.60%	10.36%	6.70%	3.60%

SOURCE: BUREAU OF LABOR STATISTICS

Discount Rates

Total agency lifecycle cost analysis results are provided in YOE dollars and also provided in discounted 2021 dollars that align with U.S. Department of Transportation (USDOT) benefit-cost analysis requirements. The lifecycle cost model employs nominal discount rate of 9.5%. The rate accounts for the typical 7% real discount rate required by

USDOT on federal grant applications and an addition of average escalation of approximately 2.5% to offset escalation factors assumed in the lifecycle cost model. The application of discount rates reflects that benefits and costs incurred in the near term are more highly valued than benefits and costs incurred in a future year. The costs incurred are assumed to divert funds from alternative investments in economically beneficial activities in future years, which is quantified through discounting, and normalization of future benefits and costs in present values to provide a comparable basis in investment alternatives.

5.3 COST ANALYSIS

This section outlines the cost assumptions for the lifecycle cost analysis of continued operations of diesel buses and the cost to transition to BEB (Scenario 1) and BEB/FCEB (Scenario 2) vehicles for TARC. The four major categories for the cost assumptions are capital, operating, disposal, and environmental.

Vehicle Procurement Schedule

Two main factors are considered with vehicle procurement: timing and quantity. The number of vehicles being procured is determined by how many vehicles can be accommodated at each facility and the quantity needed to maintain services.

The procurement timeline needs to align with facility enhancements and is subject to considerations such as the useful life of the vehicles and any established procurement goals. The lifecycle model assumes that buses will be retired 15 years after their acceptance date.

The following vehicle procurement schedule (Table 5-3: Build and No Build Scenario Vehicle Replacement Schedule) was developed by WSP in alignment of TARC's transition schedule.

Table 5-3: Build and No Build Scenario Vehicle Replacement Schedule

VEHICLE TYPE	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
NO BUILD SCENARIO														
35ft Diesel	-	-	6	-	-	-	-	-	-	-	-	7	-	-
40ft Diesel	14	-	10	5	14	16	5	14	14	15	16	10	17	17
40ft HYB	-	8	-	10	-	-	11	-	1	-	-	-	-	8
BUILD SCENARIO 1: 100% BEB														
35ft BEB	-	-	6	-	-	-	-	-	-	-	-	7	-	-
40ft BEB	14	8	10	15	14	16	16	14	15	15	16	10	17	17
BUILD SCENARIO 2: MIXED BEB/FCEB														
35ft BEB	-	-	6	-	-	-	-	-	-	-	-	7	-	-
40ft BEB	14	8	10	-	-	-	-	-	-	5	16	10	17	17
40ft FCEB	-	-	-	15	14	16	16	14	15	10	-	-	-	-

SOURCE: WSP

Capital Cost

Bus capital costs are based on standard vehicle purchase prices, after-market equipment, allowances for contingency, and charging infrastructure. Charging and fueling infrastructure requirements are a key consideration for BEBs and FCEBs. Costs are based on the number of operating vehicles per facility and their expected lifespan, to estimate the total infrastructure costs per bus.

VEHICLE PURCHASE COST

Vehicle purchase costs includes the standard purchase price and additional options and charges as shown in Table 5-4: Vehicle Purchase Price Assumptions (2021 dollars). The values provided exclude sales tax costs assumed to be 6.0 percent. For BEBs, an additional cost for battery extended warranty over the life of the vehicle is assumed. All values are rounded to the nearest thousands.

VEHICLE MODIFICATIONS AND CONTINGENCY

In addition to the vehicle purchase costs, considerations are made for service preparation and inspection (2 percent of base vehicle price), special tools and diagnostic equipment (0.3 percent of base vehicle price) and allowances for contingency based on the vehicle base price and existing experience of the bus manufacturer (5 percent for hybrids and diesels and 10 percent for BEB and FCEB models).

Table 5-4: Vehicle Purchase Price Assumptions (2021 dollars)

VEHICLE TYPE	BUS COST ESTIMATE	ADDITIONAL OPTIONS AND CHARGES	TOTAL VEHICLE PURCAHSE COSTS[2]
35ft Diesel	$428,000[3]	$58,000	$487,000
40ft Diesel	$433,000[4]	$58,000	$492,000
40ft Hybrid	$836,000[5]	$58,000	$894,000
35ft BEB	$783,000[6]	$100,000	$883,000
40ft BEB	$956,000[7]	$100,000	$1,056,000
40ft FCEB	$1,087,000[8]	$58,000	$1,145,000

SOURCE: WSP

SUPPORTING INFRASTRUCTURE COST

Charging and fueling infrastructure includes the supporting equipment and facility construction to support the operations and maintenance of buses. Charging infrastructure conceptual estimates are developed by a WSP cost estimator based on the equipment and construction needs to host battery electric buses at TARC facility. Hydrogen costs are based on infrastructure to support hydrogen delivery, as well as mitigation of "lighter than air" flammable gas risk. Hydrogen facility improvements are anticipated to happen in two stages with each stage supporting the acquisition of 50 FCEBs. For the FCEB/BEB scenario, BEB facility costs are based on estimates developed for the full BEB scenario, with adjustments made to account for the smaller size of the fleet based on a cost per bus value derived from the full BEB scenario and applied to the number of BEBs in the FCEB/BEB scenario. For the No Build case the costs are based on assumed future replacements of underground storage tanks, pumps, and dispensers. The next major tank replacement is assumed to occur in 2033.

Table 5-5 shows the overall capital investment costs assumed for each of the scenarios.

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[2] Excludes 8.1 percent California sales tax

[3] From TARC document and escalated from 2020 price

[4] From TARC document and escalated from 2020 price

[5] From TARC document and escalated from 2020 price

[6] CA New Flyer Contract with 388 kWh battery and extended warranty

[7] BYD CA Contract Pricing with 446 kWh battery and extended warranty

[8] Current market price as of March 2022

Table 5-5: Facility Improvement Costs by Scenario (2021 dollars)

SCENARIO	DIESEL FUELING INFRASTRUCTURE	BEB IINFRASTRUCTURE	FCEB INFRASTRUCTURE	TOTAL
No Build	$1,530,000	$-	$-	$1,530,000
1: BEB	$-	$18,600,000	$-	$18,600,000
2: BEB/FCEB	$-	$9,700,000	$22,000,000	$31,700,000

SOURCE: WSP COST ESTIMATOR

Operating and Maintenance Costs

Vehicle operations and maintenance (O&M) costs include general vehicle maintenance costs, tire service costs, fueling infrastructure annual maintenance costs, fuel or energy costs, and bus disposal and retirement costs. Vehicle O&M costs are specific to the vehicle types and the length of the vehicles. Overall O&M costs are influenced by the operating costs per mile of each vehicle and annual mileage, both direct inputs into the lifecycle cost model.

AVERAGE MILEAGE PER VEHICLE AND USEFUL LIFE

Average miles per vehicle are estimated using the fleet odometer for each vehicle. Vehicle life was assumed based on the TARC's vehicle replacement experience. Average mileage and useful life for each fleet type is shown in Table 5-6. Average annual mileage for 35' diesel 35', 40' diesel 40', and 40' hybrid buses was applied to 35' and 40' BEBs and FCEBs, respectively for a direct comparison, respectively.

Table 5-6: Average Mileage per Vehicle and Useful Life

VEHICLE TYPES	AVERAGE VEHICLE MILEAGE[9]	USEFUL LIFE (YEARS)[10]
35ft Diesel	50,252	15
40ft Diesel	58,222	15
40ft Hybrid	58,222	15
35ft BEB	50,252	15
40ft BEB	58,222	15
40ft FCEB	58,222	15

SOURCE: TARC

MAINTENANCE AND TIRE COSTS

General vehicle maintenance costs, tire replacement costs, and fueling unit maintenance costs for the Build and No-Build scenarios are outlined in Table 5-7: O&M Costs -Build/No Build Scenarios (2021 $/mile):O&M Costs-Build/No Build Scenarios (2021 $/mile). The charging unit cost for BEB vehicles assumes a five-year warranty on charging infrastructure, drastically lowering O&M costs in the first five years. After the five-year warranty period charging costs include preventative and failure maintenance costs. Hydrogen costs include the ongoing maintenance and operation of the hydrogen delivery, conversion, storage, and fueling systems.

SOURCE: TARC AND PEER AGENCY

[9] Estimated based on the fleet age and mileage outlined in the TARC ThingTech Revenue Vehicles document

[10] TARC operational experience

Table 5-7: O&M Costs -Build/No Build Scenarios (2021 $/mile):O&M Costs-Build/No Build Scenarios (2021 $/mile)

COST CATEGORY	DIESEL 35'	DIESEL 40'	HYBRID 40'	BEB 35'	BEB 40'	FCEB 40'
Maintenance Cost ($/mi)[11]	0.81	0.81	1.19	1.84	1.84	1.09
Tires ($/mi) [12]	0.065	0.065	0.065	0.072	0.072	0.065
Fueling Unit/Charger ($/year/bus) [13]	100	100	100	2,000	2,000	1,200

FUEL AND ENERGY COST

Fuel costs are based on average 2022 prices through June, escalated using the U.S. Department of Energy, Energy Information Administration (USEIA) 2022 Annual Energy Outlook Reference Case Scenario price forecast. The USEIA price forecast is referenced as annual percent increases which are applied to the 2021 price baseline. Prices for electric vehicles are based on LG&E and USEIA's five-year historical utility rates. Table 5-8 summarizes the energy cost assumptions. Demand charges are rounded to the nearest thousands. Hydrogen prices of $8.00 per kg are based on delivered costs for other agencies currently using hydrogen vehicles.

Table 5-8: Fuel/Energy Cost per Bus (2022 $ Values)

	ELECTRICITY		DIESEL	HYBRID		HYDROGEN
Fuel/Energy Cost	$0.03/kWh[14]		$2.70/gal[15]	$2.70/gal[16]		$8.00/kg[17]
Demand Charges ($/kW)	$25.61[1718]		N/A	N/A		N/A
Vehicle Type	*35'*	*40'*	*35'*	*40'*	*40'*	*40'*
Vehicle Fuel Efficiency Diesel Equivalent (mpdge)	-	-	5.52	4.90	5.58	8.86
Vehicle Fuel Efficiency (kWh/mi)	1.88	2.40		-	-	-
Average Annual Miles	50,252	58,222	50,252	58,222	58,222	58,222
Total Fuel/Energy Costs per Year per Bus	**$21,613**	**$23,135**	**$24,570**	**$32,069**	**$28,161**	**$52,571**

SOURCE: VARIOUS ENERGY PROVIDERS AND USEIA ESCALATION

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[11] TARC operational data for existing fleet and BEB ratio based on existing BEB operations for peer agencies

[12] Based on a peer agency experience. Assumed 10 percent higher than baseline existing vehicles to account for the heavier weight of BEBs and greater tire wear

[13] Based on current on-site fueling capacity for the no-build case with costs per vehicle for BEB and FCEB based on peer agency experience operating charging and hydrogen fueling infrastructure respectively

[14] Based on Louisville Gas & Electric (LGE) Power Service Secondary rates.

[15] 2022 Existing value based on January 2022 MSE901 rates and quantities of $2.02 per gallon, adjusted for diesel prices through August from USEIA compared to USEIA January 2022 prices which resulted in a 1.33 multiplier for 2022 average prices.

[16] ibid

[17] Based on estimate from peer agency

[18] Based on LGE Power Service Secondary rates. Summer demand charges are assumed between May and September and winter demand rates for all other months.

Disposal and Resale Value

It is assumed that at the end of the vehicle life, TARC will sell the vehicle. Vehicle sales pricing is assumed to be $5,000 per vehicle as any sales above that value must be returned to FTA.

Environmental Cost

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

GREENHOUSE GAS, TAILPIPE AND PARTICULATE MATTER

The analysis applies the average annual mileage and the tailpipe and greenhouse gas emissions of grams of CO2 equivalent per millijoule per mile to estimate the lifecycle emissions in the build and no build scenarios. Table 5-9: V outlines the vehicle tailpipe emissions in g/mi provided by AFLEET Analysis, and EPA MOVES 2014b model. Table 5-10: Lifecycle GHG Emissions (g/VMT) provides the lifecycle GHG emissions based on current diesel production and energy sourced from the current LG&E grid sources.

Table 5-9: Vehicle Tailpipe / Pollutants Emissions (g/VMT)[18][19]

EMISSION	DIESEL 35'	DIESEL 40'	HYBRID 40'	BEB 35'	BEB 40'	FCEB 40'
NOX	0.21	0.18	0.18	-	-	-
SOX	-	-	-	-	-	-
PM10	0.17	0.15	0.13	0.11	0.11	0.11
VOC	0.07	0.06	0.13	-	-	-
PM2.5	0.02	0.02	0.02	0.01	0.01	0.01

SOURCE: AFLEET ANALYSIS AND EPA MOVES 2014 MODEL

Table 5-10: Lifecycle GHG Emissions (g/VMT)[20]

EMISSION	DIESEL 35'	DIESEL 40'	HYBRID 40'	BEB 35'	BEB 40'	FCEB 40'
CO2	1,771	1,995	1,751	853	1,089	2,166

SOURCE: DIESEL BASED ON EPA FACTORS AND BEB BASED ON LG&E UPSTREAM POWER PRODUCTION

Table 5-11: Noise Emissions Cost ($/VMT)[21]

EMISSION	DIESEL 35'	DIESEL 40'	HYBRID 40'	BEB 35'	BEB 40'	FCEB 40'
Noise	0.07	10.07	0.07	0.06	0.06	0.07

SOURCE: ALTOONA TESTING

Lifecycle Cost Analysis Results

The lifecycle cost analysis compares the lifecycle costs and benefits for each scenario in three primary cash cost categories: capital costs, operating costs, and disposal/salvage costs. Additionally, a non-cash cost of environmental

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[19] Values based on AFleet analysis
[20] Values based on CARB for CNG, diesel, and unleaded vehicles
[21] Values based on Altoona testing and peer agencies

benefits and costs, which the lifecycle model monetizes to account for a holistic comparative cost and benefit, is assessed. Results are presented in both 2021 $s and YOE $s in Table 5-12: Lifecycle Cost Analysis Results (2021 $ Millions) and Table 5-13: , respectively.

