NATIONAL LABORATORY OF THE ROCKIES

Fuel Cell Electric Bus Status Report 2025

Matthew Jeffers, Yi He, and Michael Lammert

National Laboratory of the Rockies

The National Laboratory of the Rockies is a national laboratory of the U.S. Department of Energy, Office of Critical Minerals and Energy Innovation, operated under Contract No. DE-AC36-08GO28308.

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List of Acronyms

APTA	American Public Transportation Association
CNG	compressed natural gas
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
FCEB	fuel cell electric bus
MBRC	miles between roadcalls
mpdge	miles per diesel gallon equivalent
NABI	North American Bus Industries
NLR	National Laboratory of the Rockies
OEM	original equipment manufacturer
SOC	state of charge
ZEB	zero-emission bus

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Executive Summary

The National Laboratory of the Rockies, funded by the U.S. Department of Energy's (DOE's) Hydrogen and Fuel Cell Technologies Office, presents this report as part of its long-standing efforts to evaluate and track the deployment of fuel cell electric buses (FCEBs) in the United States. This report highlights recent changes in the FCEB market, status updates for deployments, and a detailed performance evaluation of a large fleet of FCEBs operated by Foothill Transit in California from June 2023 to December 2024.

Key highlights:

- National FCEB deployment trends:
  - The total number of active FCEBs in U.S. transit fleets is at least 99, with an additional 103 buses on order across 14 transit agencies, per annual data from the American Public Transportation Association.
  - California leads with 89 active FCEBs and plans for more than 2,600 buses by 2040 as part of its Innovative Clean Transit regulation.
  - The FCEB market has seen notable orders by transit agencies, including Santa Cruz Metropolitan Transit District's 57 FCEBs (largest acquisition to date) and Orange County Transportation Authority's purchase of 40 FCEBs.
- Foothill Transit FCEB evaluation results:
  - Foothill Transit operates 33 model year 2022 New Flyer FCEBs, marking North America's largest fuel cell bus fleet at the time of deployment. These buses utilize advanced fuel cell and battery systems.
  - Evaluation included comparisons between the FCEB fleet and three baseline compressed natural gas (CNG) bus fleets to assess key performance metrics such as bus availability, fuel efficiency, maintenance costs, and reliability.
  - Foothill Transit FCEB fleet performance:
    - The fleet of 33 FCEBs achieved a total mileage of 1,195,339 miles during the analysis period, with an average availability of 76.8%, higher than the North American Bus Industries (NABI) CNG fleet's 72.4% but below the target of 85%.
    - The fuel efficiency for the FCEB fleet averages 9.2 miles per diesel gallon equivalent (mpdge), surpassing the ultimate DOE/U.S. Department of Transportation (DOT) target of 8.0 mpdge.
    - The monthly fuel cost per mile for the FCEB fleet ranges from $1.00 to $1.50, with an average of $1.25 per mile.
    - The fleet achieved a high value for miles between roadcalls, with 21,345 miles between general roadcalls and 44,272 miles between propulsion-related roadcalls, both exceeding performance targets.
    - Maintenance costs for the fleet during the analysis period were $0.72/mile, lower than the NABI CNG fleet's $1.13/mile, with preventive

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maintenance inspections and propulsion systems being primary cost contributors. This met DOE's interim target of $0.75/mile.

- Technological status and challenges:
    - FCEBs have progressed toward meeting DOE/DOT technical targets for fuel economy, reliability, and maintenance costs. However, challenges persist with high upfront capital costs for buses, hydrogen fuel infrastructure expenses, high costs for hydrogen fuel, and hydrogen fuel loss, which hinder wider deployment of FCEBs in U.S. transit fleets.

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Table A-3. Monthly Availability for the New Flyer CNG Fleet (2500–2529) 34

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1 Introduction

This report is part of a series of status reports from the U.S. Department of Energy's (DOE's) National Laboratory of the Rockies (NLR) tracking the evolution of fuel cell electric bus (FCEB) technology in the United States. It summarizes the status and recent progress from demonstrations of FCEBs in public transit and other passenger transport applications. Since 2000, NLR has evaluated FCEB demonstrations at several transit agencies, assessing the buses, infrastructure, and implementation experience from the partnering transit agencies. These NLR evaluations have been funded by DOE, the U.S. Department of Transportation's (DOT's) Federal Transit Administration, and the California Air Resources Board.

This status report discusses the achievements and challenges of fuel cell propulsion for transit and summarizes the introduction of fuel cell transit buses in the United States. It provides an analysis of the results from the latest FCEB deployment evaluated by NLR—a large fleet of 2022 New Flyer FCEBs operated by Foothill Transit between June 2023 and December 2024. The report's intent is to inform DOE and Federal Transit Administration decision makers who guide future research and funding, state and local government agencies that fund new propulsion technology transit buses, as well as interested transit agencies, bus manufacturers, and other industry representatives.

This report is organized into the following sections:

1. Introduction.
2. Fuel Cell Electric Buses in the United States: Provides an overview of FCEBs deployed in the United States at public transit agencies, as well as other passenger transport applications such as universities, airports, and private fleets. This section also provides a brief update on notable FCEB deployments and recent changes in the FCEB market.
3. Update of Evaluation Results – Foothill Transit: Presents the detailed results of an evaluation of 33 new FCEBs in service at Foothill Transit, compared to baseline compressed natural gas (CNG) bus fleets, including comparisons for availability, fuel economy, fuel cost, and reliability.
4. Current Status of FCEB Technology: Summary of Achievements and Challenges.

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2 Fuel Cell Electric Buses in the United States

2.1 FCEB Deployment Status

The American Public Transportation Association (APTA) takes an annual inventory of vehicles in U.S. transit fleets and publishes detailed information in the APTA Public Transportation Vehicle Database. This includes both the number of vehicles in operation and planned purchases, separated by vehicle type, fuel/powertrain type, original equipment manufacturer (OEM), vehicle model, size, and model year. Many of the records also include the total purchase cost. While the records in this database are self-reported by transit agencies, it is one of the most detailed inventories of transit bus purchases in the United States. Figure 1 shows the number of FCEBs reported to be in operation or on order for U.S. transit fleets, by model year, according to the 2024 APTA vehicle database.[1]

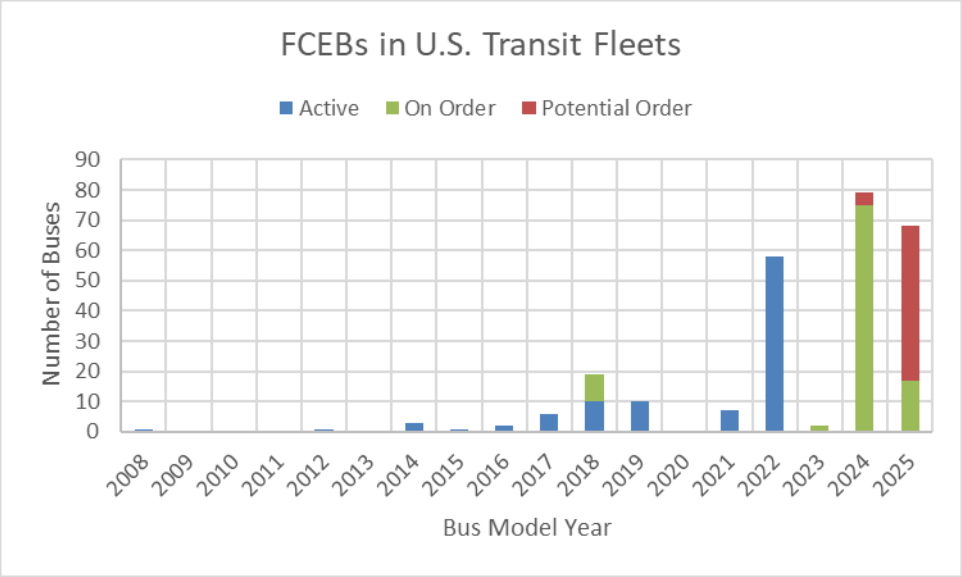

Figure 1. Number of FCEBs in U.S. transit fleets by model year.

Source: 2024 APTA vehicle database

Database entries for model year 2022 buses show a large increase in FCEBs deployed, with 58 new active buses. These new buses are divided between three transit agencies, all in California—Golden Empire Transit (5), Alameda-Contra Costa Transit District (20), and Foothill Transit (33). This signals a shift toward much larger orders of FCEBs at transit agencies, including the purchase of 33 FCEBs by Foothill Transit, which was the largest confirmed order in this dataset and is the focus of NLR's FCEB evaluation in Section 3.

There was another large increase in FCEB purchases for model year 2024, with 75 buses on order, collectively, among 11 transit agencies located in seven different states. This year

[1] Matthew Dickens and Jared Bonina. 2024. *2024 Public Transportation Vehicle Database*. Washington, D.C.: American Public Transportation Association. www.apta.com/research-technical-resources/transit-statistics/vehicle-database.

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represents smaller and more dispersed FCEB orders than 2022. Model year 2025 shows at least 17 buses on order and another 51 as potential orders, approaching the peak orders of 2024.

The reported FCEB counts are listed by transit agency in Table 1—a total of 18 agencies. There are eight transit agencies with a combined total of 99 active FCEBs. Additionally, there are 103 buses on order between 14 agencies. Ten of the transit agencies that have buses on order do not have any active FCEBs as of the time of their reporting. Thus, these agencies are likely deploying FCEBs for the first time.

Table 1. FCEB Count by Transit Agency.

Source: 2024 APTA vehicle database

Transit Agency Name	City	State	FCEBs Active	FCEBs on Order	FCEBs Total
City of Phoenix Public Transit Department	Phoenix	AZ	0	12	**12**
Foothill Transit	West Covina	CA	33	0	**33**
Golden Empire Transit District	Bakersfield	CA	10	0	**10**
Alameda-Contra Costa Transit District	Oakland	CA	30	0	**30**
Orange County Transportation Authority	Orange	CA	10	0	**10**
San Joaquin Regional Transit District	Stockton	CA	0	5	**5**
OMNITRANS	San Bernardino	CA	0	4	**4**
San Mateo County Transit District	San Carlos	CA	0	10	**10**
SunLine Transit Agency	Thousand Palms	CA	6	9	**15**
Victor Valley Transit Authority	Hesperia	CA	0	13	**13**
Champaign-Urbana Mass Transit District	Urbana	IL	2	10	**12**
Mass Transportation Authority	Flint	MI	1	2	**3**
Regional Transportation Commission of Southern Nevada	Las Vegas	NV	0	9	**9**
Regional Transportation Commission of Washoe County	Reno	NV	0	8	**8**
Regional Transit Service	Rochester	NY	0	5	**5**
Stark Area Regional Transit Authority	Canton	OH	7	1	**8**
Southeastern Pennsylvania Transportation Authority	Philadelphia	PA	0	10	**10**
Intercity Transit	Olympia	WA	0	5	**5**
Total			**99**	**103**	**202**

Table 2 shows the total number of FCEBs reported by state. California leads by a large margin, with 89 of the 99 active FCEBs and another 41 buses on order. Ohio, Illinois, and Michigan also have FCEBs in operation. Five other states have agencies with FCEBs on order but zero active FCEBs, which could therefore mark the first FCEB deployments for these states.

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Table 2. FCEB Count by State.

Source: 2024 APTA vehicle database

State	FCEBs Active	FCEBs On Order	FCEBs Total
AZ	0	12	**12**
CA	89	41	**130**
IL	2	10	**12**
MI	1	2	**3**
NV	0	17	**17**
NY	0	5	**5**
OH	7	1	**8**
PA	0	10	**10**
WA	0	5	**5**
Total	**99**	**103**	**202**

Another national inventory of zero-emission buses (ZEBs), funded by the Federal Transit Administration, has been conducted by CALSTART. This annual report, *Zeroing in on Zero-Emission Buses: The U.S. Advanced Technology Transit Bus Index*, expands beyond public transit agencies to also include ZEBs that are in service or on order at universities, airports, and private bus fleets.[2] The 2025 report calculates a total of 575 full-size (Class 7 or 8) FCEBs either funded, ordered, delivered, or deployed in service in the United States. This represents a 55% increase over the previous year's total. California accounts for 435 (or 76%) of those FCEBs. The report identifies only nine small FCEBs (Class 3–6, <30 feet) in the United States—five in Ohio and four in California—and counts zero new small FCEBs purchased since 2022. This report highlights that FCEBs continue to be deployed in applications beyond public transit service, but bus types are limited to full-size ("standard") transit buses. The industry would benefit from additional FCEB manufacturers and bus sizes and types, especially a fuel cell powered cutaway shuttle or other style of minibus, which is preferred in numerous passenger transport applications such as at airports, hotel shuttles, rural transit agencies, and in paratransit or on-demand services.

Transit agencies in California have developed and submitted ZEB rollout plans that outline their plans to meet the Innovative Clean Transit regulation, which requires all agencies to transition to 100% transit ZEBs by 2040.[3] An analysis of the submitted rollout plans indicates that agencies in the state anticipate purchasing more than 2,600 FCEBs by 2040, and potentially more, as some agencies will decide in the coming years which ZEB technology to adopt—battery electric or hydrogen fuel cell.[4]

[2] Mike Hynes and Kaila Lemons. 2025. *Zeroing in on Zero-Emission Buses: The U.S. Advanced Technology Transit Bus Index*. Pasadena, CA: CALSTART. calstart.org/wp-content/uploads/2025/03/20250305-ZIO-ZEB-March-2025_Final.pdf.

[3] California Air Resources Board. 2025. "Innovative Clean Transit." Accessed Oct. 28, 2025. ww2.arb.ca.gov/our-work/programs/innovative-clean-transit.

[4] California Air Resources Board. 2025. "ICT-Rollout Plans." Last updated Sept. 29, 2025. ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans.

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2.2 Notable Fuel Cell Bus Deployments

As shown, the 2024 APTA vehicle database documents new orders of FCEBs for a combined total of 75 buses in 2024. Of all the new orders, the largest single order was for 13 FCEBs from Victor Valley Transit Authority in California, who is budgeted for another 10 FCEBs. This is a significant new order for a small transit agency (that has fewer than 100 buses in their fleet), as most FCEB deployments thus far have been at larger transit agencies that have greater capacity to pilot and test new ZEB technologies in their revenue service. With the experience gained by these agencies during previous FCEB demonstrations, and continuous advancements of the technology, smaller transit agencies are now able to adopt FCEBs with more confidence. Similarly, Humbolt Transit recently purchased 11 FCEBs and began incorporating into their fleet of fewer than 50 buses.

The APTA vehicle database reports three other transit agencies having ordered 10 buses each in 2024—San Mateo County Transit District (California), Champaign-Urbana Mass Transit District (Illinois), and Southeastern Pennsylvania Transportation Authority (Pennsylvania).

