Foothill Transit

Executive Board Meeting AGENDA

EXECUTIVE BOARD MEETING – STUDY SESSION
8:00 AM, APRIL 27, 2018
Foothill Transit Administrative Office
2nd Floor Conference Room
100 South Vincent Avenue
West Covina, CA 91790

1. CALL TO ORDER

2. PLEDGE OF ALLEGIANCE

3. ROLL CALL: MEMBERS CALAYCAY, HERRERA, PEDROZA, STERNQUIST, WARSHAW

4. APPROVAL OF AGENDA

5. PUBLIC COMMENT

   5.1. Executive Director Response to Public Comment

6. ELECTRIC BUS PROGRAM UPDATE

   Recommended Action: Receive and file the update on Foothill Transit's Electric Bus (EB) program.

Public Comment: Members of the public shall have the right to address the Board on any item of interest which is within the jurisdiction of the Board before or during the Board's consideration of the item. Presentation shall not exceed three minutes in length. Action may be taken on any item identified on the agenda. Persons wishing to comment should submit a "Request to Speak" form to the Secretary. Note: ACTION MAY BE TAKEN ON ANY ITEM IDENTIFIED ON THE AGENDA.

The public may view and obtain all written information supporting this agenda provided to the board both initially and supplementary prior to the meeting by calling (626) 931-7300 extension 7204 or at the agency's offices located at 100 S. Vincent Ave., Suite 200, West Covina, CA 91790. Documents, including PowerPoint handouts, distributed to Board Members by staff or Board Members at the meeting will simultaneously be made available to the public upon request.

7. CONTRACT AWARD – MOBILE FARE PAYMENT SYSTEM

Recommended Action: Authorize the Executive Director to negotiate final contract terms and conditions and enter into a sole source agreement in the amount of $515,000, including all merchant processing fees with AmericanEagle.com for a Mobile Ticketing and Retail Point-of-Sale system. The agreement has a three-year term.

8. EXECUTIVE DIRECTOR COMMENT

9. BOARD MEMBER COMMENT

10. ADJOURNMENT

The next Regular Meeting of the Executive Board is scheduled for Friday, May 25, 2018 at 8:00 AM

In accordance with the Americans with Disabilities Act of 1990, if you require a disability-related modification or accommodation to attend or participate in this meeting, including auxiliary aids or services, please contact the Executive Director's office at (626) 931-7300 extension 7204, at least 48 hours prior to the meeting.

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Nếu Quý vị có yêu cầu dịch vụ dịch thuật, xin vui lòng liên hệ với văn phòng Giám đốc Điều hành tại (626) 931-7300 số lẻ 7204, ít nhất 48 giờ trước khi cuộc họp.

Kung nangangailangan ka ng mga serbisyo sa pagsasalin, pakisuyong makipag-ugnayan sa opisina ng Executive Director sa (626) 931-7300 extension 7204, ng hindi bababa sa 48 oras bago ang pulong.

번역 서비스가 필요하시면 미팅 최소 48시간 이전에 임원 사무실로 (626-931-7300, 내선 번호 7204) 전화주시기 바랍니다.

翻訳サービスが必要な方は、会議の48時間前までに(626) 931-7300 内線 7204のエグゼクティブディレクター事務所にご連絡ください。

إن كنت بحاجة إلى خدمات ترجمة، برجاء الاتصال بالمدير التنفيذي للمكتب على رقم 931-7300(626) (الرقم الداخلي 7204) قبل الاجتماع بـ 48 ساعة على الأقل.

Եթե Ձեզ թարգմանչական ծառայությունների են հարկավոր, հանդիպումից առնվազն 48 ժամ առաջ խնդրում ենք զանգահարել Գործադիր տնօրենի գրասենյակ՝ (626) 931-7300 լրացուցիչ՝ 7204 հեռախոսահամարով:

ប្រសិនបើលោកអ្នកស្នើសុំសេវាកម្មបកប្រែភាសា សូមទាក់ទងមកការិយាល័យនាយកប្រតិបត្តិ តាមលេខទូរស័ព្ទ៖ (626) 931-7300 លេខបញ្ជូនបន្ត 7204 ដែលមានរយៈពេលយ៉ាងតិច 48 ម៉ោង មុនពេលកិច្ចប្រជុំ"។

در صورت نیاز به خدمات ترجمه، لطفاً حداقل 48 ساعت قبل از جلسه ملاقات با مدیر اجرایی دفتر به شماره931-7300(626) داخلی 7204 تماس حاصل فرمایید.