Table 5-12: Lifecycle Cost Analysis Results (2021 $ Millions)

		STANDARD SCENARIO ("NO BUILD")	BUILD SCENARIO 1: 100% BEB	BUILD SCENARIO 2: MIXED BEB/FCEB
Capital	VEHICLE PURCHASE PRICE	$84.0	$164.0	$171.4
	MODIFICATIONS & CONTINGENCY	$13.5	$27.6	$28.2
	CHARGING/FUELING INFRASTRUCTURE	$1.5	$18.6	$31.7
	TOTAL CAPITAL COSTS	*$99.0*	*$210.2*	*$231.3*
Operating	VEHICLE MAINTENANCE	$63.1	$128.0	$103.5
	VEHICLE TIRES	$4.8	$5.3	$5.2
	VEHICLE FUEL COSTS	$38.1	$21.2	$36.7
	CHARGING/FUELING INFRASTRUCTURE	$0.0	$12.2	$5.8
	TOTAL OPERATING COSTS	*$106.0*	*$169.2*	*$152.5*
Disposal	BATTERY DISPOSAL	$0.0	$0.0	$0.0
	BUS DISPOSAL	-$0.3	-$0.3	-$0.4
	TOTAL DISPOSAL COSTS	*-$0.3*	*-$0.3*	*-$0.4*
Total Cash Costs		$204.8	$379.1	$383.4
Comparison to Base	DOLLARS	$0.0	$174.3	$179
	PERCENT	-	85%	87%
Total Cash Cost per Mile		$1.13	$2.08	$2.11
Environmental	EMISSIONS - VEHICLE	$2.0	$1.2	$1.2
	EMISSIONS - REFINING/UTILITY	$12.3	$6.8	$3.4
	NOISE	$4.8	$3.8	$4.3
	TOTAL ENVIRONMENTAL COSTS	*$19.0*	*$11.8*	*$8.9*
Total Cash and Non-Cash Costs		$223.8	$390.9	$392.2
Comparison to Base	DOLLARS	$0.0	$167.0	$168
	PERCENT	-	75%	75%
Total Cash and Non-Cash Costs per Mile		$1.23	$2.15	$2.16
Total Mileage (million miles)		182	182	182

SOURCE: WSP

Table 5-13: Lifecycle Cost Analysis Results (YOE $ Millions)

		STANDARD SCENARIO ("NO BUILD")	BUILD SCENARIO 1: 100% BEB	BUILD SCENARIO 2: MIXED BEB/FCEB
Capital	VEHICLE PURCHASE PRICE	$164	$331	$344
	MODIFICATIONS & CONTINGENCY	$27	$56	$57
	CHARGING/FUELING INFRASTRUCTURE	$2	$20	$36
	TOTAL CAPITAL COSTS	***$192***	***$406***	***$436***
Operating	VEHICLE MAINTENANCE	$254	$549	$444
	VEHICLE TIRES	$19	$21	$21
	VEHICLE FUEL COSTS	$161	$79	$136
	CHARGING/FUELING INFRASTRUCTURE	$0	$10	$5
	TOTAL OPERATING COSTS	***$434***	***$671***	***$612***
Disposal	BATTERY DISPOSAL	$0	$0	$0
	BUS DISPOSAL	-$2.2	-$2.7	-$3
	TOTAL DISPOSAL COSTS	***-$2***	***-$3***	***-$3***
Total Cash Costs		$624	$1,075	$1,045
Comparison to Base	DOLLARS	$0	$452	$422
	PERCENT	-	72%	68%
Total Cash Cost per Mile		$3.43	$5.91	$5.75
Environmental	EMISSIONS - VEHICLES	$7.9	$4.7	$5
	EMISSIONS - REFINING/UTILITY	$45.0	$28.0	$15
	NOISE	$19.0	$15.0	$17
	TOTAL ENVIRONMENTAL COSTS	***$72***	***$48***	***$37***
Total Cash and Non-Cash Costs		$696	$1,123	$1,082
Comparison to Base	DOLLARS	$0	$427	$386
	PERCENT	-	61%	56%
Total Cash and Non-Cash Costs per Mile		$3.83	$6.18	$5.95
Total Mileage (million miles)		*182*	*182*	*182*

Source: WSP

5.4 SUMMARY

Total Project Cost

The full lifecycle cash cost of a transition to BEBs and FCEBs is higher than the continued reliance on internal combustion (diesel). While the initial capital and operating costs are higher for ZEBs, there are opportunities for some savings in fuel costs. Additionally, operating cost benefits are highly dependent on factors that are continually evolving as battery-electric and hydrogen buses deploy in transit services.

The analysis also shows that the No-Build scenario would result in a large emission generation over the lifecycle of diesel operations in comparison to the Build scenarios. The large vehicle emission difference between the two replacement scenarios was expected, as the technology in the battery electric buses are aimed to reduce GHG emissions, particularly for carbon emissions. Table 5-14 shows the overall estimated capital costs (in year of expenditure dollars (YOE$)). These costs are inclusive of ZEB purchases, charging/fueling infrastructure, additional options and charges, or vehicles and battery extended warranties.

Table 5-14: Estimated Overall Capital Costs by Scenario by Year (all amounts in millions of YOE$)

YEAR	NO-BUILD	BUILD SCENARIO 1: 100% BEB	BUILD SCENARIO 2: MIXED BEB/FCEB
2022	$8.76	$20.67	$21.38
2023	$9.77	$12.60	$13.04
2024	$11.02	$24.50	$25.34
2025	$16.69	$25.36	$28.40
2026	$10.39	$24.52	$27.46
2027	$12.30	$29.03	$32.51
2028	$20.01	$30.08	$33.68
2029	$11.55	$27.26	$30.53
2030	$13.53	$30.26	$33.89
2031	$13.28	$31.35	$34.21
2032	$14.68	$34.64	$35.83
2033	$16.10	$35.57	$36.79
2034	$16.77	$39.58	$40.93
2035	$17.39	$41.04	$42.44
Total	**$192.27**	**$406.47**	**$436.44**

SOURCE: WSP

6 FEDERAL FUNDING OPPORTUNITIES

6.1 BACKGROUND

On November 15, 2021, the Infrastructure Investment and Jobs Act (IIJA or “Act”) was signed into law. Now formally known as the Bipartisan Infrastructure Law (BIL), the act reauthorizes surface transportation programs for five years and provides new investments in transportation, energy, water, buildings, and other programs to improve America’s infrastructure.

BIL contains $550 billion in new spending over five years. It provides new federal funding to support roads and bridges, public transit, freight and passenger rail, ports, and airports; investment in broadband infrastructure; water systems; modernizing the power sector; and improving climate resilience. In addition to authorizing these programs, BIL also provides $113.3 billion in advance general fund appropriations to allow agencies to begin funding infrastructure improvements before the fiscal year (FY) 2022 appropriations process is completed.

Above baseline investments for sectors addressed in BIL include:

- Transportation: $284 billion
- Water: $55 billion
- Broadband: $65 billion
- Energy & Power: $73 billion
- Environmental remediation: $21 billion
- Western water infrastructure: $8.3 billion
- Resiliency: $46 billion

BIL emphasizes investments in equity and measures to mitigate climate change, while safety remains a top priority for the US Department of Transportation (USDOT). It includes separate sections for equity, climate and safety programs that impact the provision of funding for transportation, energy, water, and other programs in the act. Federal agencies overseeing these programs have been updating their policies to include these cross-cutting requirements in their regulations, guidance, future Notices of Funding Opportunities (NOFOs) and project rating criteria in the months ahead. The amounts included in the authorizing language are included in this chapter. For some programs, the amounts made available by the advanced appropriations are noted.

The purpose of this section of the report is to identify the universe of funding sources that may potentially be available to support TARC in its evaluation and transition to a cleaner emission bus fleet. Funding sources are applicable for funding ZEB vehicle purchases and/or associated facility enhancements and charging infrastructure to accommodate ZEBs. Options considered include federal formula and discretionary grant funding options, including programs that were created or expanded via BIL.

The following agencies in charge of administering funds are:

- Federal Transit Administration (FTA)
- Federal Highway Administration (FHWA)
- US Department of Transportation (USDOT)

- Other non-transportation departments including US Department of Energy (DOE) and US Department of Treasury (USDT).

Section 6.2 outlines TARC's current capital funding sources and funding strategy. Sections 6.3 through 6.6 provide an overview of BIL funding programs based on information available as of January 2022. Each section begins with a description of each funding option with information pertaining to the order of magnitude of available funding and a discussion of whether the source may be a good fit for ZEB purchases and/or associated bus charging/fueling and maintenance facility infrastructure. A summary table comparing key components of each option, including eligible project criteria and funding amount are provided at the end of each section.

6.2 CURRENT CAPITAL FUNDING STRATEGY

TARC's pre-BIL projected programmable capital revenues include the receipt of following federal formula funding between FY 2022 through 2026[22]:

- FTA Section 5307 Urbanized Area Assistance Program ~$77.6 million
- FTA Section 5339 Bus and Bus Facilities Formula Program: ~$9.0 million
- FTA Section 5310 Enhanced Mobility of Seniors and Individuals with Disabilities Program; ~$5.0 million

As is outlined in the TARC Transportation Improvement Program (TIP) Capital Improvement Program (CIP) projections (April 2021), these funds are already largely programmed to support projects and expenditures listed in the existing 6-year capital plan; however, since BIL will be providing major increases in the allocations for some of FTA's formula programs (between 4% and 60% increase in annual funding over FY 2021 levels depending on the program), the amounts above will increase and TARC could consider allocating a portion of these additional federal funds to support capital projects like ZEB purchases and charging infrastructure as well. Figure 6-1 illustrates the projected additional FTA Section 5307, 5339, and 5310 formula funding to come to TARC over the next five years. These sources of formula funding are fairly flexible and can be leveraged at 80% federal/20% local match to fund capital projects, including procurement of ZEBs, and construction of charging/fueling infrastructure and/or associated maintenance facilities.

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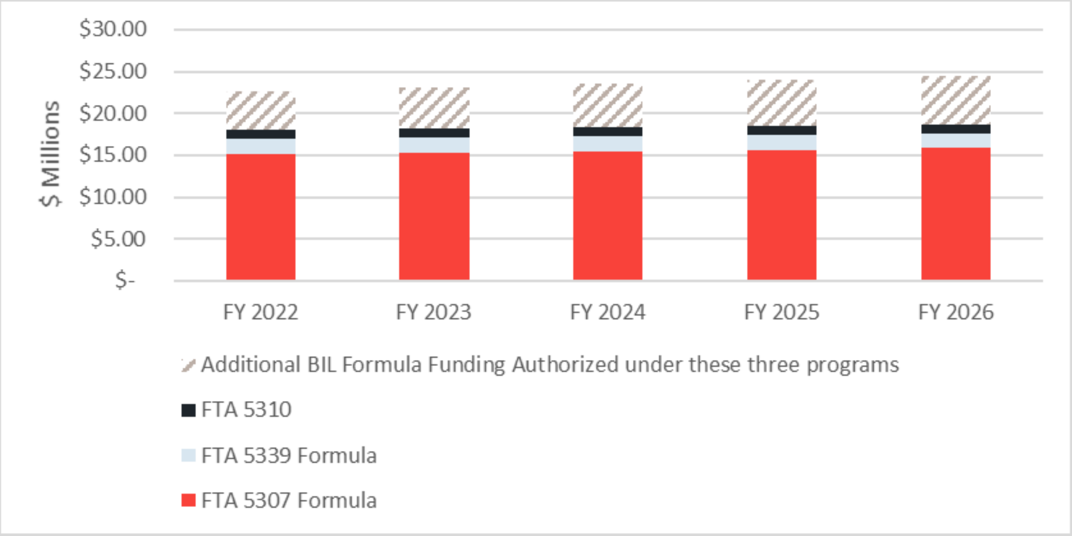
[22] TARC Transportation Improvement Program Capital Improvement Program (April 2021)

Figure 6-1: Projected TARC Federal Formula Funding (FY 2021-2026)



In addition to these formula funding programs, TARC has applied to the FTA Section 5339(c) Low or No Emissions competitive grant program to support the purchase of electric buses starting in FY 2022. This program also received a big boost through BIL – increasing in size from $182 million/year in FY 2021 to $1.1 billion/year in awards starting in FY 2022 through FY 2026.

The remaining sections of this white paper outline the universe of other federal formula and discretionary grant programs that could potentially be leveraged to buttress these sources and help fund TARC's ZEB fleet transition.

6.3 FTA FUNDING PROGRAMS

This section outlines relevant FTA funding programs that could perhaps be used to support TARC's ZEB fleet transition.

FTA has instituted some new requirements pertaining to some of the most promising ZEB-focused programs. On December 1, 2021, FTA released a letter amending statutory provisions for the 5339 (b) Grants for Buses and Bus Facilities Competitive Program and 5339 (c) Low or No Emissions Program. The amendment includes a requirement that applicants requesting funding for zero-emissions vehicle related projects include a single Zero-Emission Transition plan document containing the following information, at a minimum:

- 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.