In 2023, Santa Cruz Metropolitan Transit District announced the purchase of 57 FCEBs—the largest FCEB acquisition in North America at the time of the announcement. The order is a combination of 40-ft and 60-ft articulated buses, with delivery and preparation for service occurring in early 2025.[5]

In late 2024, New Flyer of America announced the company's largest single order of FCEBs to date—a contract with San Mateo County Transit District (SamTrans) for an additional 108 FCEBs, to be delivered in the coming years.[6] SamTrans is on track to achieve their transition to a 100% ZEB fleet by 2034.[7] Also in late 2024, Orange County Transportation Authority approved the purchase of 40 FCEBs in their effort to transition to a 100% ZEB fleet by 2040.[8]

2.3 Notable Changes in the FCEB Market

The APTA database of U.S. transit fleets lists only two OEMs for FCEBs—ElDorado-National (ENC) and New Flyer of America. The latest data available have no reported FCEB purchases from ENC after 2018 (Figure 2). In January 2024, ENC's parent company REV Group Inc. announced it would wind down and close its ENC business by the end of 2024. The sale of ENC to Rivaz Inc. was finalized in October 2024 for a purchase price of approximately $52

[5] Santa Cruz Metropolitan Transit District. 2023. "METRO to Purchase 57 Zero-Emissions, Fuel Cell Electric Buses." Press release, Sept. 22, 2023. scmtd.com/images/department/ceo/METRO_HydrogenBusPurchase_Release092223FINAL.pdf.
[6] New Flyer. 2024. "New Flyer awarded largest hydrogen fuel cell-electric contract in company history, 108 buses to California's SamTrans." Press release, Oct. 21, 2024. www.newflyer.com/2024/10/nfi-subsidiary-new-flyer-awarded-largest-hydrogen-fuel-cell-electric-contract-in-company-history-108-buses-to-californias-samtrans/.
[7] SamTrans. 2025. "Emission Zero." Accessed June 25, 2025. www.samtrans.com/zeb.
[8] OCTA. 2024. "OCTA Investing in More Zero-Emission Buses, Moving Toward a Greener, Sustainable Transit Future." Nov. 26, 2024. www.octa.net/news/news-releases/octa-investing-in-more-zero-emission-buses-moving-toward-a-greener-sustainable-transit-future/.

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million.[9,10] In April 2025, ENC announced that bus production and customer deliveries would restart under the new ownership in June 2025; however, ENC does not advertise a fuel cell powertrain option for any length of their standard bus models.[11]

In April 2024, Gillig announced it was developing a hydrogen fuel cell powertrain option for its Low Floor bus platform, with production anticipated to begin in 2026. The development was in partnership with Ballard Power Systems for the fuel cell powerplant and BAE Systems for the electrical system integration.[12] However, by 2025, Gillig had canceled its FCEB development program. This leaves New Flyer as the only U.S.-based manufacturer of FCEBs in 2025.

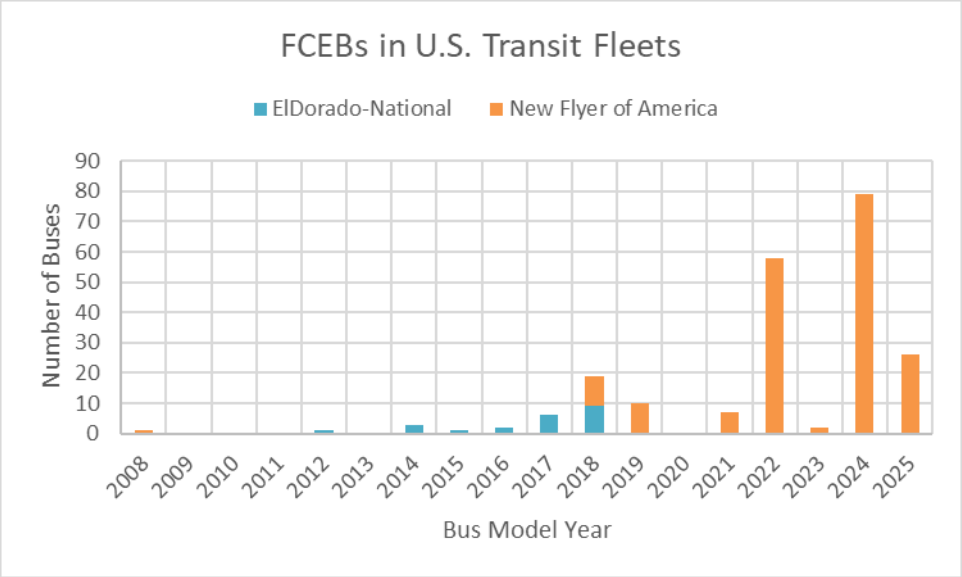

Figure 2. Number of FCEBs in U.S. transit fleets per model year by OEM.

Source: 2024 APTA vehicle database

[9] Mischa Wanek-Libman. 2024. "Rev Group to close ENC by the end of 2024, sells school bus business to Forest River Bus." *Mass Transit*, Jan. 29, 2024. www.masstransitmag.com/bus/vehicles/article/53087536/rev-group-inc-rev-group-to-close-enc-by-the-end-of-2024-sells-school-bus-business-to-forest-river-bus.

[10] REV Group. 2024. "REV Group Completes Sale of ENC, Its Transit Bus Business." Oct. 18, 2024. investors.revgroup.com/investor-releases/2024/10-18-2024-140118176.

[11] ENC. 2025. "ElDorado National to Restart Heavy-Duty Transit Bus Production and Deliveries Under New Ownership." Press release, April 24, 2025. https://eldorado-ca.com/productionupdate/.

[12] Gillig. 2024. "Gillig Expands Zero-Emission Lineup With Introduction of BAE Systems & Ballard-Powered Hydrogen Fuel Cell Electric Bus." Press release, April 24, 2024. www.gillig.com/2024/04/24/gillig-expands-zero-emission-lineup-with-introduction-of-bae-systems-ballard-powered-hydrogen-fuel/.

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3 Update of Evaluation Results – Foothill Transit

This section presents the evaluation results from a deployment of FCEBs operated by Foothill Transit in the San Gabriel and Pomona valleys in eastern Los Angeles County, California. Foothill Transit currently operates 33 hydrogen fuel cell buses, which is one of the largest fuel cell bus fleets in North America.[13] These buses also represent the latest generation of FCEB technology from the primary domestic manufacturer of FCEBs, which have been operated and evaluated in service for more than one year. The goal of this evaluation is to compare the FCEB performance to that of conventional technology and to track progress over time toward meeting the technological targets set by DOE and DOT, as shown in Table 3. NLR collected data on the 33 FCEBs and three CNG bus fleets covering the period of June 2023 through December 2024 for the analysis. The dataset includes daily mileage and fuel consumption records, maintenance records, vehicle availability records, monthly hydrogen bills and CNG fuel bills, recorded roadcalls, and detailed work orders for all non-warranty maintenance performed. NLR's standardized evaluation protocol was applied to assess the FCEBs' vehicle usage, availability, fuel efficiency, fuel costs, roadcall frequency, and maintenance costs, with performance compared to the baseline conventional CNG buses.

Table 3. Targets From DOE/DOT Program Record.

Source: U.S. Department of Energy. 2012. "Fuel Cell Bus Targets." Fuel Cell Technologies Program Record # 12012. www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/12012_fuel_cell_bus_targets.pdf?Status=Master.

Metric	Units	Interim Target	Ultimate Target
Bus lifetime	years/miles	12/500,000	12/500,000
Powerplant lifetime	hours	18,000	25,000
Bus availability	%	85	90
Roadcall frequency (bus/fuel cell system)	miles between roadcalls (MBRC)	3,500/15,000	4,000/20,000
Operation time	hours per day/days per week	20/7	20/7
Maintenance cost	$/mile	0.75	0.4
Fuel economy	miles per diesel gallon equivalent (mpdge)	8.0	8.0
Bus cost	$/bus	1,000,000	600,000

3.1 FCEBs and Baseline Buses

The 33 Foothill Transit FCEBs are 40-foot, model year 2022 New Flyer Xcelsior XHE40 buses, equipped with 100 kWh of onboard energy storage and a hydrogen storage capacity of 37.5 kg at 77°F and 5,057 psi. The fueling station for these buses is located at the Pomona Operations and Maintenance Facility and contains a 25,000-gallon liquid hydrogen storage tank, as shown in Figure 3. Liquid hydrogen is delivered to the hydrogen station every 2–4 days via a tanker truck. The two hydrogen fuel dispensers located at the fuel island can fuel buses simultaneously at a rate of 7–10 minutes per fill. The three CNG fleets used as baseline comparison groups are also

[13] https://www.foothilltransit.org/sustainability

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operated by Foothill Transit. Table 4 provides detailed specifications for both the FCEB and CNG fleets.

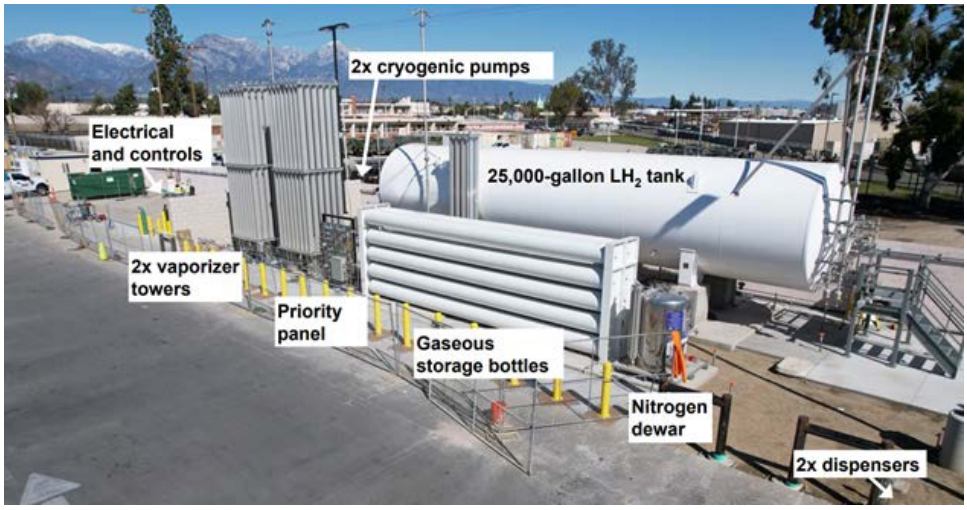

Figure 3. Hydrogen fueling station for the Foothill Transit FCEB fleet.

Photo from Foothill Transit

Table 4. Bus Specifications for the FCEB Fleet and Baseline CNG Fleets

	FCEB	CNG	CNG	CNG
Number of buses	33	30	18	30
Depot	Pomona	Pomona	Pomona	Arcadia
Bus IDs	3100–3132	2300–2329	2745–2762	2500–2529
Model year	2022	2015	2021	2016
OEM and model	New Flyer Xcelsior-XHE40	NABI 42 BRT-07.03	ENC-El Dorado AXESS BRT	New Flyer Xcelsior XN40
Length	40 ft	42 ft	40 ft	40 ft
Gross vehicle weight rating	44,004 lb	42,760 lb	43,380 lb	43,720 lb
Passenger capacity	34 seated + 10 standees	38 seated + 10 standees	36 seated + 10 standees	35 seated + 10 standees
Energy storage capacity	H_2: 37.5 kg (at 350 bar); energy storage system: 100 kWh	CNG: 25,352 scf	CNG: 23,065 scf	CNG: 23,065 scf
Power plant	Ballard FCveloCity HD85 fuel cell, Siemens electric motor	Cummins ISL-G 8.9-L CNG engine	Cummins L9N CNG engine	Cummins ISL-G 8.9-L CNG engine
Rated power	100 kW (134 hp)	280 hp	280 hp	280 hp
Capital cost ($/bus)[a]	$1,153,328	$575,000	$694,989	$652,224

[a] 2024 APTA vehicle database.

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Table 5 summarizes the data collection periods for the FCEB fleet and the three CNG fleets for this evaluation. For the FCEB fleet, data were available from June 2023 through December 2024; however, fuel and mileage records were not available from September 2024 to December 2024. NLR used data from multiple groups of CNG buses in order to compare performance between buses of similar age, OEM, fleet size, and operations (depot location) over the same time period. However, a perfect A-to-B comparison between CNG and FCEB fleets was not possible. The North American Bus Industries (NABI) CNG fleet had data only from June 2023 to December 2023, while the ENC and New Flyer CNG fleets had data limited to January 2024 through December 2024. A further limitation for the ENC and New Flyer fleets is the absence of fuel and mileage records. NLR made a best effort to analyze the data and draw insights from the analysis given the available data from the existing CNG baseline fleets.

Table 5. Summary of Data Periods for the FCEB Fleet and Baseline CNG Fleets

Transit Agency	Depot Location	Bus Fleet	Number of Buses	Data Period
Foothill Transit	Pomona	New Flyer – FCEB (3100–3132)	33	June 2023–Dec. 2024
		NABI – CNG (2300–2329)	30	June 2023–Dec. 2023
		ENC – CNG (2745–2762)	18	Jan. 2024–Dec. 2024
	Arcadia	New Flyer – CNG (2500–2529)	30	Jan. 2024–Dec. 2024

3.2 Capital Costs

Foothill Transit reported a capital cost of $1,153,328 per bus for the order of 33 New Flyer FCEBs. This is in line with other FCEB purchases reported in the 2024 APTA vehicle database for buses of a similar model year, as shown in Figure 4. Fuel cell bus prices decreased significantly since the early demonstrations conducted prior to 2018, but then leveled off at or above the threshold of $1,000,000 per bus. In recent years, prices have been trending back upward. According to records in the 2024 APTA database, the weighted average for new orders of FCEBs for model years 2024 and 2025 is approximately $1,460,000 per bus.

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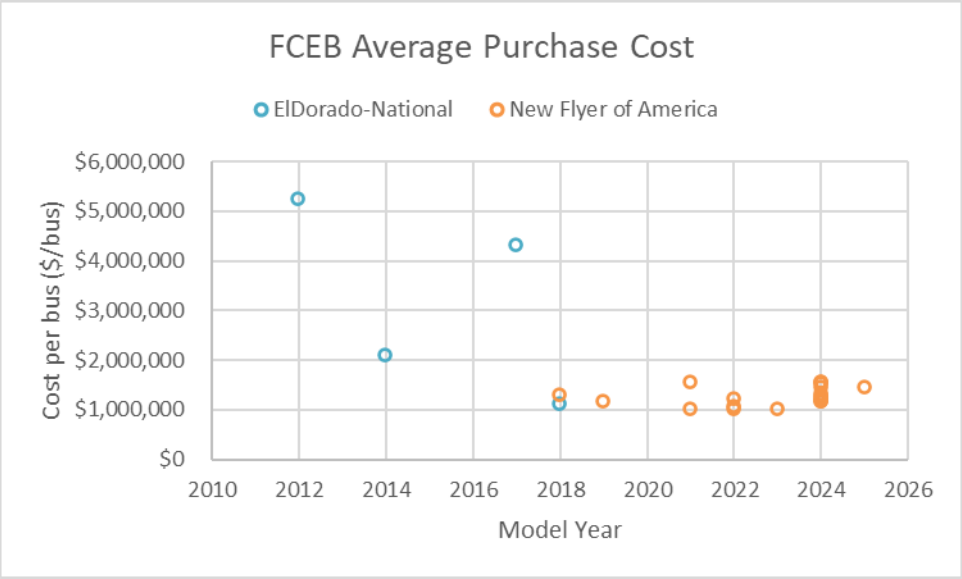

Figure 4. Capital costs for FCEBs.