หากคุณต้องการบริการการแปลภาษากรุณาติดต่อสำนักงานผู้อำนวยการบริหารที่ (626) 931-7300 ต่อ 7204, อย่างน้อย 48 ชั่วโมงก่อนที่จะมีการประชุม

April 27, 2018

To: Executive Board

Subject: **Electric Bus Program Update**

Recommendation

Receive and file the update on Foothill Transit's Electric Bus (EB) program.

Analysis

This Board item will provide the Board with an in-depth opportunity to review the status of Foothill Transit's electric bus program and discuss potential next steps regarding our future strategy for the program. It is not anticipate that the Board would take any specific action at this meeting, but instead provide broad direction to staff so that a more specific plan could be adopted.

By way of background, Foothill Transit began a demonstration of three Proterra Battery Electric Buses (BEBs) in October 2010 to evaluate the battery technology and determine if the BEBs could meet Foothill Transit's service requirements. The demonstration included the construction of two bus charging stations at the Pomona Transit Center funded by the American Recovery and Reinvestment Act of 2009 (ARRA).

The initial demonstration went well and in 2014, Foothill moved forward with an order of twelve next-generation BEBs from Proterra through a $10.2 million grant under the Federal Transit Administration's (FTA) Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program. Foothill Transit's project goal was to fully electrify one route in its service area—Line 291—and to investigate the feasibility of the technology for other routes. These electric buses are 35-foot composite-body buses that are capable of being charged quickly at a point along the route via Proterra's overhead charging system. The buses are charged midway along the route at the Pomona Transit Center.

In 2016, Foothill Transit expanded its fleet of electric buses by acquiring two 40-foot Catalyst Fast Charge buses to complement service on Line 291. In 2017, Foothill Transit acquired 14 40-foot Catalyst E2 Extended-Range buses to operate service on Line 280, a 22-mile roundtrip between the Azusa Intermodal Transit Center and Puente Hills Mall.

Over the last eight years, the EB program has provided a great learning experience through some successes and challenges. Implementing BEBs is complex and the learning process continues as we look forward to implementing a full fleet of electric buses by 2030.

Attachments A and B are a detailed history of the program and an assessment and proposed next steps to further assess the viability of EBs in transit service.

Budget Impact

This staff report is for information and discussion purposes only and has no impact on the FY 2017-2018 budget.

Sincerely,

Roland M. Cordero
Director of Maintenance
and Vehicle Technology

Doran J. Barnes
Executive Director

Attachments

Attachment A

Electric Bus Update Briefing Document

Current Challenges and Proposed Large Scale Demonstration

4/27/18

Since 2010, Foothill Transit has been a leader in the deployment and operation of electric buses. Now, with over 1.4 million accumulated electric miles from our fleet of 30 electric buses, it is a good time to take stock of our progress to date and look forward to what changes need to happen in the future.

<u>Foothill Transit's Electric Bus History</u>

Foothill Transit first deployed three Proterra built 35 ft. fast-charge electric operating on line 291 through La Verne and Pomona. Foothill Transit built a fast-charge station at the Pomona Transit Center (PTC) with two overhead chargers. The buses have a range of 35 miles, but can recharge back to 100 percent in less than 10 minutes. By locating a fast-charge station at an on-route transit center, these buses operate all day long by charging at PTC on every roundtrip.

Foothill Transit expanded the fast-charge fleet in 2014 with fourteen additional Proterra fast-charge buses, all passing through PTC. In 2016 Foothill Transit added two new 40 ft. Catalyst fast-charge buses, and the following year exchanged with Proterra, one of the original fleet for a 40 ft. Catalyst E2 extended-range bus. This transaction was approved by the Federal Transportation Administration. Today, Foothill Transit operates 16 fast-charge buses in total, all of which run through and charge at PTC and are domiciled at our Pomona Operations & Maintenance Facility.

This model has proven very successful. In 2014 Foothill Transit Foothill was the first transit agency to fully electrify a single bus line, and to-date Foothill Transit have completed over 1.4 million electric bus miles and 140,000 charge events. The buses operate on a route with a roundtrip of 16.1 miles, recharge for 6 or 7 minutes every hour. Part of the reason for the success is Foothill Transit designed a service that fit well within the bus capabilities. With a short roundtrip distance and frequent recharging events, the bus does not exceed the vehicle's limited range ability.