Furthermore, the following two provisions are also stated:

- FTA's guidance permits agencies to include vehicles that have met their minimum useful life in their contingency fleet if an agency is introducing zero-emission vehicles into its fleet, and those vehicles are not included in the calculation of spare ratio.
- The federal share of the cost of leasing or purchasing a zero-emission transit bus is not to exceed 85% of the total transit bus costs, and the federal share of the cost of leasing or acquiring low-or no-emission bus-related equipment and facilities is 90% of the net project cost.

FTA Section 5339 (A) & (B): Bus and Bus Facilities Program, Formula and Competitive

- Program focuses on assisting bus operators, states, or local governmental authorities that operate fixed route in the financing of buses and bus facilities.
- Program goal is to replace, rehabilitate and purchase buses, vans, and related equipment, and to construct bus-related facilities, including technological changes or innovations to modify low or no emission vehicles or facilities.
- Applications for the competitive discretionary program, Section 5339 (b) are evaluated based on demonstration of need, or the quality and extent to which they demonstrate how the proposed project will address the need for capital investment in bus vehicles and/or supporting facilities. Applications are also assessed based on demonstration of benefits, or how well they describe how the proposed project will improve the condition of the transit system, improve the reliability of transit service for its riders, and enhance access and mobility within the service area.
- Program Includes $3.16 billion in authorizations for 5339 (a) and $1.97 billion for 5339 (b) over the next five years.
- A maximum federal share of 80% is in place for this program, and 25% of funds from this program will be reserved for low emission bus projects. The rural areas set aside increased to 15%.
- The BIL authorizes major increases in 5339 formula and discretionary funding over the next several years. TARC could consider allocating a portion of 5339 funds above those amounts needed for operations to capital projects like ZEB purchases and charging infrastructure.

FTA Section 5539 (C): Low or No Emission Vehicle Program

- The BIL includes massive increases in funding for the 5339(c) discretionary funding over the next several years. The FY 2022 funding exceeds the FY 2021 amount by six-fold, increasing from $182 million to $1,122 million.
- The Low or No Emission Vehicle Competitive ("LoNo") program provides funding to state and local governmental authorities for the purchase or lease of zero-emission and low-emission transit buses as well as acquisition, construction, and leasing of required supporting facilities.
- Eligible projects include:
    - Purchasing or leasing low- or no-emission buses
    - Acquiring low- or no-emission buses with a leased power source
    - Constructing or leasing facilities and related equipment (including intelligent technology and software) for low- or no-emission buses
    - Constructing new public transportation facilities to accommodate low- or no-emission buses
    - Rehabilitating or improving existing public transportation facilities to accommodate low- or no-emission buses
- The FY 2021 LoNo program application cycle closed on April 12, 2021. During that cycle, funding was awarded to 49 projects totaling $182 million in grants. The maximum funding awarded to a single project was $7.2 million.

FTA Section 5307: Urbanized Area Formula Grants

- Program makes federal resources available for transit capital and operating assistance in urbanized areas and for transportation-related planning.
- Eligible activities include:

  - Planning, engineering, design and evaluation of transit projects and other technical transportation-related studies
  - Capital investments in bus and bus-related activities such as replacement, overhaul and rebuilding of buses, crime prevention and security equipment and construction of maintenance and passenger facilities
  - Capital investments in new and existing fixed guideway systems including rolling stock, overhaul and rebuilding of vehicles, track, signals, communications, and computer hardware and software
  - Transit improvements associated with capital investments and certain expenses associated with mobility management programs.
- Program focuses on preventive maintenance and some Americans with Disabilities Act complementary paratransit service costs, which are considered capital costs under this program.
- BIL authorizes major increases in 5307 formula funding over the next several years -- 28% increase in overall FY 2021 levels in FY 2022, steadily increasing to 41% increase above FY 2021 funding levels by FY 2026. TARC could consider allocating a portion of 5307 funds above those amounts needed for operations for capital projects like ZEB purchases and charging infrastructure.

FTA Capital Investment Grants (CIG) – Small Starts

- The total maximum allowable cost of Small Starts Projects is raised from $300 million to $400 million, with the CIG share capped at $150 million.
- If TARC is planning a fixed-guideway or corridor-based bus rapid transit (BRT) project, ZEBs and associated charging/fueling and O&M facility infrastructure could potentially be funded by the CIG program.

FTA Section 5310: Enhanced Mobility of Seniors & Individuals with Disabilities

- Formula funding allocated based on the population of older adults and people with disabilities established by FTA.
- A three-tiered formula with 60% of the funds going directly to urbanized areas over 200,000, 20% allocated to states for urbanized areas under 200,000 and 20% to states for non-urbanized areas.
- BIL authorizes major increases in 5310 formula funding over the next several years -- 44% increase in overall FY 2021 levels in FY 2022, steadily increasing to 56% increase above FY 2021 funding levels by FY 2026. TARC could consider allocating a portion of 5310 funds above those amounts needed for operations to capital projects like ZEB purchases that support the goals of the 5310 program.

FTA Funding Sources Summary

Table 6-1 provides a high-level summary of the key characteristics and considerations of each funding sources evaluated in this section.

Table 6-1: Potential FTA Federal Funding Sources Overview

FTA FUNDING PROGRAM	PROGRAM TYPE	ELIGIBILITY			FUNDING AMOUNT (FY 22 – FY 26)
		ZEV PURCHASE	VEHICLE CHARGING INFRASTRUCTURE	FACILITY CAPITAL IMPROVEMENTS	
Bus and Bus Facilities Program, both formula and discretionary	Formula and Discretionary	✓	✓	✓	$ 5.1 B

Low or No Emission Vehicle Program	Discretionary	✓	✓	✓	$ 5.6 B
Urbanized Area Formula Grants	Formula	✓	✓	✓	$ 33.5 B
Capital Investment Grants (CIG) – Small Starts	Discretionary	✓	✓	✓	$ 23 B
FTA Section 5310: Enhanced Mobility of Seniors & Individuals with Disabilities	Formula	✓	✓		$ 2.2 B

6.4 FHWA FUNDING PROGRAMS

This section outlines relevant FHWA funding programs that could perhaps be used to support TARC's ZEB fleet transition.

[New Program] **FHWA** Carbon Reduction Program

- Program authorizes the distribution of funds to metropolitan planning organizations (MPOs), 65% of which will be sub-allocated by population.
- MPOs can award these funds to eligible projects that support the reduction of transportation emissions
- Program funds can be used to aid public mass transportation systems that operate buses transporting passengers on federal-aid highways via construction of bus and passenger infrastructure along federal-aid highways. Eligible projects include electric vehicle charging stations and/or natural gas vehicle refueling stations.

FHWA Surface Transportation Block Grant (STBG)

- Provides flexible funding that may be used by states and localities for projects to preserve and improve the conditions and performance on any federal-aid highway, bridge and tunnel projects on any public road, pedestrian and bicycle infrastructure, and transit capital projects, including intercity bus terminals.
- BIL expanded STBG funding eligible uses expanded to include installation of electric vehicle (EV) charging infrastructure.

FHWA Congestion Mitigation and Air Quality (CMAQ)

- A significant amount of flexible funding is available, and changes have been made to the program with the 2021 BIL.
- Most changes to the CMAQ section relate to eligible projects and the addition of the following project types:
  - Bike-sharing and shared scooter systems
  - Diesel retrofit replacements
  - Purchase of medium- or heavy-duty zero emissions vehicles and related charging equipment
  - Purchase of construction vehicles to support alternative fuel projects, including port-related freight operations

[New Program] FHWA Charging and Refueling Infrastructure Grants Program

- Program focuses on deploying publicly accessible vehicle charging and fueling infrastructure for low or no-emission vehicles along key corridors throughout the US.

- Program supports ZEV charging/fueling projects that could exclusively be utilized by a transit agency would not be considered eligible.

[New Program] FHWA Strengthening Mobility and Revolutionizing Transportation (SMART)

- Program supports projects that incorporate innovative transportation technologies or uses of data, including coordinated automation, connected vehicles, and intelligent sensor-based infrastructure.
- Proposed projects will be evaluated against the sponsor's ability to successfully undertake the project and is serving a population with a demonstrated need; ability to advance data, technology and applications that provide significant benefits to the area served.

FHWA Funding Sources Summary

Table 6-2 provides a high-level summary of the key characteristics and considerations of each funding sources evaluated in this section.

Table 6-2. Potential FHWA Federal Funding Sources Overview

FHWA FUNDING PROGRAM	PROGRAM TYPE	ELIGIBILITY			FUNDING AMOUNT (FY 22 – FY 26)
		ZEV PURCHASE	VEHICLE CHARGING INFRASTRUCTURE	FACILITY CAPITAL INVESTMENTS	
Carbon Reduction Program	Formula		✓		$ 6.4 B
Surface Transportation Block Grant (STBG)	Formula	✓	✓	✓	$72 B
Congestion Mitigation and Air Quality (CMAQ)	Formula	✓	✓	✓	$13.2 B
Charging and Refueling Infrastructure Grants Program	Discretionary		✓		$ 2.5 B
Strengthening Mobility and Revolutionizing Transportation (SMART)	Discretionary		✓		$ 500 M

6.5 USDOT Funding Programs

This section outlines relevant USDOT funding programs that could perhaps be used to support TARC's ZEB fleet transition.

USDOT Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Program

- Current FY 22 RAISE Program consists of $1.5 billion in federal funds, excluding an additional $1.5 billion in advanced appropriations that could still be made available in FY 2022, intended to leverage money from private sector partners, states, local governments, metropolitan planning organizations and transit agencies. Applications are due to USDOT by April 14, 2022.
- Individual grants are limited to $25 million and provide and equal split between rural and urban areas.
- Applicants must match funds with a minimum of 20% non-federal funds (no local match required in Areas of Persistent Poverty).
- Applications require a benefit-cost analysis and projects compete best if their benefit-cost ratio is above 1.0.
- Additional merit criteria related to climate change, racial equity, barriers to opportunity, and to enhance community connectivity and mobility.

[NEW PROGRAM] **USDOT RECONNECTING COMMUNITIES PILOT PROGRAM**

- Eligible entities may apply for planning funds to study the feasibility and impacts of removing, retrofitting, or mitigating existing transportation facilities that create barriers to mobility, access, or economic development.
- Program includes construction funds to carry out projects to remove, retrofit or mitigate an eligible facility and, if appropriate, to replace it with a new facility.

[New Program] **USDOT**/USDOE National Electric Vehicle (EV) Formula Funding Program

- Program focuses on further deployment of an interconnected network of EV charging stations along critical corridors and will focus on public accessibility.
- Program prioritizes data collection, access, and reliability of charging infrastructure with primary criteria established including:
  - The acquisition and installation of EV charging infrastructure to serve as a catalyst for the deployment of such infrastructure and to connect it to a network to facilitate data collection, access, and reliability.
  - Proper operation and maintenance of EV charging infrastructure.
  - Data sharing about EV charging infrastructure to ensure the long-term success of investments made under the program.
  - The federal share maximum for projects funded under the program is 80%.

[New Program] **USDOT**/USDOE National Electric Vehicle Charging and Fueling Infrastructure Discretionary Grant Program

- Program provides funding to strategically deploy EV charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability.
- Funding can only be used to support electric vehicle charging infrastructure projects that are open to the general public (or commercial motor vehicle operators from more than one company) and located along a designated alternative fuel corridor.
- Funds must be used for the Federal share payable for projects funded under the EV Charging Program is 80 percent.

USDOT Funding Sources Summary

Table 6-3 provides a high-level summary of the key characteristics and considerations of each funding sources evaluated in this section.

Table 6-3. Potential USDOT Federal Funding Sources Overview

USDOT FUNDING PROGRAM	PROGRAM TYPE	ELIGIBILITY			FUNDING AMOUNT (FY 22 – FY 26)
		ZEV PURCHASE	VEHICLE CHARGING INFRASTRUCTURE	FACILITY CAPITAL INVESTMENTS	
RAISE	Discretionary	✓	✓	✓	$15 B
Reconnecting Communities Pilot	Discretionary		✓	✓	$1 B
National EV Formula Fund*	Formula		✓		$ 2.5 B
National EV Charging and Infrastructure*	Discretionary		✓		$ 2.5 B

* National EV Formula Funds and EV Charging and Infrastructure Grants can only be used on charging infrastructure available for public use.

6.6 OTHER FEDERAL FUNDING PROGRAMS

This section outlines relevant USDOE and USDT programs that could perhaps be used to support TARC's ZEB fleet transition.

[New Program] **USDOE** State Energy Program

- Program supports grants for vehicle-to-grid storage and to support the reliability of electric grids to meet the increased demand from EV charging and electrification of appliances.
- Program focuses on projects to increase transportation energy efficiency, including programs to help reduce carbon emissions in the transportation sector by 2050 and accelerate the use of alternative transportation fuels for, and the electrification of, State government vehicles, fleet vehicles, taxis and ridesharing services, mass transit, school buses, ferries, and privately owned passenger and medium- and heavy-duty vehicles.

[New Program] USDOE Hydrogen Research and Development

- DOE to develop:
    - four regional clean hydrogen hubs ($8 billion)
    - a clean hydrogen manufacturing and recycling program ($500 million)
    - a program to reduce costs of clean hydrogen production from electrolyzers ($1 billion)

[New Program] USDOE Advanced Energy Manufacturing and Recycling Grant Program

- For small businesses investing in certain advanced energy technologies that will reduce greenhouse gas emissions in communities that have been impacted by closures of coal mines or coal-fired power plants.
- Qualifying projects (1) re-equip, expand, or establish a manufacturing or recycling facility to produce certain types of advanced energy property; or (2) re-equip a facility with equipment designed to substantially reduce greenhouse gas emissions.