Source: 2024 APTA vehicle database

3.3 FCEB Fleet Bus Use

To assess FCEB usage, NLR evaluated total vehicle mileage, trip distance, duration, speed distributions, and the trip initial and final state-of-charge (SOC) levels of the 33 FCEBs. Figure 5 shows the monthly total miles traveled by the FCEB fleet. The unusually low total travel distance in October 2023 was due to a 27-day hydrogen fueling station outage, during which the FCEBs were not operated. During the 16-month evaluation period, the FCEB fleet traveled a total of 1,195,339 miles, with an average of 2,264 miles per vehicle per month. The NABI 42 BRT CNG fleet, consisting of 30 buses, recorded a total of 714,860 miles from June to December 2023, which resulted in an average of 3,404 miles per vehicle per month. Mileage data were not available for the other two CNG fleets. The comparison between the FCEB fleet and the NABI CNG fleet indicates that the NABI CNG fleet had a higher average monthly mileage per vehicle.

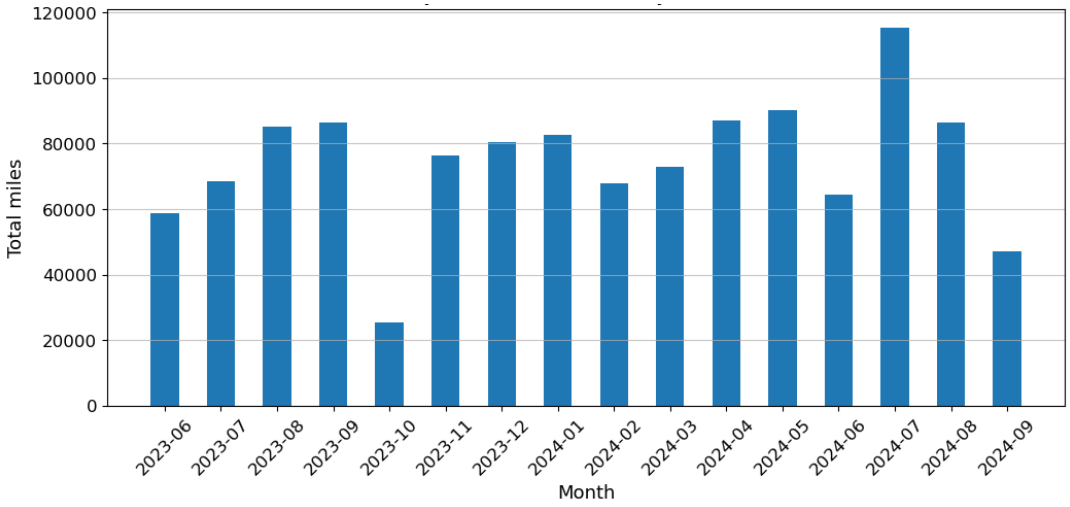

Figure 5. Monthly total miles traveled by the FCEB fleet

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Figure 6 shows the distributions of the trip distance, trip duration, and average speed for the FCEB fleet. The majority of trips cover less than 50 miles and last less than 5 hours. Most buses operate at typical speeds between 10 and 20 miles per hour. On average, each bus completes around four trips per day. The average speed of the FCEBs during operation is 15.6 mph. The average trip distance is 33.3 miles, and the average trip duration is 2.4 hours.

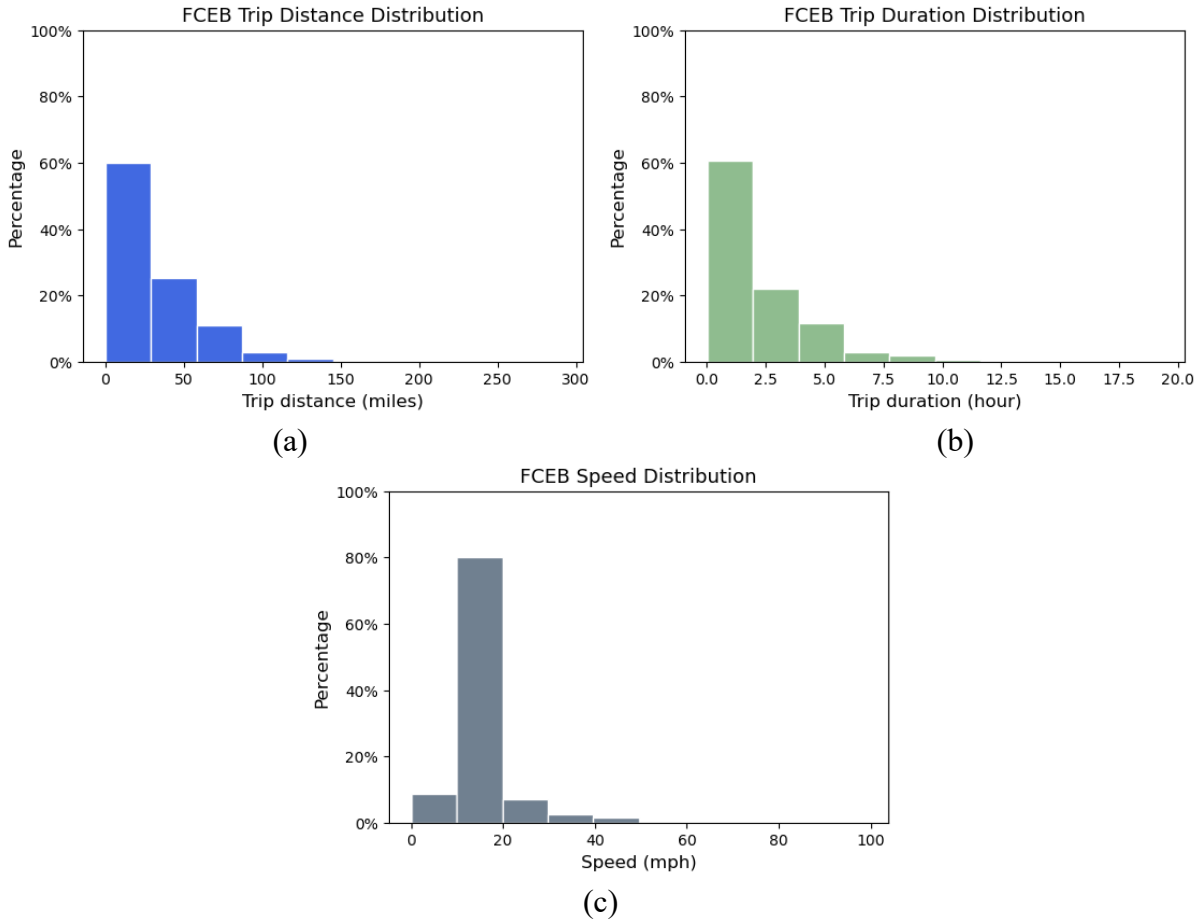

Figure 6. FCEB distributions for (a) trip distance, (b) trip duration, and (c) average speed

Figure 7 shows the distributions for trip starting and ending SOC level for the FCEB fleet. The majority of FCEB trips begin and end with a battery SOC between 50% and 80%. This indicates that the energy management system is functioning efficiently, keeping the battery within a healthy SOC range. It also indicates that the fuel cell is contributing consistently, recharging the battery during operation, and the battery is not being overly relied upon.

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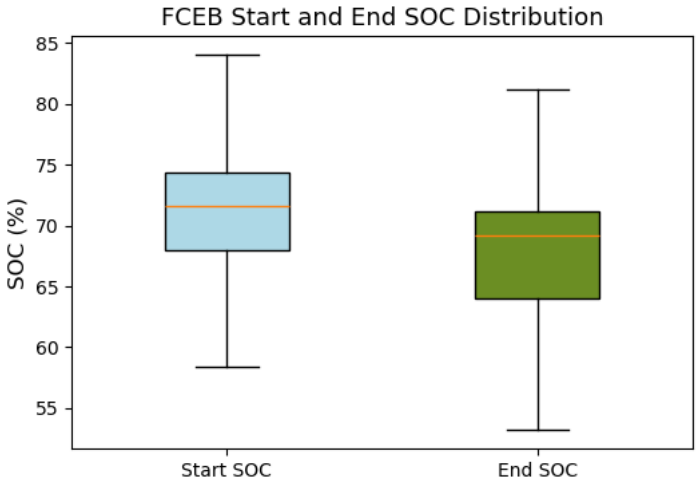

Figure 7. FCEB trip starting and ending SOC distributions

3.4 Availability

NLR calculates bus availability as the percentage of days buses are available for passenger service (whether or not they are used) out of days the buses are planned for service. Buses that are available may be used for passenger service, training, or special events, or they may be available but not used for any purpose (e.g., spares). Buses unavailable for service may have had issues with the propulsion system (fuel cell system or electric drive system), had general bus maintenance, or been undergoing scheduled preventive maintenance. Any issues not covered by the other listed categories for preventive maintenance or propulsion-related systems fall into the general "bus maintenance" category—this includes items such as wheels and tires, steering, bus chassis, windows and mirrors, and seats and interior. The results presented are based on availability for morning pullout and do not necessarily reflect all-day availability. Transit agencies typically have a target of 85% availability for their fleets to allow for time to handle scheduled and unscheduled maintenance. Accidents are removed from the data—the bus is considered "not planned" during the repair time for accident-related repairs. To calculate availability for the FCEB and the baseline CNG fleets, NLR used the daily down sheets for the Pomona and Arcadia facilities, which list each bus that is not available for morning pullout and provide a general reason for unavailability.

Table 6 summarizes the availability of the FCEB fleet and the three CNG fleets. The overall availability of the FCEB fleet during the analysis period is 76.8%, which is higher than the 72.4% availability of the NABI CNG fleet. Notably, the NABI fleet consists of model year 2015 buses, which is the oldest among the fleets, which may contribute to its lower availability. In contrast, the other two CNG fleets, ENC and New Flyer, both have higher overall availability and met the target of 85%. Detailed monthly available days and unavailable days, sorted by reasons for each bus fleet, are provided in Table A-1–Table A-3.

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Table 6. Overall Availability of the FCEB Fleet and Baseline CNG Fleets

Bus Fleet	Data Period	Months	Number of Buses	Planned Days	Days Available	Percent Availability
New Flyer – FCEB (3100–3132)	June 2023–Dec. 2024	19	33	12,176	9,343	76.8
NABI – CNG (2300–2329)	June 2023–Dec. 2023	7	30	4,169	3,032	72.4
ENC – CNG (2745–2762)	Jan. 2024–Dec. 2024	12	18	4,082	3,605	88.3
New Flyer – CNG (2500–2529)	Jan. 2024–Dec. 2024	12	30	6,975	5,973	85.7

Figure 8 shows four pie charts that illustrate the overall availability and the breakdown of unavailability reasons for each of the four bus fleets during their respective data periods. The breakdown of unavailability reasons indicates that energy storage system issues, general bus maintenance, fuel cell system issues, and electric drive system issues significantly contributed to the FCEB fleet's unavailability. Unavailability due to battery or charging issues and scheduled preventive maintenance was relatively minor. For the NABI CNG fleet, engine issues are the primary cause of unavailability, followed by transmission problems. This is likely due to the fact that this is the oldest fleet, consisting of 2015 model year buses. Engine-related downtime also significantly affects the New Flyer CNG fleet (2500–2529), which is the second oldest, with 2016 model year buses. For the newer ENC CNG fleet (2745–2762), most unavailability is due to scheduled preventive maintenance and general bus maintenance.

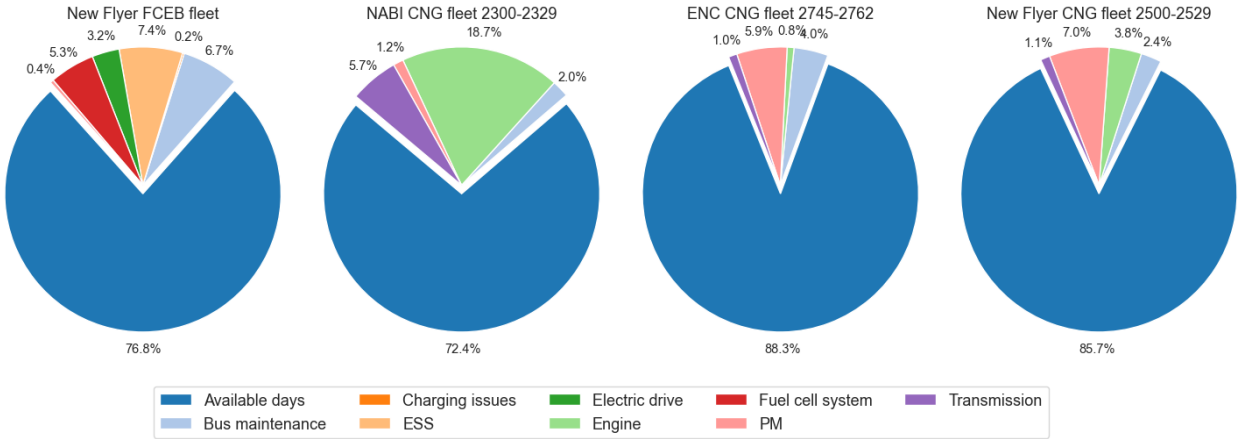

Figure 8. Overall bus availability and breakdown of unavailable reasons for the four fleets.

ESS: energy storage system; PM: preventive maintenance

The following figures further present the monthly average availability (line) and the average number of unavailable days per bus (bars), broken down by the reasons for unavailability for the FCEB fleet (Figure 9) and the three baseline CNG fleets (Figure 10, Figure 11, Figure 12). The monthly availability of the FCEB fleet ranges from 65.4% to 91.2%, with an overall average of 76.8%. The NABI CNG fleet consistently shows low monthly availability, ranging from 61.5% to 83%, primarily due to engine and transmission issues. The ENC and New Flyer CNG fleets

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maintain generally high monthly availability, typically above 80%, and a large portion of the downtime is due to scheduled preventive maintenance work.