Since 2014, our fast-charge fleet has been monitored by the National Renewable Energy Laboratory (NREL) to evaluate its performance compared to our CNG buses. NREL's regularly-published updates have been utilized by other agencies to understand the benefits and drawbacks of the technology.

In 2017, Foothill Transit grew our program to include extended range buses, which will primarily charge overnight at the Arcadia facility. In December, Foothill Transit received its order of fourteen 40 ft. Proterra Catalyst E2 extended range buses at the Arcadia Operations & Maintenance Facility. Currently, Foothill Transit is undergoing operator training and bus testing to understand the buses capabilities and real-world range. Foothill Transit has also been working with Proterra on a design plan for the purchase and installation of 14 in-depot chargers at the Arcadia facility. The buses, once fully deployed into revenue service, are planned to operate on Line 280 from the Azusa Intermodal Transit Center (AITC) to Puente Hills Mall. While the depot chargers are being built, the buses are currently charged at a new on-route charger at AITC.

Part of the bus testing has focused on how the buses perform on different types of route (local streets, express) and what range Foothill Transit can expect in different scenarios. Results from this test have been eye opening. They are described more fully below:

Required by this extended range deployment is an installation of bus chargers at the Arcadia yard. Design for these chargers has taken several forms. In early 2017, Proterra proposed a solution of fourteen plug-in chargers mounted on the exterior walls of the yard. This concept was turned down because it was not capable of scaling up for future deployments. Subsequent design included an overhead solar panel canopy installation with chargers mounted to the structure, which was rejected after the vendor withdrew. The current vision is for plug-in chargers to be suspended on an overhead signal bridge, with reels to house the cabling. This design is currently being reviewed for feasibility and code compliance, with an initial cost estimate of $1.4 million. Foothill Transit has not yet entered into a contract for the full design and construction of this concept.

Deployment Fast Facts

2010, First three buses deployed, along with on-route fast-charge station

- Cost per bus: $1.2 million Pre-Sales Tax
- Cost for fast-charge station: $2 million
- Funding source: American Recovery Reinvestment Act, $6.5 million.

2014, Fourteen additional fast-charge buses deployed, leveraging the existing fast-charge station

- Cost per bus: $904,000 Pre-Sales Tax
- Funding source: FTA TIGGER grant, $10.2 million.

2016, Two additional fast-charge buses deployed, leveraging the existing fast-charge station

- Cost per bus: $792,000 Pre-Sales Tax
- Funding source: Local funds

2017, fourteen extended range electric buses deployed.

- Cost per bus: $898,854 Sales Tax Including
  $823,639 Pre-Sales Tax
- Funding source: Section 5307 funds

<u>Industry Barriers</u>

The learnings from Foothill Transit's deployments highlight several barriers that the electric bus industry must overcome if it wants to continue growing into larger fleet sizes.

1. *Bus Range*

Vehcile range is a key issue in the deployment of electric vehicles. While the bus manufacturers have calculated bus ranges, but there is still limited experience with extended range, buses in a real world transit operating environment. It has been suggested that electric vehicles can achieve a range of 250 miles or more.

From our standpoint, Foothill Transit has seen in our very early in-service testing of Proterra's Catalyst E2 bus, the real world capabilities of the bus may fall short of the claimed range. The impact of this shortfall is significant: if Foothill Transit had an electric bus that could actually go 251 miles in revenue service, it could meet the large majority of our bus needs. However, with our initial tested range of as low as 149 miles, this bus is much less functional than was originally expected, and meets much less of our transit needs.

Our challenge now is to work with Proterra to implement both technology and operational improvements that will result in improved range. We will take a fact-driven approach to analyzing our data and implementing these improvements.

2. *Electricity Costs*

It is sometimes claimed that electric buses have lower operating costs than diesel or natural gas buses, but for Foothill Transit, the opposite has proven to be true. While maintenance costs tend to be lower, due to the elimination of consumable items such as oil, filters, and fan belts, the costs of electricity have dwarfed that of natural gas. In 2017, our electricity costs, in terms of cost per bus mile, were 48 cents per mile, and our CNG cost was 36 cents per mile. This is a 50 percent premium for electricity as a transportation fuel.

If electric buses are to be truly deployed at scale, the cost of electricity must come down to parity, or near parity, with diesel and natural gas. The degree to which this is feasible will depend greatly on innovations from the electric utility on how electricity is sold and rates are structured. Additionally, there are technical opportunities, such as smart charging, battery storage, and vehicle-grid integration, which may lower costs.