[New Program] USDOE Demonstration of Electric Vehicle Battery Second-Life Applications for Grid Services

- Program supports projects that demonstrate second-life applications of electric vehicle batteries as aggregated energy storage installations to provide services to the electric grid.

USDOE Alternative Fuel Tax Credit

- Credit is available for alternative fuel that is sold for use or used as a fuel to operate a motor vehicle.
- $0.50 per gallon is available for the following alternative fuels: natural gas, liquefied hydrogen, propane, P-Series fuel, liquid fuel derived from coal through the Fischer-Tropsch process and compressed or liquefied gas derived from biomass.

USDOE Energy Efficiency and Conservation Block Grant Program

- Program supports state and local public agencies in projects that reduce fossil fuel emissions and total energy use, improve energy efficiency, and create and retain jobs.
- Prior program funding has been focused on projects that are shovel ready or could break ground in less than two years. Transportation projects accounted for 4.3% of prior funding and building and facilities accounted for 9.7%.
- Program formula funds are allocated to units of government including 68% to cities and counties and 28% to states.

[New Program] USDOE Upgrading Our Electric Grid and Ensuring Reliability and Resiliency Program

- Program supports projects that demonstrate new and innovative approaches to enhance resilience and reliability of the electric grid.

  Program offers $5 billion in competitive grants for states, Indian tribes, local governments, and public utilities. An additional $1 billion is available in this program for rural or remote areas.

[New Program] USDOE Smart Grid Investment Matching Grant Program

- Program focuses on expanding eligible activities under the existing Smart Grid Investment Matching Grant Program to include activities that allow increased integration of renewable energy, storage, and mitigation of natural disasters to the electric grid.
- Program allows grants for vehicle-to-grid storage and to support the reliability of electric grids to meet the increased demand from EV charging and electrification of appliances.

USDT New Markets Tax Credit (NMTC) Program

- Program focuses on stimulating investment in low-income areas. Commercial real estate developers secure advantageous debt and equity terms for developments.
- Awards a 39% tax credit on invested capital to investors on qualified projects.
- Assuming a site is selected that meets the program criteria TARC would likely need to partner with an eligible Community Development Entities who could apply to the program.

USDT Opportunity Zones

- Program is an economic development tool that allows people to invest in distressed areas in the United States.

- Program goal is to spur economic growth and job creation in low-income communities while providing tax benefits to investors.
- TARC would not receive any direct benefit through opportunity zone tax incentives; however, this program could be used as a lever to attract a private entity to invest equity in the project since this entity would benefit from the tax incentives. The tax incentives apply to the private entity's capital gains on the investment, meaning the investment must be revenue-generating to receive the benefit. It may be difficult for TARC or a member agency to identify a private entity interested in investing in a standalone Maintenance facility. However, if the project were to incorporate a public-private partnership to construct, operate, and maintain solar panels on the bus canopies, that would be a qualified, revenue-generating investment (e.g., the revenue stream would come from selling the energy back to the grid).

Other Federal Funding Sources Summary

Table 6-4 summarizes the key characteristics and considerations of each funding sources evaluated in this section.

Table 6-4. Potential Other Federal Funding Sources Overview

USDOE or USDT FUNDING PROGRAM	PROGRAM TYPE	ELIGIBILITY			FUNDING AMOUNT (FY 22 – FY 26)
		ZEV PURCHASE	**VEHICLE CHARGING INFRASTRUCTURE**	**FACILITY CAPITAL REQUIREMENTS**	
State Energy Program	Formula		✓		$1.0 B
Hydrogen Research and Development	Discretionary			✓	$ 19 B
Advanced Energy Manufacturing and Recycling Grant Program	Discretionary		✓		$ 1.5 B
Demonstration of Electric Vehicle Battery Second-Life Applications for Grid Services	Cooperative Agreement		✓		$ 400 M
Alternative Fuel Tax Credit	Discretionary				n/a
Energy Efficiency and Conservation Block Grant	Formula		✓		$ 550 M
Upgrading Our Electric Grid and Ensuring Reliability and Resiliency Program	Discretionary		✓		$ 11 B
Smart Grid Investment Matching Grant Program	Discretionary	✓	✓		$ 6 B

USDOE or USDT FUNDING PROGRAM	PROGRAM TYPE	ELIGIBILITY			FUNDING AMOUNT (FY 22 – FY 26)
		ZEV PURCHASE	VEHICLE CHARGING INFRASTRUCTURE	FACILITY CAPITAL REQUIREMENTS	
New Markets Tax Credit (NMTC)	Discretionary		✓	✓	$ 5 B
Opportunity Zones	Discretionary		✓	✓	n/a

6.7 OVERALL FINDINGS

The following list summarizes the primary programs for TARC's consideration regarding funding for ZEB purchases, ZEB charging/fueling infrastructure, and associated maintenance facility investments:

- FTA Section 5307 Urbanized Area Formula Funding
- FTA Section 5339 (a) Buses & Bus Facilities Formula Funding
- FTA Section 5339 (b) Buses & Bus Facilities Discretionary Grant Program
- FTA Section 5339 (c) Low or No Emission Vehicles Discretionary Grant Program
- FHWA CMAQ Formula Funding
- FHWA SMART Discretionary Grant Program
- FHWA Carbon Reduction Program
- FHWA Charging and Refueling Infrastructure Program
- USDOT RAISE Discretionary Grant Program
- USDOT/USDOE National Electric Vehicle Formula Program
- USDOE State Energy Program

APPENDIX

APPENDIX A: FLEET INVENTORY

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2004	Gillig	40' Hyb	2402	diesel	Inactive	for disposal
2004	Gillig	40' Hyb	2403	diesel	Inactive	for disposal
2004	Gillig	40' Hyb	2404	diesel	Active	for disposal
2004	Gillig	40' Hyb	2405	diesel	Inactive	for disposal
2005	Gillig	40'	2501	diesel	Active	projected disposal Feb 2023
2005	Gillig	40'	2502	diesel	Active	projected disposal Feb 2023
2005	Gillig	40'	2503	diesel	Inactive	projected disposal Feb 2023
2005	Gillig	40'	2504	diesel	Inactive	projected disposal Feb 2023
2005	Gillig	40'	2505	diesel	Inactive	projected disposal Feb 2023
2005	Gillig	40'	2506	diesel	Active	projected disposal Feb 2023
2005	Gillig	40'	2507	diesel	Inactive	projected disposal Feb 2023
2005	Gillig	40'	2508	diesel	Active	projected disposal Feb 2023
2005	Gillig	40'	2509	diesel	Inactive	projected disposal Feb 2023
2005	Gillig	40'	2510	diesel	Active	projected disposal Feb 2023
2005	Gillig	40'	2511	diesel	Inactive	projected disposal Feb 2023
2005	Gillig	40'	2512	diesel	Inactive	projected disposal Feb 2023
2005	Gillig	40'	2513	diesel	Active	projected disposal Feb 2023
2005	Gillig	40'	2514	diesel	Active	projected disposal Feb 2023
2005	Gillig	40'	2515	diesel	Inactive	projected disposal May 2023
2005	Gillig	40'	2516	diesel	Inactive	projected disposal May 2023
2007	Gillig	35'	2720	diesel	Active	
2007	Gillig	35'	2721	diesel	Inactive	
2007	Gillig	35'	2722	diesel	Active	
2007	Gillig	35'	2723	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2007	Gillig	35'	2724	diesel	Inactive	
2007	Gillig	35'	2725	diesel	Active	
2007	Gillig	40'	2801	diesel	Inactive	projected disposal May 2023
2007	Gillig	40'	2802	diesel	Inactive	projected disposal May 2023
2007	Gillig	40' Hyb	2701	diesel	Active	projected disposal May 2023
2007	Gillig	40' Hyb	2702	diesel	Active	projected disposal May 2023
2007	Gillig	40' Hyb	2703	diesel	Active	projected disposal May 2023
2007	Gillig	40' Hyb	2704	diesel	Active	projected disposal May 2023
2008	Gillig	40'	2803	diesel	Active	
2008	Gillig	40'	2804	diesel	Active	
2008	Gillig	40'	2805	diesel	Active	
2008	Gillig	40'	2806	diesel	Active	
2008	Gillig	40' Hyb	2901	diesel	Active	
2008	Gillig	40' Hyb	2902	diesel	Inactive	
2009	Gillig	30'	2930	diesel	Active	
2009	Gillig	30'	2931	diesel	Active	
2009	Gillig	30'	2932	diesel	Active	
2009	Gillig	40'	2910	diesel	Active	
2009	Gillig	40'	2911	diesel	Active	
2009	Gillig	40'	2912	diesel	Active	
2009	Gillig	40'	2913	diesel	Active	
2009	Gillig	40'	2914	diesel	Active	
2009	Gillig	40'	2915	diesel	Active	
2009	Gillig	40'	2916	diesel	Active	
2009	Gillig	40'	2917	diesel	Active	
2009	Gillig	40'	2918	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2009	Gillig	40'	2919	diesel	Active	
2009	Gillig	40'	2920	diesel	Active	
2009	Gillig	40'	2921	diesel	Active	
2009	Gillig	40'	2922	diesel	Active	
2009	Gillig	40'	2923	diesel	Active	
2009	Gillig	40'	2924	diesel	Active	
2009	Gillig	40'	2925	diesel	Active	
2009	Gillig	40'	2926	diesel	Active	
2009	Gillig	40' Hyb	1001	diesel	Active	
2009	Gillig	40' Hyb	1002	diesel	Active	
2009	Gillig	40' Hyb	2903	diesel	Active	
2010	Gillig	40'	1301	diesel	Active	
2010	Gillig	40'	1302	diesel	Active	
2010	Gillig	40' Hyb	1003	diesel	Active	
2010	Gillig	40' Hyb	1004	diesel	Active	
2010	Gillig	40' Hyb	1005	diesel	Active	
2010	Gillig	40' Hyb	1006	diesel	Active	
2010	Gillig	40' Hyb	1007	diesel	Active	
2010	Gillig	40' Hyb	1008	diesel	Active	
2010	Gillig	40' Hyb	1009	diesel	Active	
2013	Gillig	40'	1303	diesel	Active	
2013	Gillig	40'	1304	diesel	Active	
2013	Gillig	40'	1305	diesel	Active	
2013	Gillig	40'	1306	diesel	Active	
2013	Gillig	40'	1307	diesel	Active	
2013	Gillig	40'	1308	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2013	Gillig	40'	1309	diesel	Active	
2013	Gillig	40'	1310	diesel	Active	
2013	Gillig	40'	1311	diesel	Active	
2013	Gillig	40'	1312	diesel	Active	
2013	Gillig	40'	1313	diesel	Active	
2013	Gillig	40'	1314	diesel	Active	
2013	Gillig	40'	1315	diesel	Active	
2013	Gillig	40'	1316	diesel	Active	
2013	Gillig	40' Com	1350	diesel	Active	
2013	Gillig	40' Com	1351	diesel	Active	
2013	Gillig	40' Com	1352	diesel	Active	
2013	Gillig	40' Com	1353	diesel	Active	
2013	Gillig	40' Com	1354	diesel	Active	
2013	Gillig	40' Com	1355	diesel	Active	
2013	Gillig	40' Com	1356	diesel	Active	
2013	Gillig	40' Com	1357	diesel	Active	
2013	Gillig	40' Com	1358	diesel	Active	
2013	Gillig	40' Com	1359	diesel	Active	
2013	Gillig	40' Com	1360	diesel	active	
2013	Gillig	40' Com	1361	diesel	Active	
2013	Gillig	40' Com	1362	diesel	Active	
2013	Gillig	40' Com	1363	diesel	Active	
2013	Gillig	40' Com	1364	diesel	Active	
2013	Gillig	40' Com	1365	diesel	Active	
2013	Gillig	40' Com	1366	diesel	Active	
2013	Gillig	40' Com	1367	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2013	Gillig	40' Com	1368	diesel	Active	
2013	Gillig	40' Com	1369	diesel	Active	
2013	Gillig	40' Com	1370	diesel	Active	
2013	Gillig	40' Hyb	1320	diesel	Active	
2013	Gillig	40' Hyb	1321	diesel	Active	
2013	Gillig	40' Hyb	1322	diesel	Active	
2013	Gillig	40' Hyb	1323	diesel	Active	
2013	Gillig	40' Hyb	1324	diesel	Active	
2013	Gillig	40' Hyb	1325	diesel	Active	
2013	Gillig	40' Hyb	1326	diesel	Active	
2013	Gillig	40' Hyb	1327	diesel	Active	
2013	Gillig	40' Hyb	1328	diesel	Active	
2013	Gillig	40' Hyb	1329	diesel	Active	
2013	Gillig	40' Hyb	1330	diesel	Active	
2013	Proterra	BE35	1	electricity	Inactive	
2013	Proterra	BE35	2	electricity	Inactive	
2014	Gillig	40'	1401	diesel	Active	
2014	Gillig	40'	1402	diesel	Active	
2014	Gillig	40'	1403	diesel	Active	
2014	Gillig	40'	1404	diesel	Active	
2014	Gillig	40'	1405	diesel	Active	
2014	Gillig	40'	1406	diesel	Active	
2014	Gillig	40'	1407	diesel	Active	
2014	Gillig	40'	1408	diesel	Active	
2014	Gillig	40'	1409	diesel	Active	
2014	Gillig	40'	1410	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2014	Gillig	40'	1411	diesel	Active	
2014	Gillig	40'	1412	diesel	Active	
2014	Gillig	40'	1601	diesel	Active	
2014	Gillig	40'	1602	diesel	Active	
2014	Proterra	BE35	3	electricity	Inactive	
2014	Proterra	BE35	4	electricity	Inactive	
2014	Proterra	BE35	5	electricity	Inactive	
2014	Proterra	BE35	6	electricity	Inactive	
2014	Proterra	BE35	7	electricity	Inactive	
2014	Proterra	BE35	9	electricity	Inactive	
2014	Proterra	BE35	10	electricity	Inactive	
2016	Gillig	40'	1603	diesel	Active	
2016	Gillig	40'	1604	diesel	Active	
2016	Gillig	40'	1605	diesel	Active	
2016	Gillig	40'	1606	diesel	Active	
2016	Gillig	40'	1607	diesel	Active	
2016	Gillig	40'	1608	diesel	Active	
2016	Gillig	40'	1609	diesel	Active	
2016	Gillig	40'	1610	diesel	Active	
2016	Gillig	40'	1611	diesel	Active	
2016	Gillig	40'	1612	diesel	Active	
2016	Gillig	40'	1613	diesel	Active	
2016	Gillig	40'	1614	diesel	Active	
2016	Gillig	40'	1615	diesel	Active	
2016	Gillig	40'	1616	diesel	Active	
2016	Gillig	40'	1617	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2016	Gillig	40'	1618	diesel	Active	
2016	Gillig	40'	1619	diesel	Active	
2016	Gillig	40'	1620	diesel	Active	
2016	Gillig	40'	1621	diesel	Active	
2016	Gillig	40'	1622	diesel	Active	
2016	Gillig	40'	1623	diesel	Active	
2016	Gillig	40'	1624	diesel	Active	
2016	Gillig	40'	1625	diesel	Active	
2016	Gillig	40' Hyb	1630	diesel	Active	BAE series hybrid
2016	Proterra	Catalyst	12	electricity	Active	
2016	Proterra	Catalyst	13	electricity	Active	
2016	Proterra	Catalyst	14	electricity	Active	
2016	Proterra	Catalyst	15	electricity	Active	
2016	Proterra	Catalyst	16	electricity	Active	
2016	Proterra	Catalyst	17	electricity	Active	
2017	Gillig	35'	1701	diesel	Active	
2017	Gillig	35'	1702	diesel	Active	
2017	Gillig	40'	1901	diesel	Active	
2017	Gillig	40'	1902	diesel	Active	
2019	Gillig	40'	1903	diesel	Active	
2019	Gillig	40'	1904	diesel	Active	
2019	Gillig	40'	1905	diesel	Active	
2019	Gillig	40'	1906	diesel	Active	
2019	Gillig	40'	1907	diesel	Active	
2019	Gillig	40'	1908	diesel	Active	
2019	Gillig	40'	1909	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2019	Gillig	40'	1910	diesel	Active	
2019	Gillig	40' Com	1921	diesel	Active	
2019	Gillig	40' Com	1922	diesel	Active	
2019	Gillig	40' Com	1923	diesel	Active	
2019	Gillig	40' Com	1924	diesel	Active	
2019	Gillig	40' Com	1925	diesel	Active	
2019	Gillig	40' Com	1926	diesel	Active	
2019	Gillig	40' Com	1927	diesel	Active	
2019	Gillig	40' Com	1928	diesel	Active	
2021	Gillig	35'	2180	diesel	Active	
2021	Gillig	35'	2181	diesel	Active	
2021	Gillig	35'	2182	diesel	Active	
2021	Gillig	35'	2183	diesel	Active	
2021	Gillig	40'	2130	diesel	Active	
2021	Gillig	40'	2131	diesel	Active	
2021	Gillig	40'	2132	diesel	Active	
2021	Gillig	40'	2133	diesel	Active	
2021	Gillig	40'	2134	diesel	Active	
2021	Gillig	40'	2135	diesel	Active	
2021	Gillig	40'	2136	diesel	Active	
2021	Gillig	40'	2137	diesel	Active	
2021	Gillig	40'	2138	diesel	Active	
2021	Gillig	40'	2139	diesel	Active	
2021	Gillig	40'	2140	diesel	Active	
2021	Gillig	40'	2141	diesel	Active	
2021	Gillig	40'	2142	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2021	Gillig	40'	2143	diesel	Active	
2021	Gillig	40'	2144	diesel	Active	
2021	Gillig	40'	2145	diesel	Active	
2021	Gillig	40'	2146	diesel	Active	
2021	Gillig	40'	2147	diesel	Active	
2021	Gillig	40'	2148	diesel	Active	
2021	Gillig	40'	2149	diesel	Active	
2021	Gillig	40'	2150	diesel	Active	
2021	Gillig	40'	2151	diesel	Active	
2021	Gillig	40'	2152	diesel	Active	
2021	Gillig	40'	2153	diesel	Active	
2021	Gillig	40'	2154	diesel	Active	
2021	Gillig	40'	2155	diesel	Active	
2021	Gillig	40'	2156	diesel	Active	
2021	Gillig	40'	2157	diesel	Active	
2021	Gillig	40'	2158	diesel	Active	
2021	Gillig	40'	2159	diesel	Active	
2021	Gillig	40'	2160	diesel	Active	
2021	Gillig	40'	2161	diesel	Active	
2021	Gillig	40'	2162	diesel	Active	
2021	Gillig	40'	2163	diesel	Active	
2021	Gillig	40'	2164	diesel	Active	
2021	Gillig	40'	2165	diesel	Active	
2021	Gillig	40'	2166	diesel	Active	
2021	Gillig	40'	2167	diesel	Active	
2021	Gillig	40'	2168	diesel	Active	