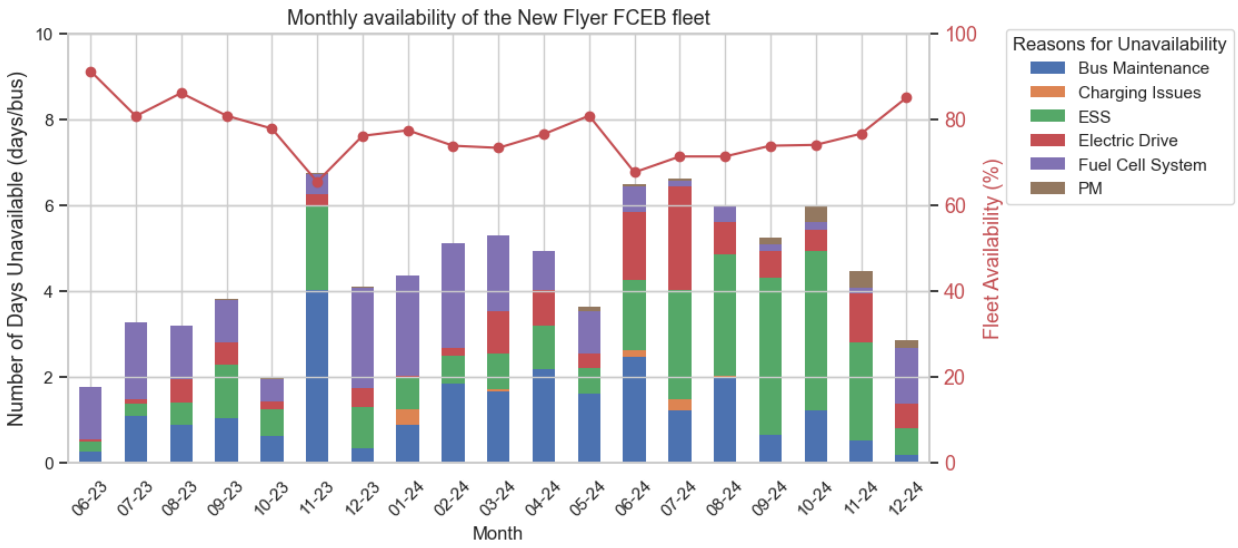

Figure 9. Monthly average availability and unavailable days for the New Flyer FCEB fleet

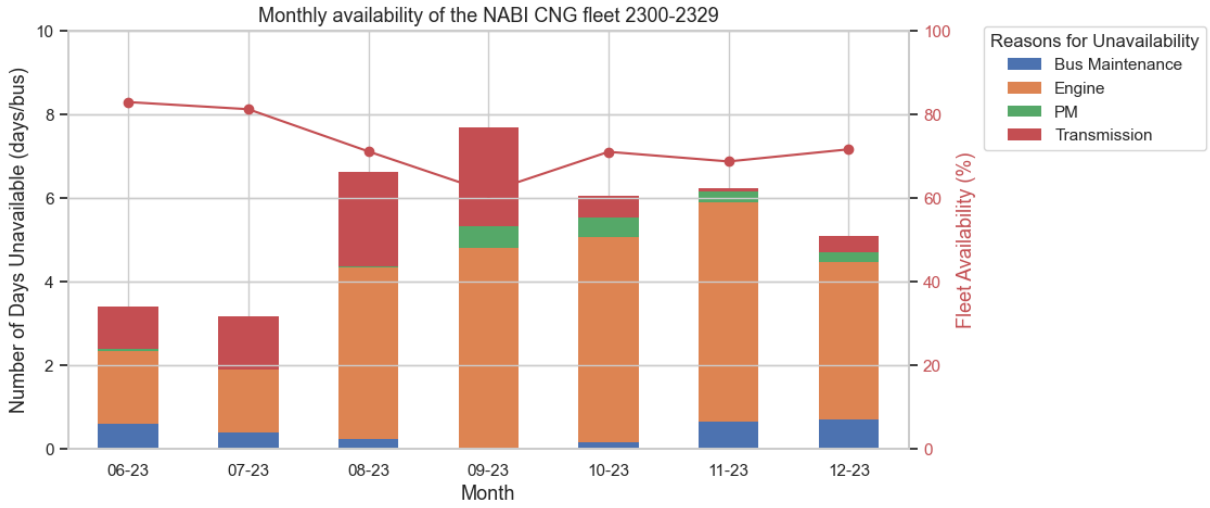

Figure 10. Monthly average availability and unavailable days for the NABI CNG fleet

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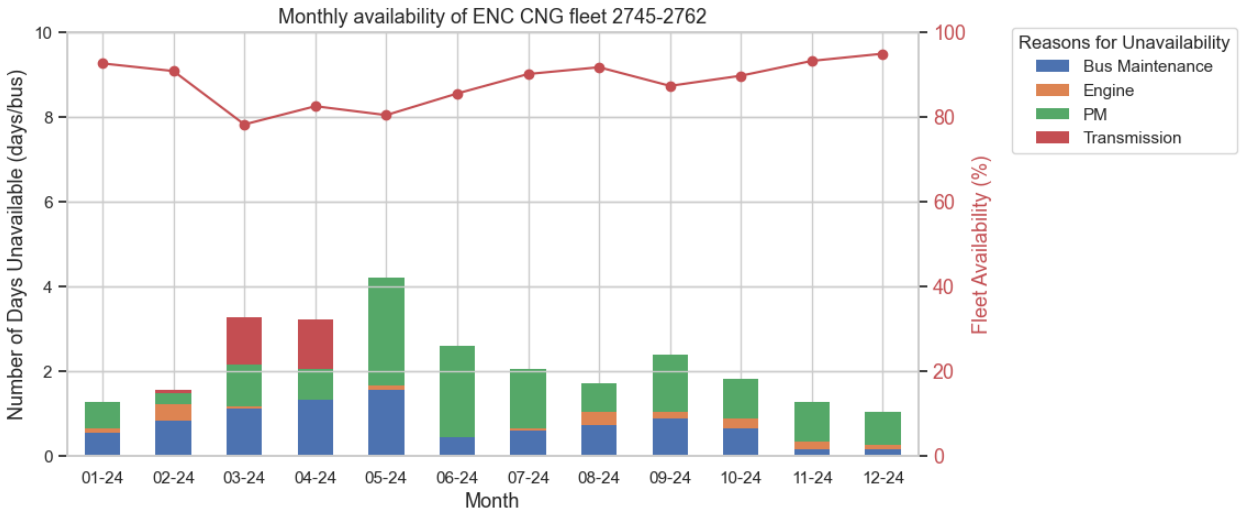

Figure 11. Monthly average availability and unavailable days for the ENC CNG fleet

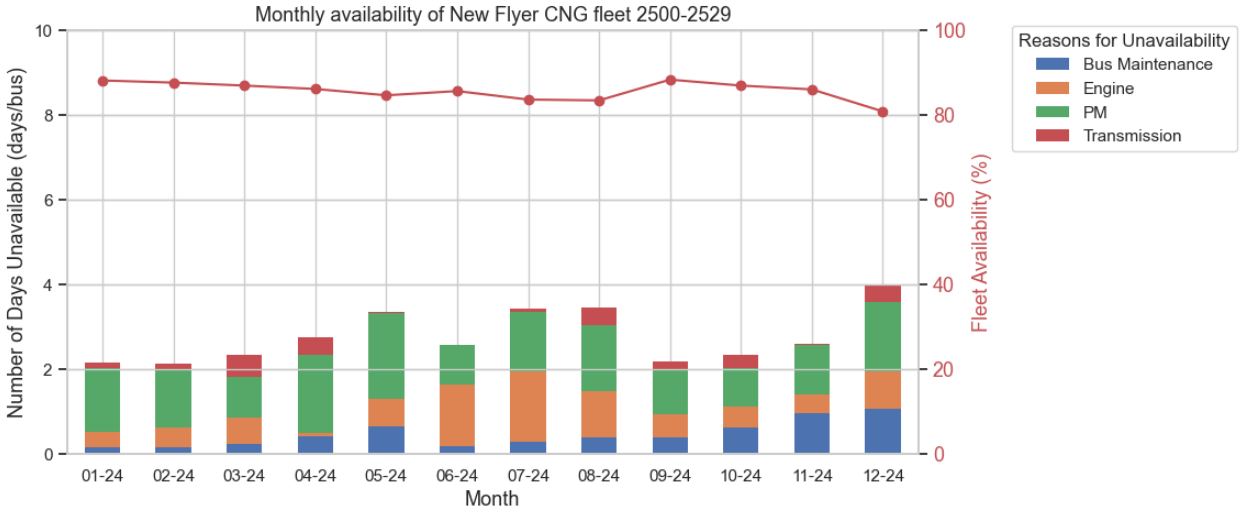

Figure 12. Monthly average availability and unavailable days for the New Flyer CNG fleet

3.5 Fuel Efficiency and Cost

As previously mentioned, Foothill Transit provided individual fueling and mileage records for the FCEB fleet (June 2023–September 2024) and the NABI CNG fleet (June–December 2023). However, these data are not available for the ENC and New Flyer CNG fleets. Despite this, Foothill Transit did provide monthly hydrogen and CNG fuel delivery volumes and cost information for all four fleets across different fueling stations. Based on these data, average hydrogen cost per kilogram and CNG cost per therm were calculated for each fueling station. Vehicle fuel efficiency could only be calculated for the FCEB and NABI CNG fleets due to the lack of fueling and mileage data for the other two fleets.

Figure 13, Figure 14, and Figure 15 present the monthly average fuel costs for hydrogen at the hydrogen fueling station and for CNG at the Pomona and Arcadia stations, respectively. For hydrogen fuel, monthly costs show minimal variation due to the established fuel contract. On average, the fuel itself accounts for 91% of the total cost, while delivery contributes only 1%, per

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the fuel delivery invoices, and operations and maintenance account for 8% of the total cost, based on information provided by Foothill Transit operations staff. The overall average hydrogen fuel cost during the data period is $10.09/kg. Compared to hydrogen fuel costs, CNG fuel costs fluctuate more over time. At the Pomona station, fuel transport and operations and maintenance costs account for a significant portion of the total CNG cost—39% and 25%, respectively. At the Arcadia station, these numbers are even higher, at 45% for transport and 26% for operations and maintenance. The overall average CNG cost is $1.51 per gasoline gallon equivalent (gge) at the Pomona station and $1.41/gge at the Arcadia station.

To conduct a direct cost comparison of the two fuel types, NLR converted the unites of both to diesel gallon equivalent (dge). The conversion formulas, based on the energy content of each fuel, are shown below:

$$H_2(kg) * 0.885 \left(\frac{dge}{kg}\right) = H_2\ (dge) \quad (1)$$

$$CNG\ (gge) * 0.895 \left(\frac{dge}{gge}\right) = CNG\ (dge) \quad (2)$$

After conversion, the hydrogen cost is $11.40/dge, and the CNG cost is $1.68/dge at the Pomona station and $1.58/dge at the Arcadia station.

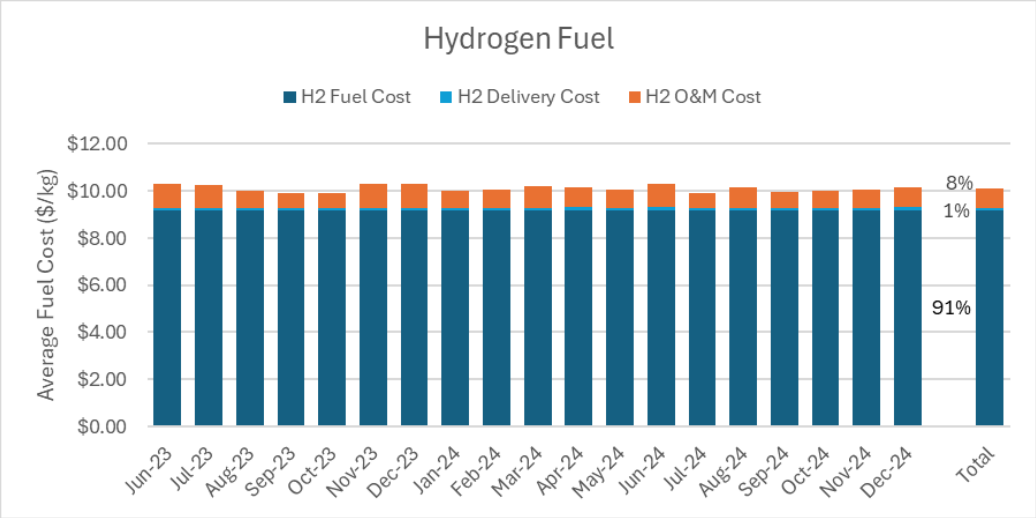

Figure 13. Monthly average fuel cost for hydrogen fuel

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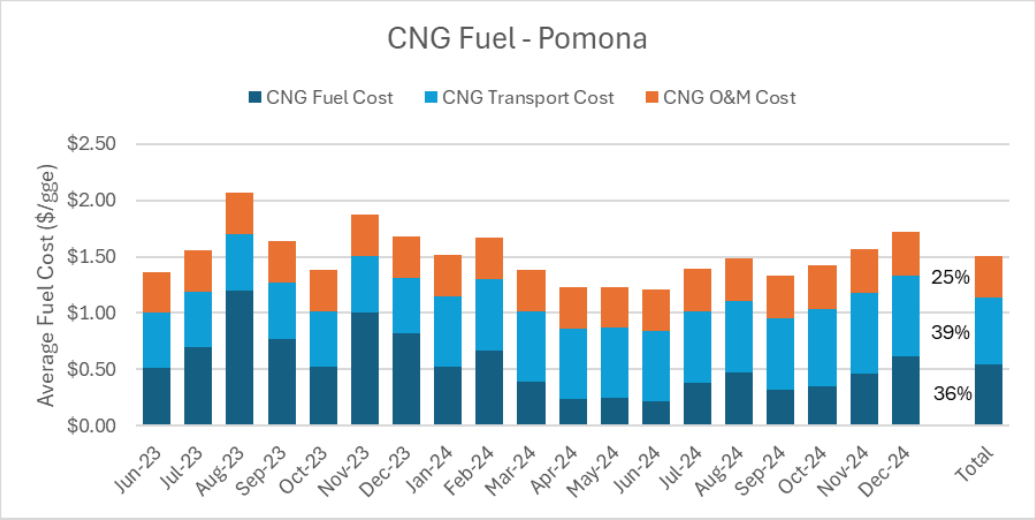

Figure 14. Monthly average fuel cost for CNG fuel at the Pomona station

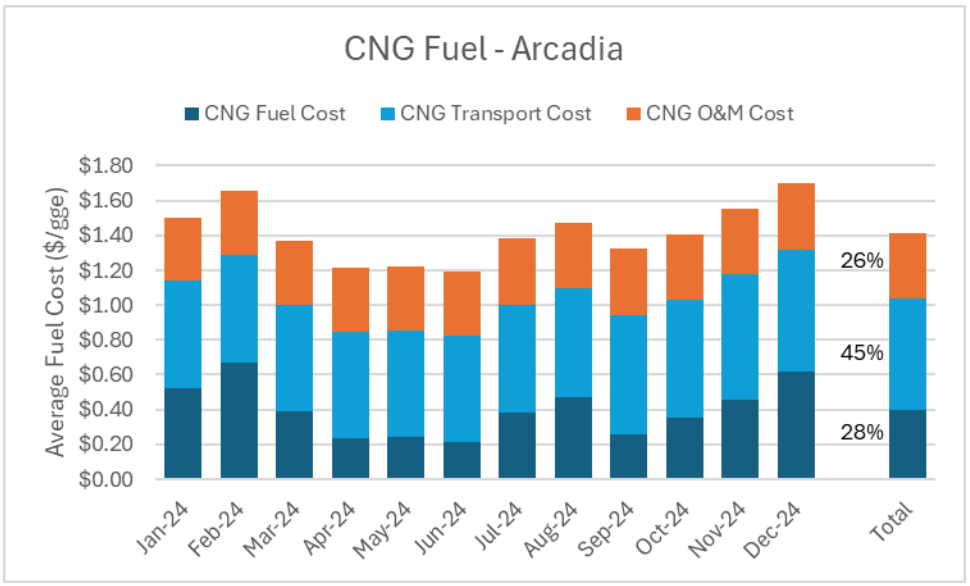

Figure 15. Monthly average fuel cost for CNG fuel at the Arcadia station

For hydrogen use, Foothill Transit provides data on both hydrogen deliveries and individual vehicle fueling events, including quantities dispensed. NLR compared the total monthly hydrogen delivered with the total monthly hydrogen dispensed to analyze potential losses. Figure 16 illustrates the monthly hydrogen amount delivered versus the total monthly amount dispensed for the FCEB fleet. The figure shows that a significant amount of hydrogen loss (usually between 20% and 50%) occurs each month, primarily due to factors such as venting and boil-off. The high percentage of hydrogen loss in October 2023 was attributed to the hydrogen station outage when maintenance was performed. The elevated loss indicated in September 2024 was likely due to incomplete fuel dispensing records for that month at the end of the data collection period. Foothill Transit is working to reduce hydrogen fuel losses and monitor the boil-off more closely, in order to reduce its effective fuel costs.

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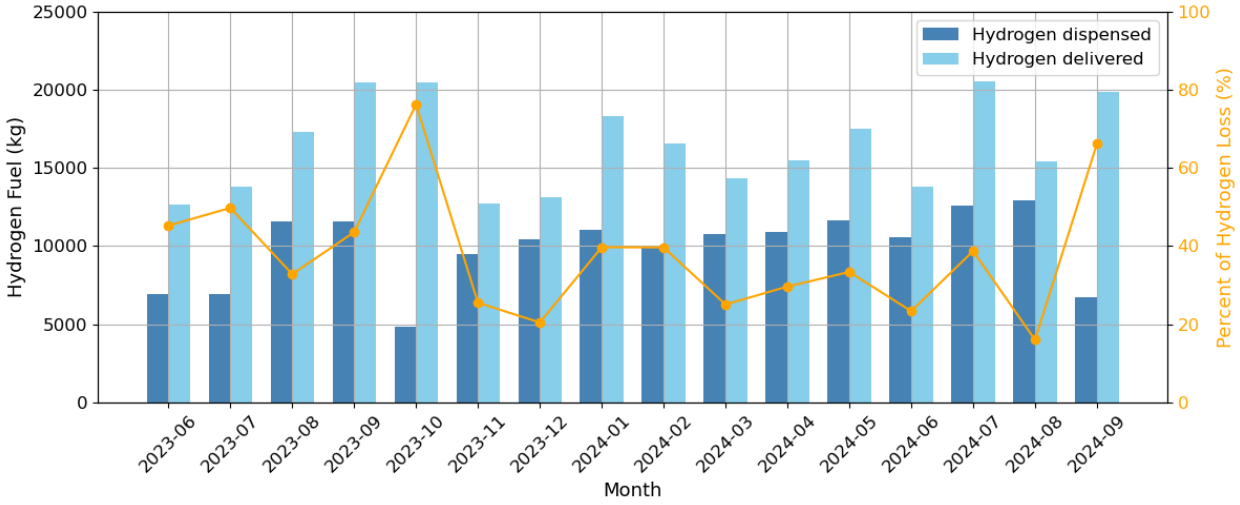

Figure 16. Monthly hydrogen delivered verses hydrogen dispensed for the FCEB fleet

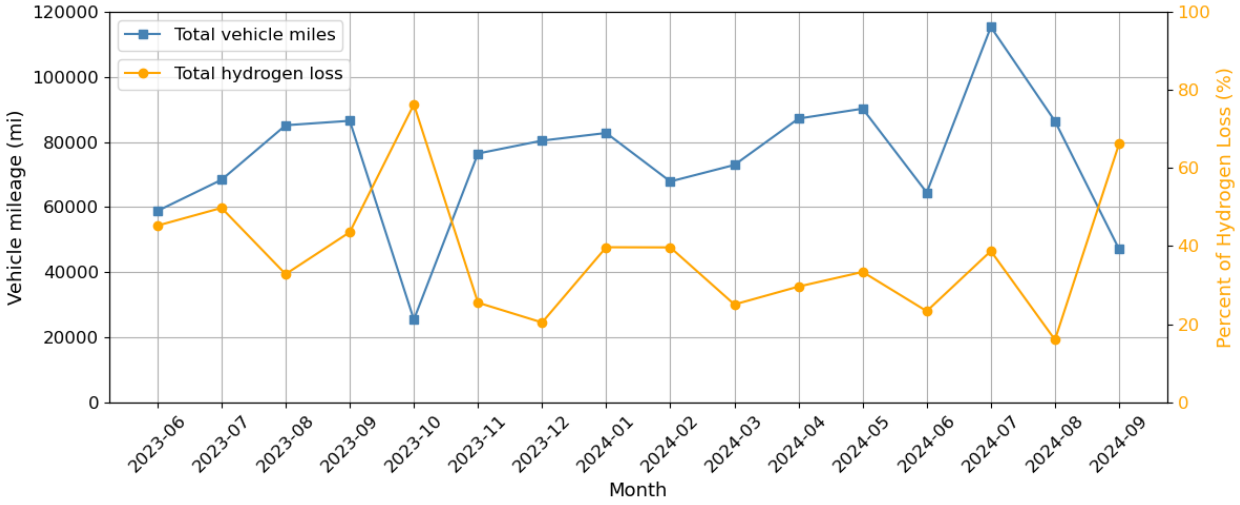

Figure 17. Monthly total vehicle miles and hydrogen percent loss for the FCEB fleet

Using data on bus mileage and fuel usage, NLR calculated the monthly fuel economy for the FCEB fleet, as shown in Figure 18. Fuel economy for the CNG fleets was excluded from the analysis due to missing fueling records and mileage data. The figure shows that fuel economy of the FCEB fleet fluctuates monthly between 8 and 12 mpdge, with an average of 9.2 mpdge. Monthly average temperatures in the study region were also collected and presented as blue bars in the figure. The figure indicates no clear correlation between fuel economy and temperature in this dataset because the variation in monthly average temperatures is minimal. With temperatures ranging from 55°F to 80°F, conditions remain within the optimal operating range for efficient FCEB performance and there are other operational factors that have a stronger influence on bus fuel economy, such as traffic conditions, passenger loading, and driving behavior.

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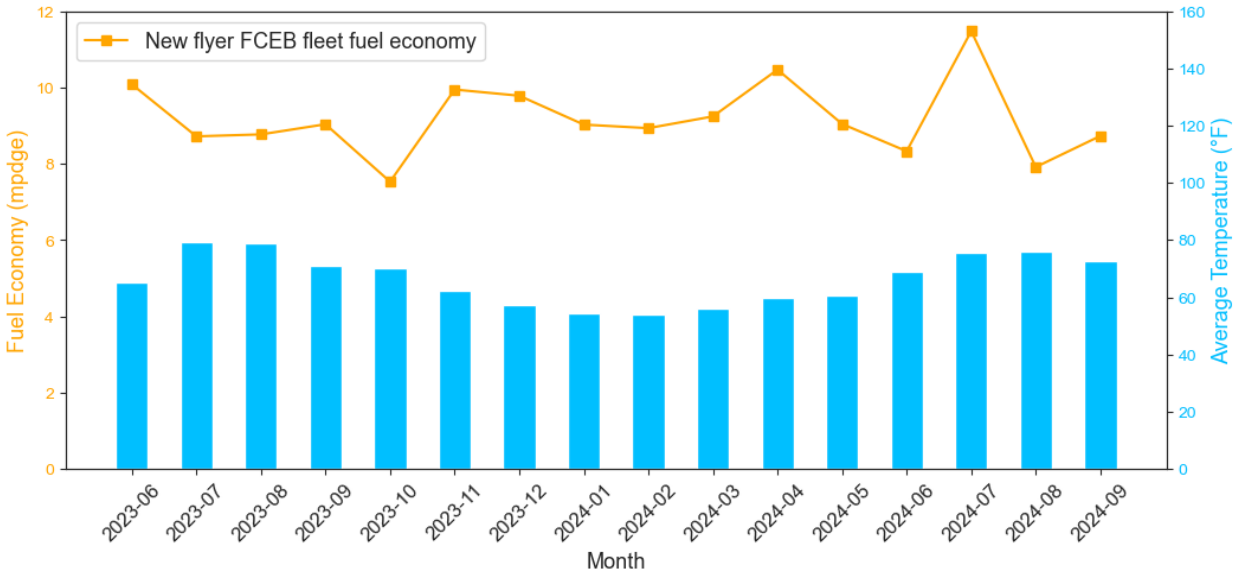

Figure 18. Monthly fuel economy for the FCEB fleet

The fuel cost per mile for the FCEB fleet was further calculated and is presented in Figure 19. Monthly costs range from $1.00 to $1.50 per mile, with an average of $1.25 per mile.

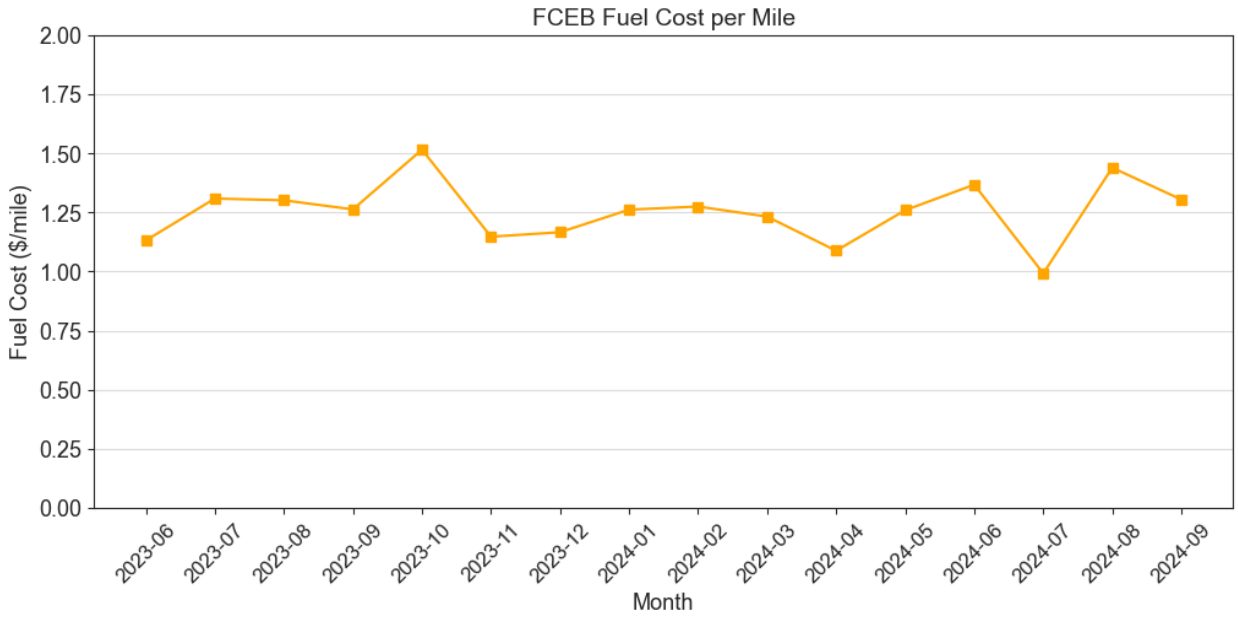

Figure 19. Monthly average fuel cost per mile for the FCEB fleet

NLR also reviewed published ZEB evaluations from previous years and conducted a meta-analysis of reported performance and cost metrics for FCEBs. The average fuel cost per mile calculated from the Foothill Transit FCEB data is similar to previous FCEB evaluations in the past 10 years, which were typically between $1.10 and $1.40 per mile for fuel costs. Although the fuel economy has improved for this latest generation of FCEBs—up to 9.2 mpdge, compared to approximately 7.5–8.5 mpdge in previous evaluations—the unit price of hydrogen fuel ($/kg) has also increased in recent years, largely offsetting the fuel economy improvements on a cost-

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per-mile basis. Average fuel cost per mile for other fuel types in the published bus studies were, on average, approximately $0.50/mile for BEB, $0.40/mile for CNG, $0.60/mile for diesel, and $0.50/mile for diesel hybrid.

3.6 Reliability: MBRC

A roadcall, or revenue vehicle system failure, is defined as a failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. If the problem with the bus can be repaired during a layover and the schedule is kept, this is not considered a roadcall. The analysis described here includes only roadcalls that were caused by "chargeable" failures. Chargeable roadcalls include systems that can physically disable the bus from operating on route, such as interlocks (doors and air system), engines, or things that are deemed to be safety issues if operation of the bus continues. They do not include roadcalls for things such as problems with radios, fareboxes, or destination signs.

The transit industry measures reliability as mean distance between failures, also documented as MBRC. NLR tracks MBRC by total roadcalls, propulsion-related roadcalls, and fuel cell system-related roadcalls. Total roadcalls includes all chargeable roadcalls. Propulsion-related roadcall is a subset of total roadcalls and includes all roadcalls due to propulsion-related systems including the fuel cell system (or engine for a conventional bus), electric drive, fuel, exhaust, air intake, cooling, non-lighting electrical, transmission systems, and hydraulics. The fuel cell system-related roadcalls, a subset of the propulsion-related roadcalls, and calculated MBRC are also included for the FCEBs.

Table 7 summarizes the number of total roadcalls, propulsion-related roadcalls, fuel cell system-related roadcalls, and their corresponding MBRC. This roadcall analysis includes data accumulated since the clean point of June 2023. For the ENC and New Flyer CNG fleets, fleet mileage data are unavailable; therefore, only the number of roadcalls is reported. From January to December 2024, the ENC fleet experienced a total of 52 roadcalls, of which 32 were propulsion-related (62%). From January to December 2024, the New Flyer CNG fleet recorded a total of 118 roadcalls, 67 of which were propulsion-related (57%). The NABI CNG fleet experienced 34 roadcalls between June and December 2023, including 22 propulsion-related incidents (65%). With a total fleet mileage of 714,840 miles during that period, the calculated total MBRC was 21,025 miles, and the propulsion-related MBRC was 32,494 miles, indicating the average distance traveled by the fleet between all roadcalls and propulsion-related roadcalls, respectively. For the New Flyer FCEB fleet, 56 roadcalls occurred between June 2023 and December 2024, 27 of which were propulsion-related (13%). None of the propulsion-related roadcalls were attributed to the fuel cell system. The FCEB fleet achieved a total MBRC of 21,345 miles and a propulsion-related MBRC of 44,272 miles.

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Table 7. Roadcalls and MBRC for the FCEB and CNG Fleets

	New Flyer FCEB Fleet	NABI CNG Fleet 2300–2329	ENC CNG Fleet 2745–2762	New Flyer CNG Fleet 2500–2529
Data period	June 2023–Dec. 2024	June 2023–Dec. 2023	Jan. 2024–Dec. 2024	Jan. 2024–Dec. 2024
Total fleet mileage	1,195,339	714,860	-	-
Bus roadcalls	56	34	52	118
Bus MBRC	21,345	21,025	-	-
Propulsion-related roadcalls	27	22	32	67
Propulsion-related MBRC	44,272	32,494	-	-
Fuel cell system-related roadcalls	0	-	-	-
Fuel cell system-related MBRC	n/a	-	-	-

Figure 20 shows the cumulative MBRC trends over time for the FCEB fleet and the NABI CNG fleet. The Foothill Transit performance target and DOE/DOT technology target for MBRC are shown in red and black dashed lines, respectively. The cumulative MBRC for the FCEB fleet exceeded the DOE technology target in all months, and in most months, it also surpassed the Foothill Transit performance target. The MBRC fell below Foothill's target in three of the first four months of the data collection period, and the cumulative average climbed steadily thereafter, indicating consistent improvement in operations and technology performance since the initial deployment. The NABI CNG fleet exceeded both MBRC targets during the data collection period of June through December 2023; additional data collection is needed to compare the long-term trends and to compare on a mileage-aligned basis.