YEAR	MAKE	MODEL	BUS #	FUEL	STATUS	NOTES
2021	Gillig	40'	2169	diesel	Active	
2021	Gillig	40'	2170	diesel	Active	
2021	Gillig	40' Com	2121	diesel	Active	
2021	Gillig	40' Com	2122	diesel	Active	

APPENDIX B: BEB BLOCKING ANALYSIS

January 2020 Service Statistics:

279 weekday blocks:

- 80 all-day blocks
- 199 partial-day blocks

Line Group	Line Group	Block	Revenue Trips	Distance	Remaining	Miles/ Trip	Trips to 180	BlockID	Pull Out	Pull In	Span
10	10	3	19	283.33	-103.33	14.9	7	10003	4:20 AM	1:27 AM	21:07
10	10	1	20	280.16	-100.16	14.0	8	10001	3:49 AM	1:10 AM	21:21
10	10	2	19	279.9	-99.9	14.7	7	10002	4:09 AM	12:57 AM	20:48
18	18	5	16	263.69	-83.69	16.5	6	18005	5:22 AM	1:56 AM	20:34
18	18	3	17	263.28	-83.28	15.5	6	18003	4:32 AM	1:21 AM	20:49
18	18	2	17	262.75	-82.75	15.5	6	18002	3:57 AM	1:03 AM	21:06
19	19	3	13	255.15	-75.15	19.6	4	19003	5:05 AM	12:57 AM	19:52
63	63	2	16	255.07	-75.07	15.9	5	63002	5:26 AM	11:42 PM	18:16
63	63	1	15	254.95	-74.95	17.0	5	63001	4:48 AM	10:32 PM	17:44
43	43	1	14	252.91	-72.91	18.1	5	43001	4:36 AM	11:58 PM	19:22
10	10	7	17	252.42	-72.42	14.8	5	10007	5:27 AM	12:40 AM	19:13
28	28	6	20	251.02	-71.02	12.6	6	28006	5:13 AM	12:17 AM	19:04
28	28	8	18	248.21	-68.21	13.8	5	28008	6:17 AM	12:31 AM	18:14
15	15	1	15	242.41	-62.41	16.2	4	15001	4:46 AM	11:33 PM	18:47
71	71	3	12	241.8	-61.8	20.2	4	71003	5:30 AM	10:40 PM	17:10
18	18	4	15	236.7	-56.7	15.8	4	18004	4:37 AM	12:16 AM	19:39
18	18	1	15	235.69	-55.69	15.7	4	18001	4:02 AM	10:54 PM	18:52
28	28	2	16	233.7	-53.7	14.6	4	28002	4:33 AM	11:04 PM	18:31
31	31	1	13	233.65	-53.65	18.0	3	31001	4:56 AM	10:39 PM	17:43
28	28	5	15	233.11	-53.11	15.5	4	28005	4:53 AM	11:07 PM	18:14
28	28	1	15	231.6	-51.6	15.4	4	28001	4:14 AM	9:28 PM	17:14
10	10	6	15	227.03	-47.03	15.1	4	10006	5:00 AM	10:12 PM	17:12
10	10	4	15	223.6	-43.6	14.9	3	10004	4:27 AM	9:02 PM	16:35
25	25	4	9	221.5	-41.5	24.6	2	25004	5:33 AM	9:28 PM	15:55
25	25	2	9	220.6	-40.6	24.5	2	25002	5:09 AM	9:22 PM	16:13
06	06	1	19	219.58	-39.58	11.6	4	6001	4:23 AM	11:14 PM	18:51
06	06	3	18	212.16	-32.16	11.8	3	6003	5:35 AM	11:38 PM	18:03
19	19	5	12	209.59	-29.59	17.5	2	19005	5:56 AM	11:57 PM	18:01
71	71	1	9	208.79	-28.79	23.2	2	71001	5:00 AM	6:50 PM	13:50
04	04	2	21	206.43	-26.43	9.8	3	4002	4:34 AM	12:46 AM	20:12
23	23	7	15	204.63	-24.63	13.6	2	23007	6:06 AM	12:15 AM	18:09
23	23	4	14	204.3	-24.3	14.6	2	23004	5:39 AM	11:43 PM	18:04
28	28	4	16	200.58	-20.58	12.5	2	28004	4:53 AM	8:04 PM	15:11
10	10	5	13	198.88	-18.88	15.3	2	10005	4:40 AM	7:32 PM	14:52
10	10	8	13	197.89	-17.89	15.2	2	10008	6:12 AM	9:25 PM	15:13
25	25	3	7	197.75	-17.75	28.3	1	25003	5:06 AM	6:55 PM	13:49
28	28	3	15	197.31	-17.31	13.2	2	28003	4:34 AM	7:04 PM	14:30
10	10	9	12	195.87	-15.87	16.3	1	10009	6:57 AM	9:17 PM	14:20
25	25	1	7	193.56	-13.56	27.7	1	25001	4:43 AM	6:31 PM	13:48
04	04	7	23	193.21	-13.21	8.4	2	4007	5:25 AM	12:53 AM	19:28
23	23	5	11	191.29	-11.29	17.4	1	23005	5:34 AM	10:07 PM	16:33
12	12	1	32	189.53	-9.53	5.9	2	12001	4:55 AM	8:06 PM	15:11
23	23	3	13	189.12	-9.12	14.5	1	23003	5:01 AM	9:42 PM	16:41
71	71	2	10	188.43	-8.43	18.8	1	71002	5:23 AM	7:23 PM	14:00
23	23	1	12	184.66	-4.66	15.4	1	23001	4:31 AM	8:35 PM	16:04

January 2020 Service Statistics:

279 weekday blocks:

- 80 all-day blocks
- 199 partial-day blocks

234 BEB Compatible Blocks (84%):

- 45 blocks exceed 180 miles
- Longest blocks on Routes 10, 18, 28, 43, 63

Line Group	Line Group	Block	Revenue Trips	Distance	Remaining	Miles/Trip	Trips to 180	BlockID	Pull Out	Pull In	Span
10	10	3	19	283.33	-103.33	14.9	7	10003	4:20 AM	1:27 AM	21:07
10	10	1	20	280.16	-100.16	14.0	8	10001	3:49 AM	1:10 AM	21:21
10	10	2	19	279.9	-99.9	14.7	7	10002	4:09 AM	12:57 AM	20:48
18	18	5	16	263.69	-83.69	16.5	6	18005	5:22 AM	1:56 AM	20:34
18	18	3	17	263.28	-83.28	15.5	6	18003	4:32 AM	1:21 AM	20:49
18	18	2	17	262.75	-82.75	15.5	6	18002	3:57 AM	1:03 AM	21:06
19	19	3	13	255.15	-75.15	19.6	4	19003	5:05 AM	12:57 AM	19:52
63	63	2	16	255.07	-75.07	15.9	5	63002	5:26 AM	11:42 PM	18:16
63	63	1	15	254.95	-74.95	17.0	5	63001	4:48 AM	10:32 PM	17:44
43	43	1	14	252.91	-72.91	18.1	5	43001	4:36 AM	11:58 PM	19:22
10	10	7	17	252.42	-72.42	14.8	5	10007	5:27 AM	12:40 AM	19:13
28	28	6	20	251.02	-71.02	12.6	6	28006	5:13 AM	12:17 AM	19:04
28	28	8	18	248.21	-68.21	13.8	5	28008	6:17 AM	12:31 AM	18:14
15	15	1	15	242.41	-62.41	16.2	4	15001	4:46 AM	11:33 PM	18:47
71	71	3	12	241.8	-61.8	20.2	4	71003	5:30 AM	10:40 PM	17:10
18	18	4	15	236.7	-56.7	15.8	4	18004	4:37 AM	12:16 AM	19:39
18	18	1	15	235.69	-55.69	15.7	4	18001	4:02 AM	10:54 PM	18:52
28	28	2	16	233.7	-53.7	14.6	4	28002	4:33 AM	11:04 PM	18:31
31	31	1	13	233.65	-53.65	18.0	3	31001	4:56 AM	10:39 PM	17:43
28	28	5	15	233.11	-53.11	15.5	4	28005	4:53 AM	11:07 PM	18:14
28	28	1	15	231.6	-51.6	15.4	4	28001	4:14 AM	9:28 PM	17:14
10	10	6	15	227.03	-47.03	15.1	4	10006	5:00 AM	10:12 PM	17:12
10	10	4	15	223.6	-43.6	14.9	3	10004	4:27 AM	9:02 PM	16:35
25	25	4	9	221.5	-41.5	24.6	2	25004	5:33 AM	9:28 PM	15:55
25	25	2	9	220.6	-40.6	24.5	2	25002	5:09 AM	9:22 PM	16:13
06	06	1	19	219.58	-39.58	11.6	4	6001	4:23 AM	11:14 PM	18:51
06	06	3	18	212.16	-32.16	11.8	3	6003	5:35 AM	11:38 PM	18:03
19	19	5	12	209.59	-29.59	17.5	2	19005	5:56 AM	11:57 PM	18:01
71	71	1	9	208.79	-28.79	23.2	2	71001	5:00 AM	6:50 PM	13:50
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12	12	1	32	189.53	-9.53	5.9	2	12001	4:55 AM	8:06 PM	15:11
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January 2020 Service Statistics:

279 weekday blocks:

- 80 all-day blocks
- 199 partial-day blocks

234 BEB Compatible Blocks (84%):

- 45 blocks exceed 180 miles
- Longest blocks on Routes 10, 18, 28, 43, 63

Pre-pandemic service to current service comparison:

- January 2020 peak: 174 buses
- June 2022 peak: 141 buses
- Reduction: 33 buses (19%)

Line Group	Line Group	Block	Revenue Trips	Distance	Remaining	Miles/ Trip	Trips to 180	BlockID	Pull Out	Pull In	Span
10	10	3	19	283.33	-103.33	14.9	7	10003	4:20 AM	1:27 AM	21:07
10	10	1	20	280.16	-100.16	14.0	8	10001	3:49 AM	1:10 AM	21:21
10	10	2	19	279.9	-99.9	14.7	7	10002	4:09 AM	12:57 AM	20:48
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18	18	3	17	263.28	-83.28	15.5	6	18003	4:32 AM	1:21 AM	20:49
18	18	2	17	262.75	-82.75	15.5	6	18002	3:57 AM	1:03 AM	21:06
19	19	3	13	255.15	-75.15	19.6	4	19003	5:05 AM	12:57 AM	19:52
63	63	2	16	255.07	-75.07	15.9	5	63002	5:26 AM	11:42 PM	18:16
63	63	1	15	254.95	-74.95	17.0	5	63001	4:48 AM	10:32 PM	17:44
43	43	1	14	252.91	-72.91	18.1	5	43001	4:36 AM	11:58 PM	19:22
10	10	7	17	252.42	-72.42	14.8	5	10007	5:27 AM	12:40 AM	19:13
28	28	6	20	251.02	-71.02	12.6	6	28006	5:13 AM	12:17 AM	19:04
28	28	8	18	248.21	-68.21	13.8	5	28008	6:17 AM	12:31 AM	18:14
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06	06	3	18	212.16	-32.16	11.8	3	6003	5:35 AM	11:38 PM	18:03
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71	71	1	9	208.79	-28.79	23.2	2	71001	5:00 AM	6:50 PM	13:50
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28	28	3	15	197.31	-17.31	13.2	2	28003	4:34 AM	7:04 PM	14:30
10	10	9	12	195.87	-15.87	16.3	1	10009	6:57 AM	9:17 PM	14:20
25	25	1	7	193.56	-13.56	27.7	1	25001	4:43 AM	6:31 PM	13:48
04	04	7	23	193.21	-13.21	8.4	2	4007	5:25 AM	12:53 AM	19:28
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12	12	1	32	189.53	-9.53	5.9	2	12001	4:55 AM	8:06 PM	15:11
23	23	3	13	189.12	-9.12	14.5	1	23003	5:01 AM	9:42 PM	16:41
71	71	2	10	188.43	-8.43	18.8	1	71002	5:23 AM	7:23 PM	14:00
23	23	1	12	184.66	-4.66	15.4	1	23001	4:31 AM	8:35 PM	16:04

APPENDIX C: HYDROGEN-RELATED CODES, STANDARDS, AND REGULATIONS

Hydrogen and Building Codes

The design of facilities for hydrogen fueled vehicles is regulated and guided by codes and standards that include:

- NFPA 2, Hydrogen Technologies Code
- NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages
- NFPA 55: Compressed Gases and Cryogenic Fluids Code
- NFPA 70, National Electrical Code
- NFPA 88A, Standard for Parking Structures (NFPA 88A refers to NFPA 2)
- ICC, International Mechanical Code
- ICC, International Fire Code
- OSHA Regulations 29 CFR 1910, Subpart H (https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.103)

Codes and standards relating to installation, operation, and maintenance of facilities for vehicles fueled with lighter than air fuels such as hydrogen and CNG are still evolving. As such, the available codes and standards are not in agreement regarding specific requirements. Facilities for maintenance of vehicles using hydrogen fuels are designed to code requirements, as well as reference guidelines and current industry practice.

Code provisions define the minimum acceptable standards to which facilities are allowed to be built in a given area. Code requirements define a degree of safety, performance, and quality that has been generally accepted by building officials and refined over time. Industry standards expand on code requirements by defining additional technical recommendations that are adopted by the specialty technical organization which published such standards. Standards are generally adopted through a consensus process, and as such are subject to input from parties with special interests and publishing delays. Industry practice represents how facilities are actually designed and constructed at a given time. Industry practice and standards often adopt provisions before those provisions appear in codes due to the delay in updating the codes.

Codes may adopt industry standards by reference, but if not adopted by a code in force in a local jurisdiction, the provisions of that standard, which might be more current, may be considered optional.

Designers interpret the array of codes, standards, and industry practices, to make a judgment of what might be considered best practice. These judgments consider available guidance to provide a level of safety, but such judgments may involve subjective selection between two or more alternatives, each of which meets the prescribed guidance. Future codes may or may not adopt industry practice and standards that are in place today, and owners and designers should consider what represents best practice at such time as a facility is designed, constructed, or modified.

Hydrogen (H_2) Properties and Hazards

Hydrogen Characteristics

Gaseous hydrogen consists of 100% hydrogen, which at atmospheric conditions is much lighter than air and quickly rises when not otherwise contained. In contrast, diesel and gasoline vapors are heavier than air and settle to the ground. Facilities for maintenance of hydrogen fueled vehicles need to be constructed to limit sources of ignition for flammable gas that may be accidentally released and to evacuate any such gas that is released. Facilities in which a combination of diesel, unleaded and lighter than air gas fueled vehicles may be maintained need to restrict ignition sources where flammable fumes may accumulate, both near the floor and near the ceiling.

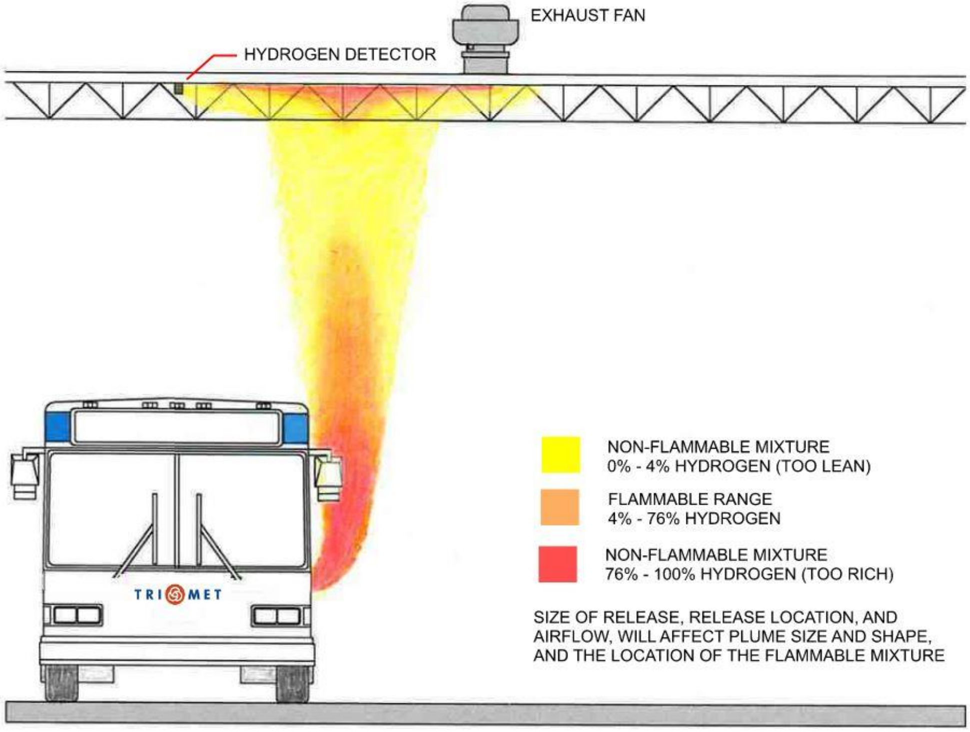
For fuel vapors to catch fire, the fuel must exist in certain proportions as a combustible gas and air mixture, along with an ignition source with sufficient energy to ignite the mixture. The minimum concentration of a particular combustible gas in air required to support its combustion is defined as the lower flammable limit (LFL), for that gas. Below this level, the mixture is too "lean" to burn. The maximum concentration of a gas that will burn in air is defined as the upper flammable limit (UFL). Above this level, the mixture is too "rich" to burn. The range between the LFL and UFL is the flammable range for that gas. Hydrogen is flammable in a wide range of 4% to 76% mixture with air.

Since hydrogen is lighter than air at ambient conditions, hydrogen that may be released will behave as a buoyant gas and tend to rise naturally. A high-pressure release may initially act as a neutrally buoyant gas, but as it dissipates the gas will become buoyant. The rising gas plume mixes with surrounding air and the concentration of the gas will decrease. The gas plume will either: (1) Continue to rise in a space until it reaches a fixed barrier such as a ceiling where the gas will spread across the fixed barrier and may separate from the ambient air to increase the gas concentration; or (2) Become neutrally buoyant as it mixes with air and the gas will then tend to move around with the ambient air currents.

Compressed hydrogen stored in containers on vehicles is too rich to ignite. In the event of a leak from a hydrogen fueled vehicle, the gas leaving the vehicle is also too rich to ignite. As the gas escaping from the vehicle rises and mixes with air, the concentration of gas in air will drop until the mixture is within the flammable range. As the gas plume continues to rise and mix with air, the concentration of gas in air will continue to drop below the LFL at which point the mixture will be too lean to burn. When the rising plume reaches the ceiling, the plume will collect and gas that is lighter than air will separate from air. The concentration of gas may then increase to a point within the flammable range, or more at which point the gas concentration would again be too rich to burn. As the plume collects, the mixture will spread out across the ceiling.

In the event of a release of flammable gas, before the gas dissipates to a non-flammable concentration, there will necessarily be a flammable mixture of gas somewhere between the point of the leak, which is too rich to burn and the point at which the gas-air mixture becomes too lean to burn. If gas detectors are installed and detect gas at a nominated percentage of the LFL, a flammable mixture must exist somewhere between the source of the leak and the detector. This concept is illustrated in the figure on the following page. The location of the flammable mixture would generally be above the location of the leak as the gas rises, but the actual location of the flammable mixture would be unknown. The location and size of the flammable mixture is dependent on several factors, including, but not limited to, the pressure and volume of the release, the location of the release, and surrounding ambient airflow.

Appendix C Figure 0-1: Flammable Gas Plume Behavior



Source: Tri-Met, Portland, OR

Hydrogen Properties

Given that hydrogen is lighter than air and has a higher ignition temperature than gasoline or diesel fuel, it naturally rises and dissipates in open air and is more difficult to ignite than gasoline or diesel vapors.

Hydrogen is a colorless, odorless gas. Unlike compressed natural gas, which is odorized with mercaptan as a safety precaution so that leaking CNG can be detected by smell the same as natural gas used for comfort heating, hydrogen used in HFCBs is not odorized. Because of the buoyancy of hydrogen, 2.5 times the odorant would be required to effectively odorize hydrogen than to odorize natural gas, and the odorants used to odorize CNG contaminate the catalysts used in hydrogen fuel cells. Therefore, hydrogen is not odorized and requires hydrogen gas sensors to detect and alert operators to the presence of the odorless, colorless, gas.

Additional specific properties of hydrogen gas are presented below and compared with gasoline, diesel, and CNG.

Appendix C Table 0-1: Properties of Select Liquid and Gaseous Fuels

PROPERTY	GASOLINE	DIESEL NO. 2	CNG	HYDROGEN
Physical state	Liquid	Liquid	Compressed Gas	Compressed Gas or Liquid
Relative Vapor density (Air = 1)	3.5	5	0.56	0.07

PROPERTY	GASOLINE	DIESEL NO. 2	CNG	HYDROGEN
Boiling range (°F @ 1 atm)	80 to 420	320 to 720	-259	-423
Energy content (lower heating value) Btu/lb., Btu/gal	- 112,114 – 116,090	- 128,488	20,160 -	51,585 -
Energy content (higher heating value) Btu/lb., Btu/gal	- 120,388 – 124,340	- 138,490	22,453 -	61,013 -
Autoignition temperature (°F)	495	600	1004	1,050 to 1,080
Flashpoint (°F)	-45	165	-306	N/A
Octane number range (R+M) 2	84 to 93	n/a	120	130+
Flammability limits (volume % in air)	L = 1.2 H = 7.1	L = 0.7 H = 5.0	L = 5 H = 15	L = 4 H = 76
Gasoline/diesel gallon equivalent	97% - 100%	1 gallon of diesel has 111% of the energy of one gallon of gasoline.	123.57 cu ft. of CNG has 100% of the energy of one gallon of gasoline. 6.38 pounds or 139.30 cu ft. of CNG has 100% of the energy content of one gallon of diesel.	1 kg or 2.198 lbs. of H_2 has 100% of the energy of one gallon of gasoline. 0.9 kg or 1.973 lbs. of H2 has 100% of the energy of one gallon of gasoline.