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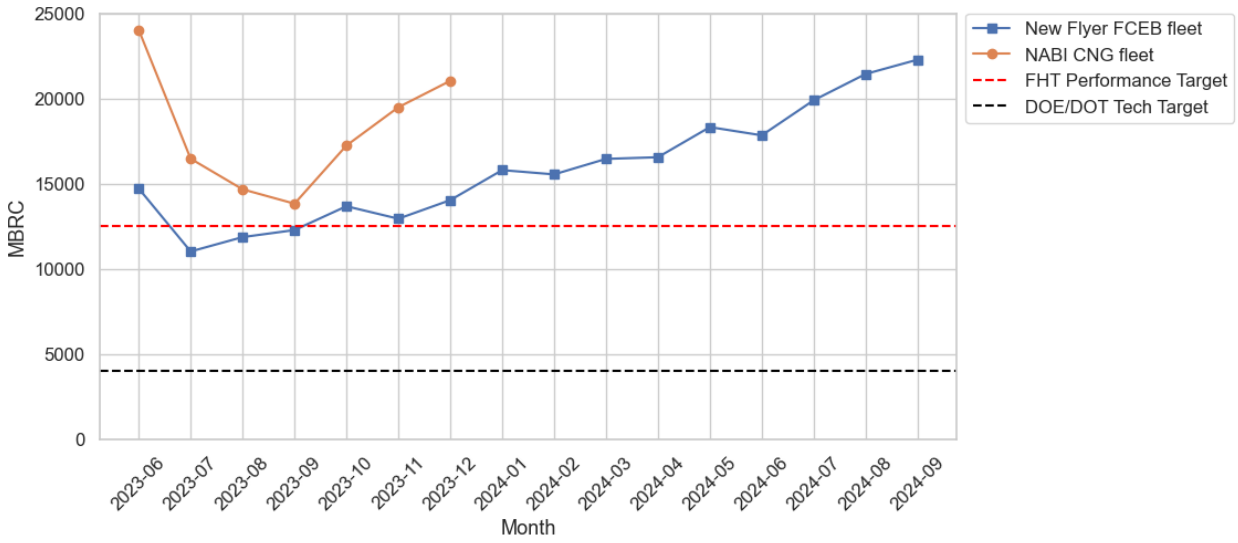

Figure 20. Cumulative MBRC for the FCEB fleet and the NABI CNG fleet

3.7 Maintenance Cost

NLR collected all work orders for the evaluation buses to calculate a maintenance cost per mile. Costs for accident-related repairs, which are extremely variable from bus to bus, were eliminated from the cost analysis. Warranty costs are not included in the cost-per-mile calculations because those costs are covered by the capital cost and purchase agreement of the buses and often are not accessible in the source data. For consistency, NLR used a constant labor rate of $100 per hour to calculate the repair cost. This does not reflect an average rate for Foothill Transit. Cost per mile is calculated as follows:

$$Maintenance\ cost\ per\ mile\ \left(\frac{\$}{mi}\right) = \frac{\left[\left(labor\ hours * \frac{\$100}{hour}\right) + parts\ cost(\$)\right]}{total\ miles} \quad (3)$$

NLR calculated total cost per mile, which is the sum of scheduled and unscheduled maintenance cost per mile. NLR also categorized maintenance cost by vehicle system to provide insight into which systems have the most costs for each technology. Parts for scheduled maintenance, such as filters and fluids, are included in the specific system categories. For example, oil and oil filters are included in the power plant (engine) subsystem parts costs, while air filters are included in the air intake subsystem parts costs. The propulsion system costs are of particular interest. Propulsion-related vehicle systems include the exhaust, fuel, engine, fuel cell system, battery modules, electric propulsion, air intake, cooling, non-lighting electrical, transmission systems, and hydraulics. These systems have been separated to highlight maintenance costs that are most directly affected by the advanced propulsion system differences between the buses.

3.7.1 Total Work Order Maintenance Costs

Table 8 summarizes the maintenance costs for the FCEB fleet and the baseline CNG fleets. It presents the total parts costs and labor hours for each fleet over their respective data collection periods, along with the total scheduled and unscheduled maintenance costs. Total maintenance cost is calculated as:

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$$Total\ maintenance\ cost = \left(labor\ hours * \frac{\$100}{hour}\right) + parts\ costs\ (\$)$$
$$= scheduled\ maintenance\ costs\ (\$) + unscheduled\ maintenance\ costs\ (\$) \quad (4)$$

Mileage data are available only for the FCEB and NABI CNG fleets; therefore, maintenance cost per mile was calculated for these two fleets only. The FCEB fleet had a maintenance cost of $0.72 per mile, which is lower than the NABI CNG fleet's $1.13 per mile. The FCEB buses, however, are significantly newer (model year 2022) than the NABI CNG buses (model year 2015), which is the primary reason for the difference in maintenance costs.

Table 8. Maintenance Cost Summary for the FCEB Fleet and CNG Fleets

Fleet	Mileage	Labor Hours	Labor ($)	Parts ($)	Scheduled Maintenance Costs ($)	Unscheduled Maintenance Costs ($)	Total Cost per Mile ($/mi)
New Flyer FCEB 3100–3132	1,195,339	7,053	705,316 82.3%	151,280.6 17.7%	363,281.6 42.4%	493,315 57.6%	0.72
NABI CNG fleet 2300–2329	714,860	5,497	549,687 67.9%	259,655.7 32.1%	122,721.07 15.2%	686,621.6 84.8%	1.13
ENC CNG fleet 2745–2762	n/a	6,561	656,095 71.1%	267,011.6 28.9%	153,561.76 16.6%	769,544.83 83.4%	n/a
New Flyer CNG fleet 2500–2529	n/a	11,919	1,191,938 64.7%	649,651.9 35.3%	279,147.48 15.2%	1,562,442.42 84.8%	n/a

3.7.2 Monthly Work Order Maintenance Costs

Figure 21 presents the monthly total maintenance costs for the FCEB fleet and the three CNG fleets, broken down by labor and parts costs. The FCEB fleet consistently shows lower total monthly maintenance costs compared to the NABI and New Flyer CNG fleets, both of which have a similar fleet size as the FCEB fleet. Even when compared to the smaller ENC CNG fleet, which operates only 18 buses, the FCEB fleet (30 buses) generally maintains lower monthly maintenance costs. For all four fleets, labor costs account for a larger portion of the total maintenance cost compared to parts costs, considering labor cost rate of $100 per hour. The FCEB fleet shows a higher ratio of labor costs than the three CNG fleets, indicating that the newer propulsion technology generally requires more time for Foothill Transit's maintenance technicians to troubleshoot, diagnose, and repair issues.

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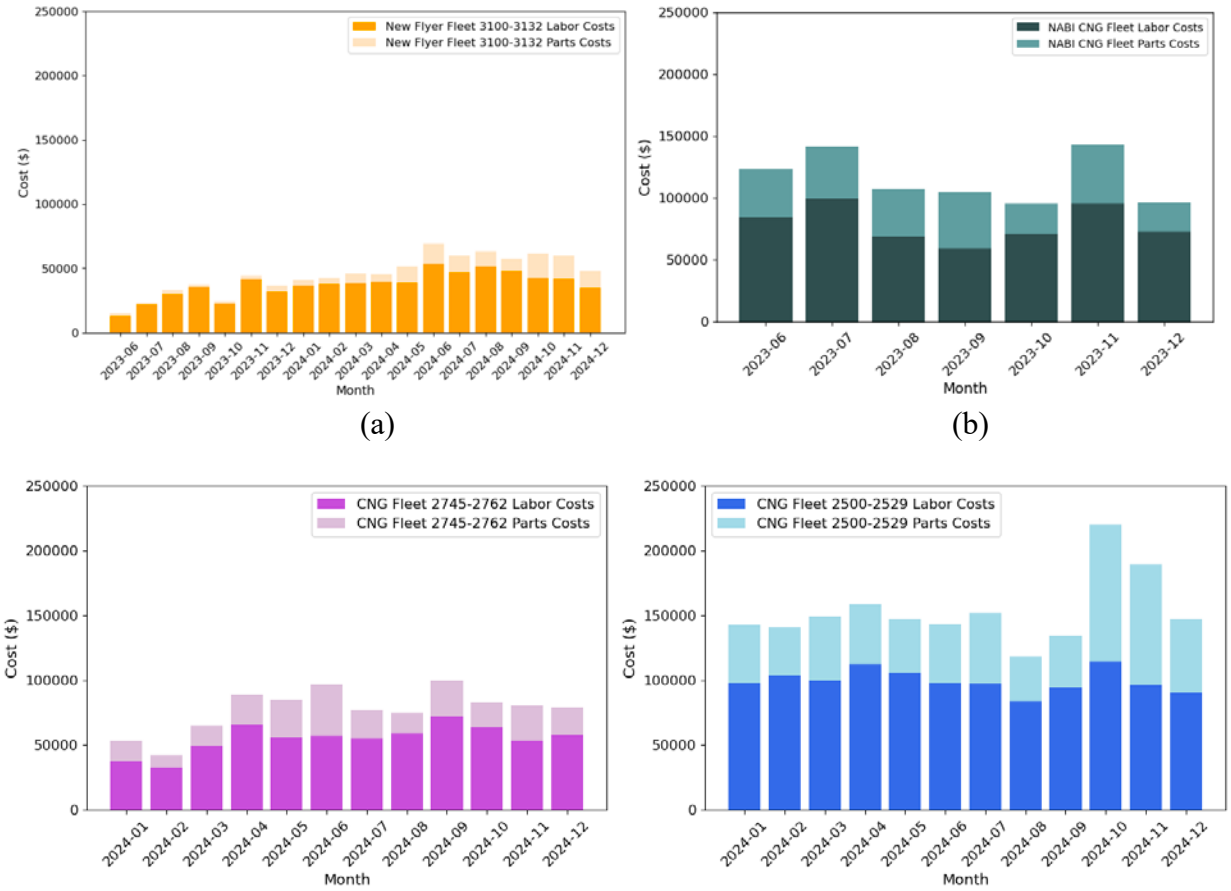

Figure 21. Monthly labor cost and parts cost for the (a) FCEB fleet, (b) NABI CNG fleet, (c) ENC CNG fleet, and (d) New Flyer CNG fleet

(c) (d)

Figure 22 further illustrates the monthly total maintenance costs for the four fleets, broken down into scheduled and unscheduled components. The FCEB fleet exhibits a higher proportion of scheduled maintenance costs compared to the three CNG fleets. Scheduled maintenance accounts for only a small fraction of the total maintenance costs in all three CNG fleets.

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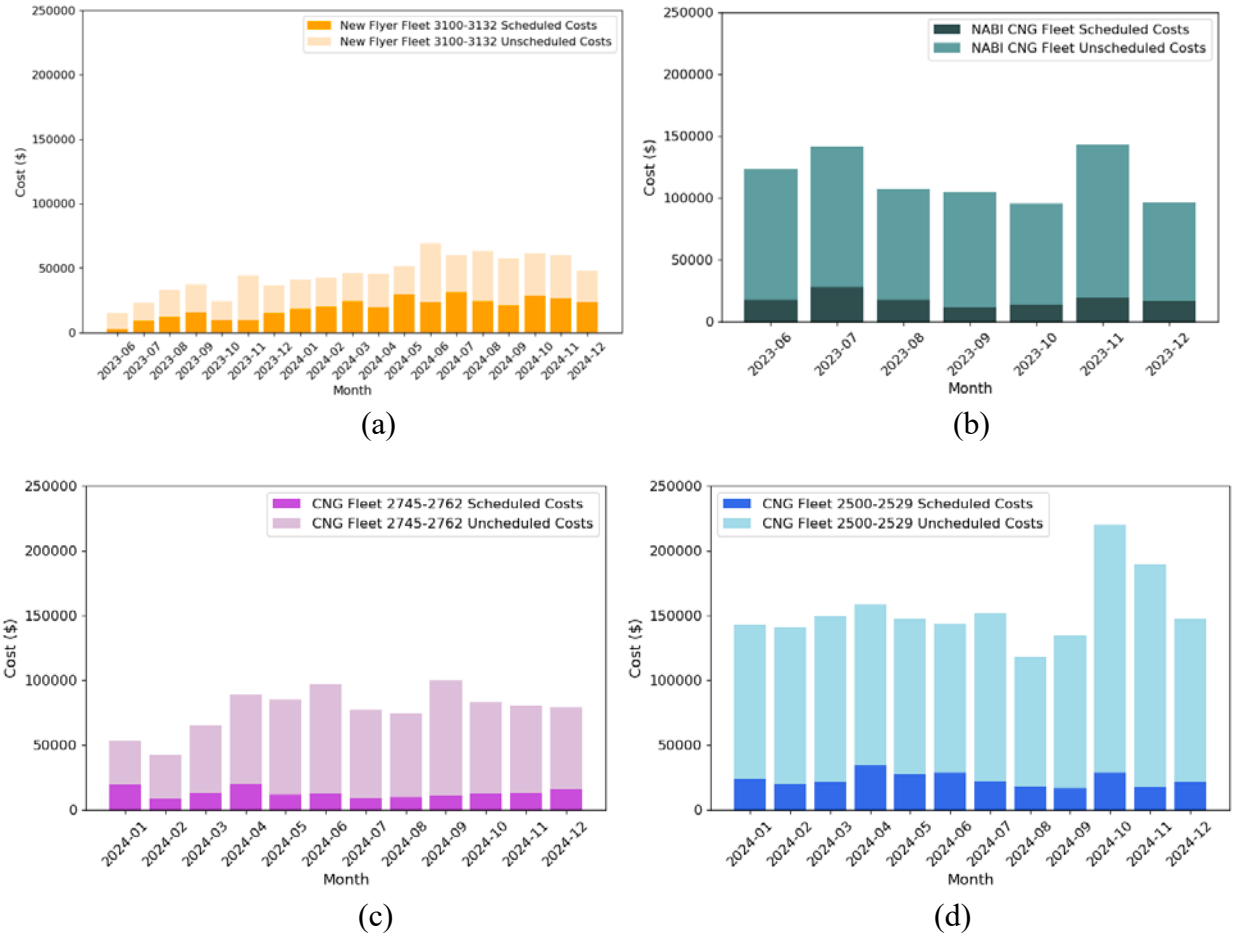

Figure 22. Monthly scheduled and unscheduled costs for the (a) FCEB fleet, (b) NABI CNG fleet, (c) ENC CNG fleet, and (d) New Flyer CNG fleet

Figure 23 and Figure 24 present the monthly maintenance cost per mile for the FCEB and NABI CNG fleets, respectively, categorized into labor and parts costs. Because mileage data are unavailable for the other two CNG fleets, their maintenance cost per mile could not be determined. For the FCEB fleet, monthly costs range from $0.25 to $1.21 per mile, while the NABI CNG fleet ranges from $1.07 to $2.24 per mile. In both fleets, labor costs make up a larger share of total maintenance costs than parts costs, with the FCEB fleet showing a higher proportion of labor costs compared to the NABI CNG fleet.

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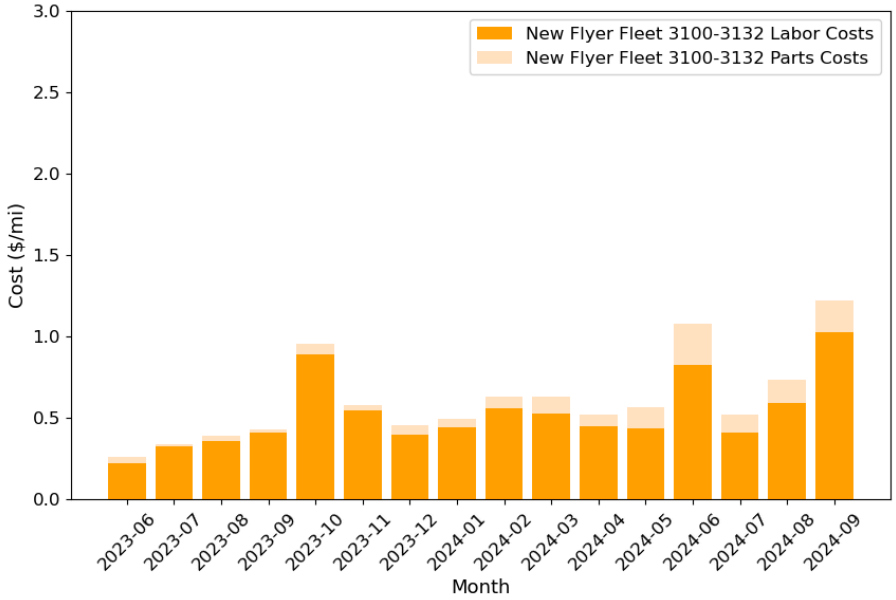

Figure 23. Monthly labor and parts costs per mile for the FCEB fleet

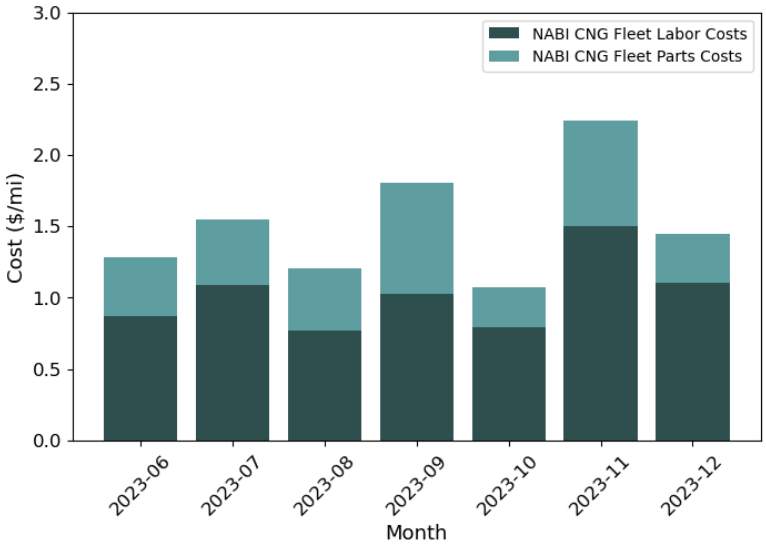

Figure 24. Monthly labor and parts costs per mile for the NABI CNG fleet

Figure 25 and Figure 26 present the monthly maintenance costs per mile for the FCEB and NABI CNG fleets, respectively, categorized into scheduled and unscheduled components. For the FCEB fleet, scheduled maintenance costs range from $0.04 to $0.44 per mile, and unscheduled costs vary from $0.20 to $0.77 per mile. In most months, unscheduled costs slightly exceed scheduled costs. The NABI CNG fleet shows scheduled costs between $0.14 and $0.30 per mile and significantly higher unscheduled costs ranging from $0.92 to $1.61 per mile. Across all months, unscheduled maintenance consistently comprises the majority of total maintenance costs for the NABI CNG fleet.

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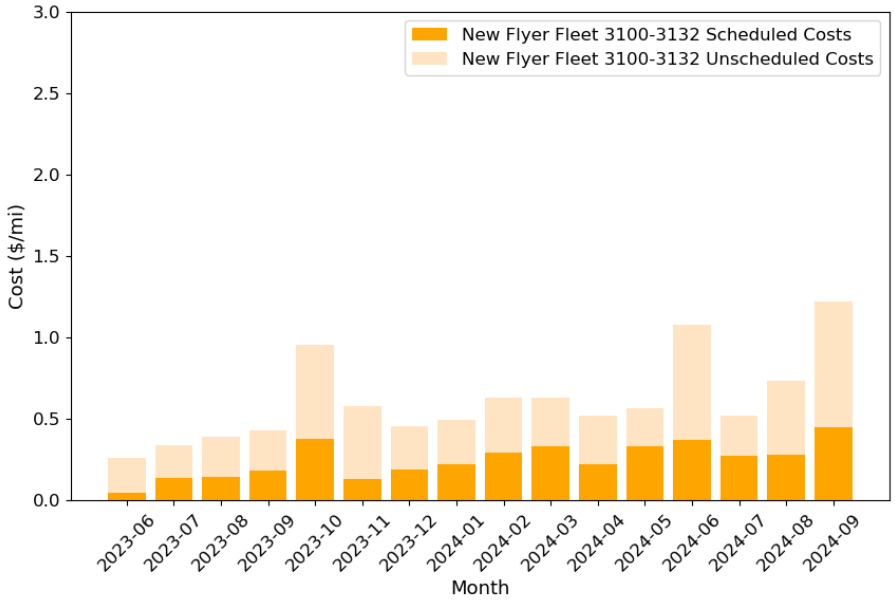

Figure 25. Monthly scheduled and unscheduled costs per mile for the FCEB fleet

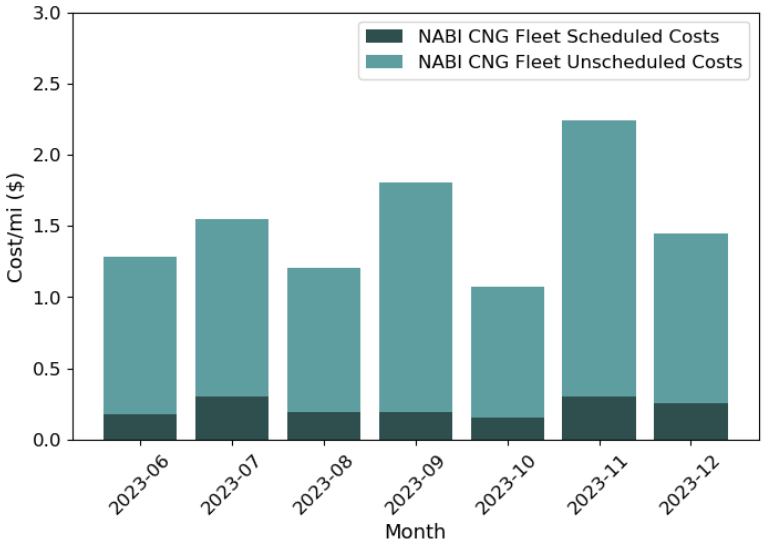

Figure 26. Monthly scheduled and unscheduled costs per mile for the NABI CNG fleet

3.7.3 Work Order Maintenance Costs Categorized by System

The work order maintenance costs for the FCEB fleet and the three baseline CNG fleets were further categorized into different vehicle system costs. The vehicle systems include:

- Propulsion-related systems: Repairs for exhaust, fuel, engine, electric motors, fuel cell modules, battery modules, propulsion control, non-lighting electrical (charging, cranking, and ignition), air intake, cooling, hydraulics, and transmission.
- Cab, body, and accessories: Includes body, glass, and paint repairs following accidents; cab and sheet metal repairs on seats and doors; and accessory repairs such as hub odometers and radios.

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- Preventive maintenance inspections (PMI): Labor for preventive maintenance.
- Brakes.
- Frame, steering, and suspension.
- Heating, ventilating, and air conditioning (HVAC).
- Lighting.
- Axles, wheels, and driveshaft.
- Air system, general.
- Tires.

Table 9 shows the maintenance costs by vehicle system and fleet. For the FCEB fleet and the NABI CNG fleet, maintenance costs per mile for each system is presented, while for the ENC and New Flyer CNG fleets that lack mileage information, total maintenance costs for each system are presented. The color shading denotes the systems with the highest percentage of maintenance costs: orange for the highest, green for the second highest, and purple for the third highest. The systems with the highest percentage of maintenance costs for the FCEB fleet and the NABI CNG fleet were (1) preventive maintenance inspection, (2) propulsion-related, and (3) cab, body, and accessories. The systems with the highest percentage of maintenance costs for the ENC CNG fleet were (1) cab, body, and accessories; (2) propulsion-related; and (3) preventive maintenance inspection. The systems with the highest percentage of maintenance costs for the New Flyer CNG fleet were (1) propulsion-related; (2) cab, body, and accessories; and (3) preventive maintenance inspection.

Table 9. Overall Maintenance Costs Categorized by System for the FCEB and CNG Fleets

System	FCEB Fleet		NABI CNG Fleet		ENC CNG Fleet		New Flyer CNG Fleet	
	Cost per Mile ($/mile)	Percent of Total (%)	Cost per Mile ($/mile)	Percent of Total (%)	Total Cost ($)	Percent of Total (%)	Total Cost ($)	Percent of Total (%)
PMI	0.335	46.9	0.444	39.2	207,236.16	22.4	339,751.53	**18.5**
Propulsion-related	0.19	26.7	0.398	35.2	258,468.77	28	637,142.43	**34.6**
Cab, body, and accessories	0.104	14.6	0.183	16.1	268,303.68	29.1	523,494.21	**28.4**
Brakes	0.026	3.7	0.036	3.2	74,646.79	8.1	140,599.34	**7.6**
HVAC	0.002	0.3	0.028	2.5	44,594.27	4.8	44,078.01	**2.4**
Lighting	0.006	0.9	0.014	1.2	27,829	3	37,049.08	**2.0**
Tires	0.037	5.2	0.012	1	11,994.19	1.3	24,585.41	**1.3**
Axles, wheels, and driveshaft	0.002	0.3	0.009	0.8	14,365.45	1.6	52,073.50	**2.8**
Frame, steering, and suspension	0.004	0.5	0.006	0.5	8,706.85	0.9	36,337.40	**2.0**
General air system repairs	0.006	0.9	0.003	0.3	6,961.43	0.8	6,479.00	**0.4**
Total	**0.712**	**100**	**1.133**	**100**	**923,107**	**100**	**1,841,590**	**100**

Figure 27 through Figure 30 provide a detailed breakdown of monthly maintenance costs by vehicle system for each of the four fleets. For the FCEB and NABI CNG fleets, the costs are shown on a per-mile basis, while for the other two CNG fleets, due to the absence of mileage

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data, total monthly maintenance costs are presented. These figures offer insight into the system-level distribution of maintenance expenses over time.