Typical fuel storage per bus is 30kg (66.15 lbs.) of gaseous hydrogen with an expected range of 250 miles with passengers and stops, or 350 miles without passengers and stops. The volume and density of a gas changes with temperature and pressure but mass stays the same. For this reason, quantities of hydrogen are usually given in mass (kg or lb.). At standard temperature and pressure of 20°C (68°F), and 1atm., hydrogen gas has a density of 0.0899 kg/m3 or 0.0056 lb./ft^3. 1 kg or 2.198 lbs. of H_2 gas at standard conditions = 11.1235 m^3 or 392.5 ft^3 (SCF).

The amount of GH2 needed to fuel a bus for a day assuming substantially empty storage tanks is 30kg (66.15 lbs.) of GH2 per bus per day. For a fleet of 250 busses 7,500 kg (16,538 lbs.) of GH2 would be required per day, which at STP is 83,426 m^3 (2,953,125 ft^3). The capacity needed for fueling multiple GH2 powered busses far exceeds the maximum allowable quantity of Hydrogen per control area, so special provisions are required for compliance with code provisions.

Design Requirements for Hydrogen Fueled Vehicles

General Requirements

The following table describes the amount of hydrogen allowed in various types of facility areas.

Appendix C Table 0-2: Maximum Allowable Quantity of Hydrogen per Control Area (Quantity Thresholds Requiring Special Provisions)

AREA	UN-SPRINKLERED AREAS		SPRINKLERED AREAS	
Material	No Gas Cabinet, Gas Room, or Exhausted Enclosure	Gas Cabinet, Gas Room, or Exhausted Enclosure	No Gas Cabinet, Gas Room, or Exhausted Enclosure	Gas Cabinet, Gas Room, or Exhausted Enclosure
GH_2	1000 ft^3 (28 m^3)	2000 ft^3 (56 m^3)	2000 ft^3 (56 m^3)	4000 ft^3 (112 m^3)

(Source: From NFPA 2, Table 6.4.1.1.1)

Note: The maximum quantity indicated is the aggregate quantity of materials in storage and use combined.
**A gas cabinet or exhausted enclosure is required (see also 6.4.1.1.2).*

Standby and Emergency Power

Where the following systems are required for the storage or use of hydrogen that exceed the quantity thresholds requiring special provisions, and where emergency power is not provided, such systems shall be connected to a standby power system in accordance with National Fire Protection Association (NFPA) 70:

- Mechanical ventilation
- Treatment systems
- Temperature controls
- Alarms
- Detection systems
- Other electrically operated systems

Emergency power systems shall meet the requirements for a Level 2 system in accordance with NFPA 110 or NFPA 111.

Ventilation

Indoor storage and use areas and storage buildings for hydrogen shall be provided with mechanical exhaust ventilation or engineered fixed natural ventilation that is approved by the AHJ. Continuous ventilation shall be provided at a rate of not less than 1 $scf/min/ft^2$ of floor area over the area of storage or use unless an alternative design is approved by the AHJ.

For gases that are lighter than air, the ventilation system shall include exhaust taken from a point within 12 in. of the ceiling and not recirculated.

Ventilation discharge systems conveying hydrogen mixtures shall terminate at a point outdoors not less than:

- 30 ft. from property lines
- 10 ft. from operable openings into buildings
- 6 ft. from exterior walls and roofs
- 30 ft. from combustible walls and operable openings into buildings that are in the direction of the exhaust discharge
- 10 ft above adjoining grade
- As far as practical from adjacent equipment that is not listed for operation in a classified environment (assume a minimum separation of 10 ft. to adjacent electrical equipment. Note that the minimum 10 ft. separation between

exhaust outlets and building openings or intakes required by mechanical codes does not account for potentially flammable vapors and nearby ignition sources.)

Outdoor Aboveground Storage

Appendix C Table 0-3: Minimum Distance (D) from Outdoor Bulk Hydrogen Compressed Gas Systems to Exposures by Maximum Pipe Size with Pressures >3000 to ≤15,000 psig

(From NFPA 2, Table 7.3.2.3.1.1(A)(c))

PRESSURE	>3000 to ≤7500 psig >20,684 to ≤51,711 kPa			>7500 to ≤15,000 psig >51,711 to ≤103,421 kPa		
	EXPOSURES			EXPOSURES		
Internal Pipe Diameter (ID)	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
ID (in.)	Ft	Ft	Ft	Ft	Ft	Ft
0.2	5	5	7	7	7	9
0.3	14	11	10	18	14	14
0.4	24	16	14	31	22	19
0.5	33	22	18	43	30	24
0.6	42	28	22	55	38	29
0.7	51	33	26	67	46	34
0.8	60	39	29	79	53	39
0.9	70	45	33	91	61	44
1.0	79	50	37	103	69	49
1.1	88	56	41	115	76	54
1.2	97	62	45	127	84	59
1.3	106	67	49	139	92	64
1.4	116	73	52	152	100	69
1.5	125	79	56	163	107	74
1.6	134	84	60	175	115	79
1.7	143	90	64	188	123	84
1.8	152	96	68	199	131	89
1.9	162	102	72	212	139	94
2.0	171	107	75	224	146	99

Note: Linear interpolation of internal pipe diameters and distances between table entries is allowed.

Except for distances to air intakes, the distances to Group 1 and 2 exposures may be reduced by one-half and shall not apply to Group 3 exposures where fire barrier walls are located between the system and the exposure.

Maintenance and Repair Facilities

The NFPA classifies vehicle repair garages in two categories to differentiate between risk associated with the type of repairs being performed on vehicles. Repair Garages are classified as Major or Minor Repair Garages; these classifications are used in most of the NFPA codes applicable to hydrogen fuel cell vehicles, including NFPA 2, NFPA 30A, and NFPA 70. Major and Minor Repair Garages are characterized as follows:

- **Major Repair Garage.** A building or portions of a building for major repairs, such as work on the hydrogen storage system, the fuel system, repairs that require defueling of the hydrogen fuel cell vehicle, and maintenance or repairs that require open flame cutting or welding.
- **Minor Repair Garage.** A building or portions of a building used for lubrication, inspection, and minor automotive maintenance work, such as engine tune-ups, replacement of parts, fluid changes (e.g., brake fluid, air conditioning refrigerants), brake system repairs, tire rotation, and similar routine maintenance work.

Major repair garages that only repair vehicles powered by hydrogen shall comply with NFPA 2. Major repair garages that repair vehicles powered by hydrogen as well as other fuels including gasoline, diesel and CNG shall comply with NFPA 2 and NFPA 30A.

NFPA 2 allows for repairs that would be required to be performed in a major repair garage (29th & Broadway facility) to be performed in a minor repair garage (10th & Broadway facility) if the vehicle is defueled in accordance to less than 400 scf and the fuel supply container is sealed. A typical HFCB might have a fuel capacity of 30kg or 11,775 SCF.

SPRINKLERS

In buildings with a major repair garage, automatic fire suppression sprinklers shall be provided throughout the entire building.

CONSTRUCTION

NFPA 2 allows repairs to HFCV in a Major Repair Garage in rooms or booths constructed to prevent migration of fugitive hydrogen to adjacent areas. Walls, doors, and ceilings that intersect or enclose a repair area are to be constructed of noncombustible or limited combustible materials or assemblies and securely and rigidly mounted.

Interior surfaces of the repair area shall be smooth, non-porous and constructed to facilitate ventilation.

Repair rooms shall be separated from surrounding areas of the building by assemblies that have a fire resistance rating of one hour.

Repair booths shall be separated from other operations by a minimum distance of 3 ft., or by a partition, wall, or floor/ceiling assembly having a fire resistance rating of not less than one hour. The clear space of not less than 3 ft. shall be maintained on all sides and above a repair booth unless a one-hour rated partition is provided and the integrity of the booth is maintained.

Multiple connected repair booths may be considered as a single operation without separation.

Supplemental Construction Recommendations:

- Install automatic doors to close off untreated areas such as parts rooms and machine shops. These should close upon gas detection.
- Install self-closing man doors to close off untreated areas from the garage.
- Install bulkheads in stairways and hallways that could lead to a gas plume migrating into untreated areas. This approach can be evaluated against or combined with HVAC system pressure balancing to keep a plume out of these areas."
- Remove, pressurize, or ventilate plenum area above ceilings to prevent intrusion and collection of flammable gas.
- Seal and fire stop wall penetrations in walls separating repair garage areas from adjacent occupancies.

DEFUELING EQUIPMENT

Hydrogen fuel shall be discharged from storage containers before maintenance or repair is performed on the fuel storage system, or when welding or open flame activities occur within 18 in. of the vehicle fuel container. Major repair garages require defueling equipment to empty vehicle fuel supply containers.

GAS DETECTION SYSTEM

Major repair garages shall be provided with an approved hydrogen detection system to detect the presence of hydrogen gas where vehicle hydrogen fuel storage systems are serviced or where defueling is performed indoors.

The detection system shall activate an alarm or other safety systems and measures such as ventilation systems, or selective system shutdown and record the gas concentration at each sensor location. Detectors should be configured to have multiple alarm levels such as a low-level alarm that activates an audible signal and increases ventilation and a high-level alarm that initiates a system shutdown and notifies first responders. Alarm levels should be set not more than 25% of the hydrogen lower flammable limit.

The hydrogen detection system shall provide coverage of the motor vehicle service area, and have sensors in the following locations:

- At inlets to exhaust systems
- At high points in service bays
- At the inlets to mechanical ventilation systems

Catalytic technology is required detect hydrogen leaks. Infrared (IR) technology will not detect GH2. Catalytic sensors should be calibrated four times per year and sensors should be replaced every three to four years.

Point detectors are recommended for hydrogen. Open path detectors use IR, so they can't be used for hydrogen. Point detectors should be installed at high points throughout the facility (approximately 15' from walls and 30' from the next detector (NTS)). For hydrogen, "detectors are required at the inlet to exhaust air systems and mech ventilation inlets where GH2 vehicles are serviced or defueled (NFPA 2 Section 18.3.3.4)".

Gas detection systems shall fail-safe. A failure of a system component shall place the system into response mode. Subject to approval by the AHJ, a trouble signal to a monitored location in response to a component failure with a brief time delay before activating the response mode, may be acceptable.

A unique identification tag should be assigned to each detector and label so the status of each detector can be electronically monitored. Each detector should be labeled so it is visible from the floor. Calibration tubing should be installed at floor level, or an automatic calibration system should be installed to facilitate and reduce the cost and operational interruption of calibration.

Gas detection circuits shall be monitored for integrity as required in NFPA 72. Gas detection controllers for hydrogen shall be listed and labelled to UL 2017 or UL 864 and detectors shall be labeled to UL 2075.

Visible status lights should be provided inside the garage and outside above overhead doors to alert workers when hydrogen is detected, as well as when the system is operational. Manual gas detection activation buttons are recommended at personnel exit doors.

Activation of the hydrogen detection system shall:

- Initiate distinct audible and visual alarm signals in the repair garage
    - It is recommended that an alarm also be activated in a location that is continuously occupied and monitored such as a dispatch center, security office, or remote service center.
    - Consideration should be given to activating a general alarm throughout connected building areas in the event of a high-level alarm.
- Deactivate all heating systems located in the repair garage except for classified heaters that are listed and labeled for Class I, Division 1, and remote sources of heating, such as forced hot air, hot water, or steam where the furnace, boiler, heat pump, etc. is located in a separate area that does not draw air from the repair area]
- Activate the mechanical ventilation system.

Activation of the hydrogen detection system may also initiate actions such as:

- Disconnect power to electrical equipment with open-bus power supplies, such as cranes and hoists, particularly those located above vehicle service bays.
- Disconnect power to welding receptacles or similar fixed equipment.
- Disconnect power to other electrical equipment located above vehicle service bays and not listed for use in a classified environment.
- Open select motorized doors to allow for supplemental ventilation or make-up air.

Appendix C Table 0-4: Suggested Gas Detection System Response

	INITIATING EVENT				
Gas Detection System Response	25% LFL Low Level	50% LFL High Level	Manual Activation	System Trouble Non-Critical	System Failure
Gas Detection Strobes (Normal = Green)	Amber	Red	Red	Blue	Red
Gas Detection Horns	X	X	X		X
Shut-down applicable heaters	X	X	X	X	X
Open select outside overhead doors for ventilation Close doors between shop and adjacent areas.	X	X	X		X
Start Emergency Fans	X	X	X		X
Remove Power for Crane and Welding/Sparking	X	X	X		X
Report and Display Fault on FACP		X	X		X
Non-latching: Automatic Reset When Condition Clears	X			X	
Latching: Manual System Reset When Condition Clears		X	X		X

HEATING, VENTILATING, AND AIR CONDITIONING

Forced air heating, air-conditioning, and ventilating systems serving a garage shall not be interconnected with any such systems serving other occupancies in the building.