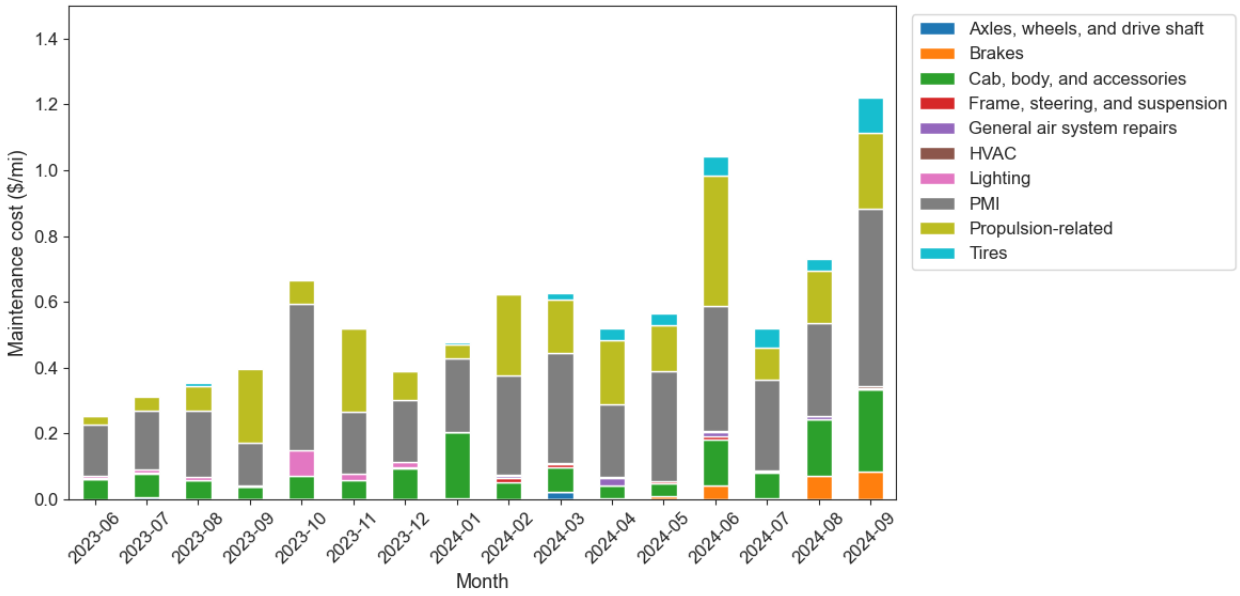

Figure 27. Monthly maintenance cost categorized by system for the FCEB fleet

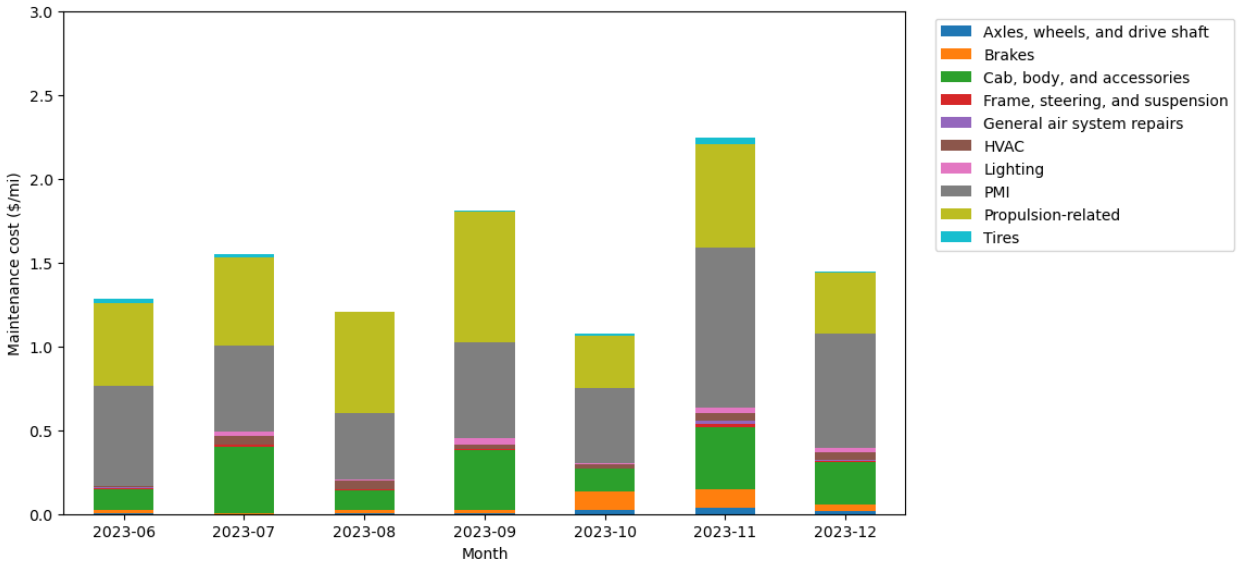

Figure 28. Monthly maintenance cost categorized by system for the NABI CNG fleet

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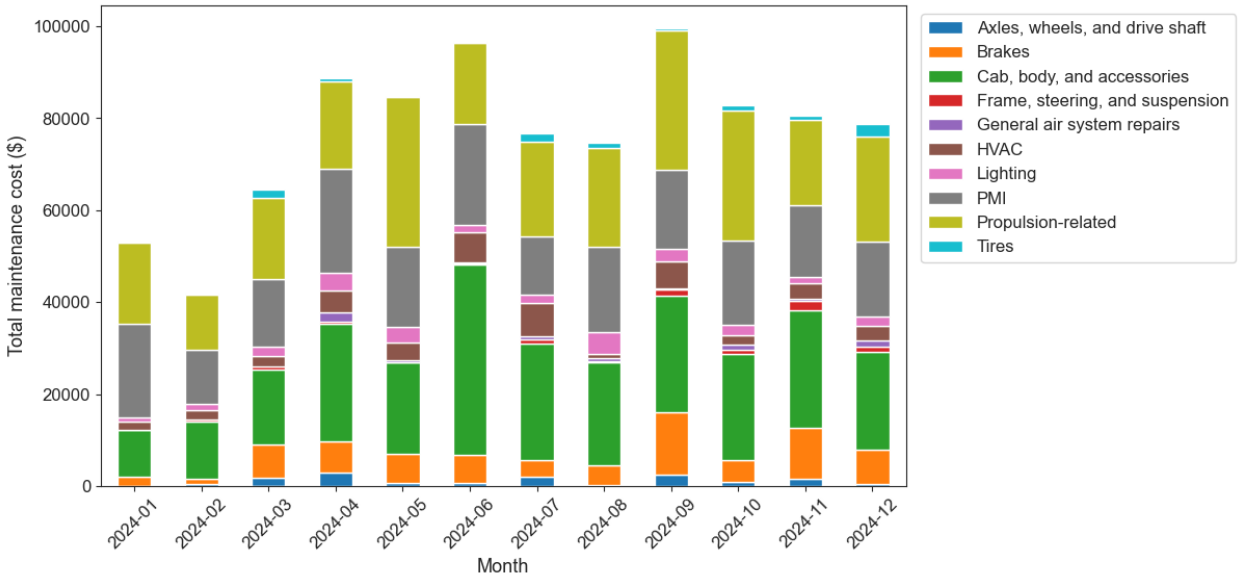

Figure 29. Monthly maintenance cost categorized by system for the ENC CNG fleet

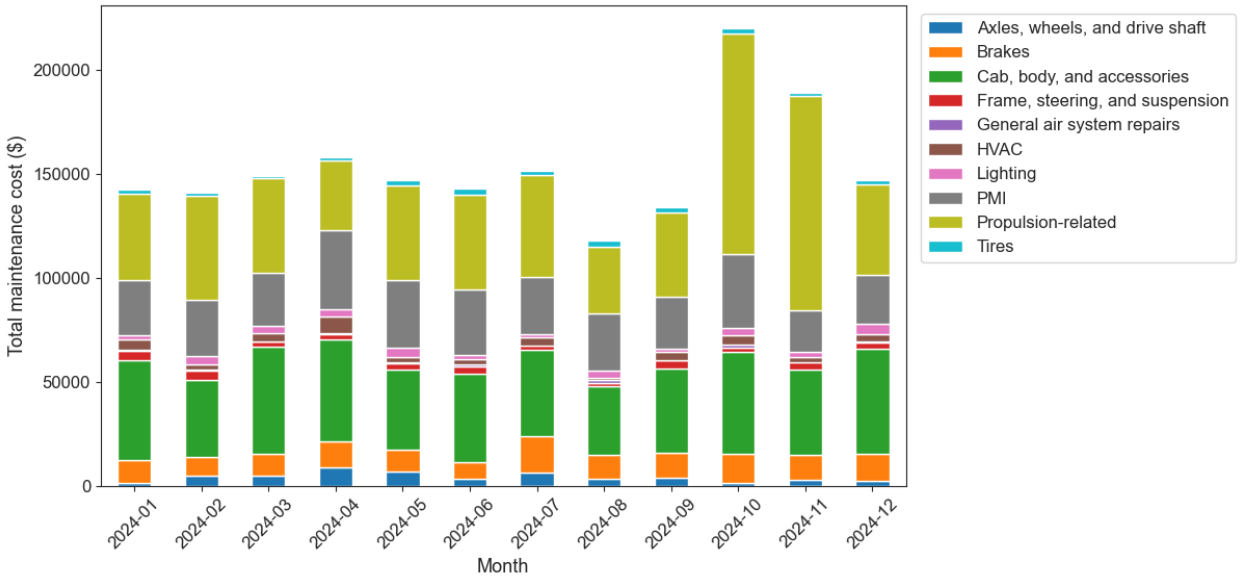

Figure 30. Monthly maintenance cost categorized by system for the New Flyer CNG fleet

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4 Current Status of FCEB Technology: Summary of Achievements and Challenges

This section discusses the progress being made and the challenges that remain to bring FCEBs to the market.

4.1 Progress Toward Meeting Technical Targets

In 2012, DOE and DOT/Federal Transit Administration established performance and cost targets for FCEBs. Interim targets were set, along with ultimate targets that FCEBs would need to meet to compete with current commercial technology buses. Although the targets set in 2012 included a 2016 interim target, not all FCEBs were expected to reach these targets in that time frame. In particular, the power plant lifetime requires 6 years/250,000 miles before reaching the target. Table 10 shows a selection of these technical targets for FCEBs.

Table 10. Targets From DOE/DOT Program Record

Metric	Units	Interim Target	Ultimate Target
Bus lifetime	years/miles	12/500,000	12/500,000
Powerplant lifetime	hours	18,000	25,000
Bus availability	%	85	90
Roadcall frequency (bus/fuel cell system)	MBRC	3,500/15,000	4,000/20,000
Operation time	hours per day/days per week	20/7	20/7
Maintenance cost	$/mile	0.75	0.4
Fuel economy	mpdge	8.0	8.0
Bus cost	$/bus	1,000,000	600,000

- Bus costs:
    - Previous status reports showed that FCEB capital costs had been decreasing steadily since the early demonstrations. Reported costs in the 2024 APTA database show average FCEB costs increasing sharply from approximately $1,000,000 per bus in 2020 to nearly $1,500,000 by 2025.
    - Foothill Transit reported a capital cost of approximately $1,150,000 per bus for the 2022 model year FCEB fleet.
- Bus lifetime:
    - Assessing the durability and lifetime of a propulsion system takes time, and the latest generation of the FCEB technology has not yet acquired enough operation time to determine the average expected lifetime of the components or system. This will need to be assessed in the coming years as the current fuel cell stacks in the buses degrade and are ultimately retired.

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    - Previous FCEB status reports demonstrated that the fuel cell stacks on the Van Hool FCEBs were meeting, and often exceeding, the ultimate target of 25,000 hours of operation before being retired from service due to voltage degradation.
- Fuel economy:
    - Previous FCEB status reports documented the average fuel economy for first- and second-generation FCEBs as 5.89 mpdge and 7.94 mpdge, respectively, noting a significant improvement in the performance of the technology and approximating the ultimate target of 8.0 mpdge. The latest generation of New Flyer FCEBs operating at Foothill Transit have achieved an average fuel economy of 9.2 mpdge in service in Southern California.
- Bus availability:
    - The FCEB fleet at Foothill Transit demonstrated a fleet average availability of 76.8%, while the comparative CNG fleets ranged between 72% and 88% during the data period. The ultimate target of 90% availability is a high threshold that most conventional bus fleets do not consistently achieve. A target of 80%-85% is more common at transit agencies.
- Maintenance cost and MBRC:
    - As with assessing total powerplant lifetime, assessing the overall maintenance costs and MBRC for a bus takes time in service. Maintenance costs tend to start lower and increase with the age of the bus but can fluctuate over time due to a variety of operation and maintenance factors.
    - Overall maintenance cost for the FCEB fleet at Foothill Transit during the data period was calculated to be $0.72 per mile, approaching the interim target of $0.75 per mile.
    - The MBRC for the FCEB fleet was approximately 21,000 miles for all bus-related roadcalls and 44,000 for propulsion-related roadcalls. The fleet has not yet experienced any fuel-cell-related roadcalls.

Some of the primary challenges remaining with deploying and operating FCEBs in transit service include the high upfront cost for purchasing the buses, as well as the cost of installing the hydrogen refueling infrastructure necessary to operate the buses. The unit price of hydrogen fuel remains high ($9–$10/kg) for many FCEB fleets in operation today, leading to higher per-mile operating costs than conventional transit buses. Reliability and durability of the technology are continuing to improve, as is the fuel economy of FCEBs. Agencies operating FCEBs are still developing and increasing their in-house technical expertise to efficiently troubleshoot and repair issues that arise with the fuel cell powerplant and electric powertrain. Continued progress in costs, performance, and reliability will encourage more transit agencies to deploy FCEBs in their service.

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Appendix A. Detailed Summary Statistics

A.1 Monthly Availability for Foothill Transit Bus Fleets

Table A-1. Monthly Availability for the New Flyer FCEB Fleet (3100–3132)

Category	23-Jun	23-Jul	23-Aug	23-Sep	23-Oct	23-Nov	23-Dec	24-Jan	24-Feb	24-Mar	24-Apr	24-May	24-Jun	24-Jul	24-Aug	24-Sep	24-Oct	24-Nov	24-Dec
Planned work days	660	561	758	655	297	644	566	636	644	656	693	624	660	759	690	660	759	627	627
Available days	602	453	653	529	231	421	431	492	475	481	530	504	446	541	492	487	562	480	533
Percent availability (%)	91.2	80.7	86.1	80.8	77.8	65.4	76.1	77.4	73.8	73.3	76.5	80.8	67.6	71.3	71.3	73.8	74.0	76.6	85.0
Unavailable days	58	108	105	126	66	223	135	144	169	175	163	120	214	218	198	173	197	147	94
ESS	8	9	17	41	37	64	32	25	21	28	33	20	54	84	93	121	123	75	20
Electric drive	2	4	18	17	1	9	14	1	6	32	28	11	53	79	25	21	16	38	19
Charging issues	0	0	0	0	0	0	0	12	0	1	0	0	5	9	1	0	0	0	0
Preventive maintenance	0	0	0	1	2	1	1	0	0	0	0	4	2	1	1	5	12	13	6
Bus maintenance	8	36	29	34	25	133	11	29	61	55	72	53	81	40	66	21	40	17	6
Fuel cell system	40	59	41	33	1	16	77	77	81	59	30	32	19	5	12	5	6	4	43
Accident (days)	0	0	1	5	0	16	28	24	16	4	0	3	0	0	3	0	0	0	0

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Table A-2. Monthly Availability for the ENC CNG Fleet (2745–2762)

Category	24-Jan	24-Feb	24-Mar	24-Apr	24-May	24-Jun	24-Jul	24-Aug	24-Sep	24-Oct	24-Nov	24-Dec
Planned work days	314	308	272	333	389	327	378	377	341	323	342	378
Available days	291	280	213	275	313	280	341	346	298	290	319	359
Percent availability	92.7	90.9	78.3	82.6	80.5	85.6	90.2	91.8	87.4	89.8	93.3	95
Unavailable days	23	28	59	58	76	47	37	31	43	33	23	19
Engine	2	7	1	0	2	0	1	6	3	4	3	2
Preventive maintenance	11	5	18	13	46	39	25	12	24	17	17	14
Bus maintenance	10	15	20	24	28	8	11	13	16	12	3	3
Transmission	0	1	20	21	0	0	0	0	0	0	0	0
Accident (days)	0	0	1	0	0	0	0	1	1	1	0	0

Table A-3. Monthly Availability for the New Flyer CNG Fleet (2500–2529)

Category	24-Jan	24-Feb	24-Mar	24-Apr	24-May	24-Jun	24-Jul	24-Aug	24-Sep	24-Oct	24-Nov	24-Dec
Planned work days	549	521	539	600	660	540	630	630	567	540	570	629
Available days	484	457	469	517	559	463	527	526	501	470	491	509
Percent availability (%)	88.2	87.7	87	86.2	84.7	85.7	83.7	83.5	88.4	87	86.1	80.9
Unavailable days	65	64	70	83	101	77	103	104	66	70	79	120
Engine	11	14	19	2	19	43	50	33	16	15	13	27
Preventive maintenance	45	41	29	55	61	28	42	46	32	27	35	49
Bus maintenance	5	5	7	13	20	6	9	12	12	19	30	32
Transmission	4	4	15	13	1	0	2	13	6	9	1	12
Accident (days)	21	19	1	0	0	0	0	0	3	0	0	1

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Appendix B. List of Published ZEB Evaluations for Meta-Analysis of Performance and Cost Metrics

Publication Title	Date Published
Orange County Transportation Authority Fuel Cell Electric Bus Progress Report Data Period Focus: Feb. 2020 through Jul. 2021	July 2022
SunLine Transit Agency Fuel Cell Electric Bus Progress Report Data Period Focus: Jan. 2020 through Dec. 2021	July 2022
Foothill Transit Battery Electric Bus Evaluation: Final Report	June 2021
Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses	April 2020
Zero-Emission Bus Evaluation Results: Stark Area Regional Transit Authority Fuel Cell Electric Buses	Oct. 2019
Zero-Emission Bus Evaluation Results: Orange County Transportation Authority Fuel Cell Electric Bus	May 2018
Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses	Dec. 2018
Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses	Feb. 2018
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Sixth Report	Sept. 2017
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report	June 2016
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fourth Report	July 2015
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Third Report	May 2014
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Second Results Report	July 2012
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report	Aug. 2011
BC Transit Fuel Cell Bus Project: Evaluation Results Report	Feb. 2014
BC Transit Fuel Cell Bus Project Evaluation Results: Second Report	Sept. 2014
American Fuel Cell Bus Project: First Analysis Report	June 2013
American Fuel Cell Bus Project Evaluation: Second Report	Sept. 2015
Zero Emission Transit Bus Technology Analysis (Volume 1)	July 2021
Zero Emission Transit Bus Technology Analysis (Volume 2)	Dec. 2021
Zero Emission Transit Bus Technology Analysis (Volume 3)	June 2022
Zero Emission Transit Bus Technology Analysis (Volume 4)	Dec. 2022
Zero Emission Program: Annual Progress Report	June 2024

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Publication Title	Date Published
Analysis of Electric Bus Deployments at Transit Agencies	May 2020
TTC's Green Bus Program: Final Results of TTC's Head-to-Head eBus Evaluation	April 2022
TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation	April 2021
AVTA FY 2021 Monthly Maintenance Key Performance Indicators	June 2021
SFMTA Battery Electric Bus Evaluation Report: Zero-Emission and Onboard Technology, Program Delivery and Support, Transit	Dec. 2024
OCTA Zero-Emission Bus Pilot Update	Feb. 2024

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