Combined ventilation and heating systems shall only recirculate air from areas that are more than 455 mm (18 in.) below the ceiling level.

Open-flame heaters and heating equipment with exposed surface temperatures over 750°F (400°C) are prohibited in Major Repair Garages for hydrogen vehicles within 18 in. of the ceiling or in areas subject to ignitable concentrations of gas, including such items as unit heaters and heating and ventilating units with gas fired or electric coils, and most infrared radiant heaters. Some manufacturers offer low intensity radiant heaters with sealed combustion chambers and low surface temperatures, but these units are less effective than standard infrared heaters, and any gas fired may effectively have an open flame if installed incorrectly or as a result of damage and corrosion over time.

A mechanical hydrogen exhaust system with exhaust drawn from within 12 inches of the high point of the ceiling shall be provided for each room, booth, or space for major repair of hydrogen fueled vehicles. Exhaust shall discharge outdoors not less than:

- 30 ft. from property lines
- 10 ft. from operable openings into buildings
- 6 ft. from exterior walls and roofs
- 30 f.t from combustible walls and operable openings into buildings that are in the direction of the exhaust discharge
- 10 ft. above adjoining grade
- As far as practical from adjacent equipment that is not listed for operation in a classified environment (assume a minimum separation of 10 ft. to adjacent electrical equipment. Note that the minimum 10 ft. separation between exhaust outlets and building openings or intakes required by mechanical codes does not account for potentially flammable vapors and nearby ignition sources.)

For repair rooms, booths, or spaces where hydrogen vehicles are repaired, the area within 18 in. of the ceiling shall be designated a Class I, Division 2, Group B hazardous (i.e., classified) location, except where a continuous mechanical ventilation system is provided and operating at a rate of not less than 1 scf/min/ft^2 of floor area over the area of storage or use. A local visual and audible alarm shall activate, and repair activities shall cease upon the loss of continuous ventilation. Note that mechanical codes may allow for intermittent ventilation to avoid classification; however, this practice is not recommended due to known presence of flammable mixture in the event of a release (See Section 2.1 and Figure 1). Exhaust air should be discharged vertically upward and away from fresh air intakes and equipment.

The mechanical code specifies a minimum separation of 10 ft. between an exhaust outlet and an air intake of building opening to prevent contamination of indoor air, but that distance does not consider potential ignition sources such as combustion air intakes or motor enclosures. Being much lighter than air, hydrogen will tend to rise quickly, but it is best practice to analyze wind patterns and exhaust airflow direction to prevent flammable vapors from coming in contact with ignition sources. It is recommended that exhaust air that may contain hydrogen be discharged at least 10 ft. from all parts of any adjacent equipment and be discharged vertically upward (upblast fans).

It is recommended that ventilation air be supplied at floor level to helps dilute leaks and push gas plumes towards ceiling detection and exhaust systems. Maintenance areas should also be designed such that normal air pressure in the area is negative relative to adjacent spaces to inhibit migration of flammable gases.

Heat recovery systems such as plate heat exchangers or run-around coils should be considered for energy conservation. Heat wheels are not acceptable as they include a purge section that can recycle air containing hydrogen mixtures.

Areas adjacent to classified locations where flammable vapors are not likely to be released, such as stock rooms, switchboard rooms, and other similar locations, where mechanically and continuously ventilated at a rate of four or more air changes per hour, designed with positive air pressure, or effectively isolated by walls or partitions, may be designated unclassified.

ELECTRICAL CLASSIFICATION

The extents of specific locations within Major Repair Garages for hydrogen as described in the following table.

Appendix C Table 0-5: Extent of Classified Locations for Major Repair Garages with Lighter-than-Air Fuel (From NFPA 30A)

LOCATION	CLASS[1]		EXTENT OF CLASSIFIED LOCATION
	Division[2]	Zone[3]	
Repair garage, major (where lighter than-air gaseous fueled[1] vehicles are repaired or stored)	2	2	Within 450 mm (18 in.) of ceiling, except as noted below
	Unclassified	Unclassified	Within 450 mm (18 in.) of ceiling where ventilation of at least .3 $m^3/min/m^2$ (1 $ft^3/min/ft^2$) of floor area, with suction taken from a point within 450 mm (18 in.) of the highest point in the ceiling
Specific areas adjacent to classified locations	Unclassified	Unclassified	Areas adjacent to classified locations where flammable vapors are not likely to be released, such as stock rooms, switchboard rooms, and other similar locations, where mechanically ventilated at a rate of four or more air changes per hour or designed with positive air pressure, or where effectively cut off by walls or partitions

[1] Includes fuels such as hydrogen and natural gas, but not LPG.

[2] For hydrogen (lighter than air) Group B, or natural gas Group D.

[3] For hydrogen (lighter than air) Group IIC or IIB+H2, or natural gas Group IIA.

Parking Garages

NFPA recommends that vehicles powered by gaseous or liquid hydrogen in parking garages be subject to the same requirements applicable to vehicles powered by traditional fuels. NFPA provides no supplemental recommendations for construction of parking garages to be used for storage of hydrogen fueled vehicles.

NFPA determined that the fire hazard presented by vehicles powered by GH2 or LH2 is sufficiently similar to those presented by vehicles fueled by liquid gasoline or diesel fuel that no additional requirements are warranted. The combustible components common to all vehicles can cause a vehicle fire to spread from one parked vehicle to another but that the presence of hydrogen fuel is not a major cause of fire spread.

Parking garages to be used for storage of HFCBs should be constructed in accordance with the locally adopted building and fire codes.

Vehicle Fueling Facilities

Dispensing equipment shall be provided with hydrogen gas detection, leak detection, and flame detection at the fueling area.

An emergency manual shutdown device shall be provided at the dispensing area and also at a location remote from the dispensing area.

Canopies that are used to shelter dispensing operations shall meet or exceed Type I construction requirements of the adopted building code and be constructed in a manner that prevents the accumulation of hydrogen gas.

ELECTRICAL INSTALLATIONS

The extents of classified areas for electrical installations based on specific locations are described in the following table.

Appendix C Table 0-6: Extent of Classified Areas for Electrical Installations

LOCATION	DIVISION OR ZONE	EXTENT OF CLASSIFIED AREA
Outdoor dispenser enclosure — exterior and interior	2	Up to 5 ft (1.5 m) from dispenser
Indoor dispenser enclosure — exterior and interior	2	15 ft (4.6 m) from the point of transfer
Outdoor discharge from relief valves or vents	1	5 ft (1.5 m) from source
Outdoor discharge from relief valves or vents	2	15 ft (4.6 m) from source
Discharge from relief valves within 15 degrees of the line of discharge	1	15 ft (4.6 m) from source

With the approval of the AHJ, the classified areas specified above shall be permitted to be reduced or eliminated by positive-pressure ventilation from a source of clean air or inert gas in accordance with methods recognized in NFPA 496.

Fire extinguishers and warning signs are required in the fueling area.

OUTDOOR FUELING

The following table describes the various distance for outdoor fueling systems for hydrogen.

Appendix C Table 0-7: Separation Distances for Outdoor Gaseous Hydrogen Dispensing Systems

SYSTEM COMPONENT	EXPOSURE	REQUIRED SEPARATION	
		ft	m
Dispensing equipment	Nearest important building or line of adjoining property that can be built upon or from any source of ignition	10	3.0
Dispensing equipment	Nearest public street or public sidewalk	10	3.0
Dispensing equipment	Nearest rail of any railroad main track	10	3.0
Point of transfer	Any important building other than buildings of Type I or Type II construction with exterior walls having a fire resistance rating of not less than not less than 2 hours	10	3.0
Point of transfer	Buildings of Type I or II construction with exterior walls having a fire resistance rating of not less than 2 hours or walls constructed of concrete or masonry, or of other material having a fire resistance rating of not less than 2 hours	No limit	No limit
Point of transfer	Storage containers	3	1.0

INDOOR FUELING

Rooms within or attached to other buildings shall be constructed of noncombustible or limited-combustible materials except window glazing shall be permitted to be plastic.

- Interior walls or partitions shall be continuous from floor to ceiling, shall be anchored, and shall have a fire resistance rating of at least 2 hours.
- At least one wall shall be an exterior wall.
- Explosion venting shall be provided in exterior walls or roof.
- Access to the room shall be from outside the primary structure.
- If access to the room from outside the primary structure is not possible, access from within the primary structure shall be permitted where such access is made through a vapor-sealing, self-closing fire door having the appropriate rating for the location where installed.

Indoor fueling locations shall be provided with mechanical exhaust ventilation at a rate of not less than 1 scf/min/ft2 of floor area. A ventilation system for a room within or attached to another building shall be separate from any ventilation system for the other building. A gas detection system shall be provided and equipped to sound a latched alarm and visually indicate when a maximum of one-quarter of the lower flammable limit is reached. Walls, ceilings, and floors within 15 ft. (4.6 m) of the dispenser shall be constructed as fire barriers having a fire resistance rating not less than two hours.

Other Operational Considerations

Overhead catenary system (OCS) such as for light rail systems are considered no more of a hazard with operation of hydrogen buses than other electrical systems that may be nearby. NFPA determined that the fire hazard presented by vehicles powered by GH2 or LH2 is similar to those presented by vehicles fueled by liquid gasoline or diesel fuel in normal operation, and no cases of GH2 igniting due to OCS wires were found in online research. Static OCS does not present an ignition source, and an ignition source only exists as a result of arcing between the contact wire and a pantograph. Such arcing would need to be concurrent with a hydrogen release such as from a pressure relief device (PRD), and PRD releases are rare. Regardless of published and anecdotal information, provisions for use of hydrogen fueled vehicles should be closely coordinated with the local fire marshal.

APPENDIX D: FCEB RESOURCES AND ADDITIONAL CONSIDERATIONS

Clean Air Program: Design Guidelines for Bus Transit Systems Using Hydrogen as an Alternative Fuel
U.S. Department of Transportation, Federal Transit Agency
DOT-FTA-MA-26-7021-98-1
DOT-VNTSC-FTA-98-6
Office of Research, Demonstration, and Innovation
October 1998 Final Report

Hydrogen Technologies Safety Guide
National Renewable Energy Laboratory (NREL)
C. Rivkin, R. Burgess, and W. Buttner
Technical Report
NREL/TP-5400-60948
January 2015

Hydrogen Vehicle and Infrastructure Codes and Standards Citations
National Renewable Energy Laboratory (NREL)
NREL/BR-5400-57943
October 2013

29 CFR 1910.103 (OSHA) Requirements for Hydrogen Systems

The Occupational Safety and Health Administration (OSHA) establishes requirements for hydrogen systems in 29 CFR 1910.103. The tabular distances reflect those values published in the July 1, 2006, edition of the CFR. The criteria established in OSHA's tables of distances are based on the 1969 edition of NFPA 50A. Six subsequent editions of NFPA 50A were adopted before NFPA 50A was integrated into NFPA 55 in 2003. NFPA 55 was revised again in 2005.

Throughout the eight revision cycles of NFPA 50A and then NFPA 55, the tabular distances in the NFPA codes were revised as the technology in the use of hydrogen advanced. However, the tabular distances listed in the OSHA tables remain based on the 1969 data. While the OSHA tables may represent the current Federal statutory requirements, it should be recognized that the OSHA tables cases lack clarity and hazards recognized by the ongoing evolution of the separation tables have not been acknowledged.

As examples of the disparity between the OSHA requirements and current codes, the OSHA Table G.2(a) (Building or structure) refers to buildings by construction types, including wood frame, heavy timber, ordinary, and fire resistive, but current construction codes and NFPA codes on building construction use building types designated as Types I through V, with variations to address the elements of construction. OSHA Table G.2(a) also specifies separation distance from flammable liquids, but excludes combustible liquids, and the OSHA table does not address distances for separation from property lines, public sidewalks.

NFPA 2 includes OSHA Table G.2(a) and Table G.2(b) in Annex G to inform the reader of NFPA 2 of the minimum requirements under 29 CFR and the federal OSHA program. Owners, designers and installers and property owners should understand the limitations of OSHA based on the precedent requirements established with the use of the 1969 edition of

NFPA 50A. The use of the recommendations for separation distance included in NFPA 2 is subject to approval on a case-by-case basis.

Traditionally, the authority having jurisdiction (AHJ) has been a building or fire official, but other authorities may have input to the review and approval process.

APPENDIX E: OTHER, FOR FINAL REV. ORGANIZATION

- Power required to energize (200) **60kW dispensers**
    - 200 x 60kW = 12,000kW
- Quantity of **Heliox 180** (180kW) chargers required to serve (200) **60kW dispensers**
    - 12,000kW ÷ 180kW = 66.67 ≈ (67) **Heliox 180** chargers or
- Quantity of **Heliox 180** chargers that can be served by a 2000 amp, 480/277 Volt switchboard (Heliox chargers are 95% efficient and have a 98% power factor)
    - 180kW ÷ [(0.98)(0.95)] = 193.3kVA   193.3kVA ÷ 0.480kV ÷ √3 = 232.5 amps
    - 2000 amp ÷ 232.5 = 8.6 ≈ (8) **Heliox 180** chargers
- Quantity of 2000 amp, 480/277 Volt double-ended switchboards required to serve (67) **Heliox 180** chargers
- 67 ÷ (8 x 2 switchboards) = 4.18 ≈ (5) **double-ended 2000A switchboards** for 67 **Heliox 180** chargers
- Quantity of 1500kVA transformers to serve (5) 2000A double-ended switchboards
- (8) **Heliox 180** x 193.3kVA = 1546 ≈ 1500kVA
- (5) double-ended switchboards = (10) 1500kVA transformers