To address these challenges, we have been engaged in conversation with representative from Southern California Edison. In addition, we are actively involved in the rate-making process with the California Public Utilities Commission. As a leader in the electric bus field, we must continue to engage with these stakeholders to find a way to lower the cost of electric power.

3. *Depot Charge Infrastructure*

The challenge of installing depot charge infrastructure is one of the greatest bottlenecks to growing an electric fleet. The problem is multifaceted – there is work that is needed on the utility grid side to ensure that adequate power is available; onsite power electronics are needed to feed electricity on-site, and charger end-points must be installed across the yard. This is in addition to the challenge of finding the funding to pay for it all.

To help us plan for the future, Foothill Transit issued a Request for Proposals (RFP) to select a partner for a study to examine all aspects of a depot charge solution, and make recommendations about how to approach each component. The study is expected to launch in the summer of 2018.

4. *Transit Operations*

Electric buses are more limited than our current legacy fleet of CNG buses. The CNGs have an operating range of 350 miles, can be dispatched for all day operation, and can re-fill in 20 minutes. This flexibility greatly simplifies the task of designing bus blocks and dispatching vehicles. The limitations of electric buses require planners and dispatchers to make more consideration of how to incorporate the technology into daily fleet operation.

This issue is tied to the idea of a “one-for-one replacement” in which an electric bus can be swapped with a CNG bus without needing additional vehicles. This one-for-one goal is not achievable today. To compensate, there is needed new strategies for deployment to still provide service with minimal impacts to cost and capability.

<u>Next Step: Electric Bus Large Scale Demonstration</u>

In the past few years, several agencies have launched electric bus programs, and electric fleets of ten buses or fewer are being deployed in several locations. However, a small fleet of ten buses will be limited in the lessons that are learned. Many of the challenges, such as the challenges above on electricity costs, depot infrastructure, and operations are only truly encountered when you start growing your electric fleet to a greater bus number and greater percentage of your total fleet. It is only by achieving this scale that you have the opportunity to address and overcome the next wave of challenges that limit electric bus growth.

Instead of funding a dozen small bus demonstrations, all of which repeat the lessons that have already been learned, what is needed is a single large deployment of 50-100 buses, concentrated in a single depot and with a single agency dedicated to operating them in the best way possible. In combination, a depot charger build-out of similar scale will be required. Then, this deployment needs to be tracked over time, to measure performance and challenges not just in year 1 or year 3, but over the entire bus life. The bus evaluation needs to be performed by an independent third party that is neutral and competent.

This Large Scale Demonstration requires a combination of significant capital funding up-front and ongoing operation funds for the evaluation and socializing results and lessons learned.

For your reference and review, please find the National Renewable Energy Labs Final Second Report. This report documents their analysis and findings related to our initial deployment of electric buses. Similar independent, third party analysis will be beneficial as we continue to advance this technology.

Attachment B

Foothill Transit Battery Electric Bus Demonstration Results: Second Report

Leslie Eudy and Matthew Jeffers
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5400-67698
June 2017

Contract No. DE-AC36-08GO28308

Attachment B

Foothill Transit Battery Electric Bus Demonstration Results: Second Report

Leslie Eudy and Matthew Jeffers
National Renewable Energy Laboratory

Prepared under Task No. WW4K.1000

NREL is a national laboratory of the U.S. Department of Energy
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Technical Report
NREL/TP-5400-67698
June 2017

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This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

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NREL prints on paper that contains recycled content.

Acknowledgments

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Proterra
Mike Finnern
Derrick Allen

Unless otherwise noted, all photos by L. Eudy, NREL

Acronyms and Abbreviations

BEB	battery electric bus
CARB	California Air Resources Board
CNG	compressed natural gas
dge	diesel gallon equivalent
DOE	U.S. Department of Energy
ESS	energy storage system
FCEB	fuel cell electric bus
ft	feet
FTA	Federal Transit Administration
gge	gasoline gallon equivalent
GVWR	gross vehicle weight rating
hp	horsepower
HVAC	heating, ventilation, and air conditioning
in.	inches
kg	kilograms
kW	kilowatts
kWh	kilowatt hours
lb	pounds
LCFS	Low Carbon Fuel Standard
MBRC	miles between roadcalls
mph	miles per hour
NREL	National Renewable Energy Laboratory
PMI	preventive maintenance inspection
psi	pounds per square inch
PTC	Pomona Transit Center
SI	International System of Units
TIGGER	Transit Investments for Greenhouse Gas and Energy Reduction
TRL	technology readiness level
ZBus	zero-emission bus

Definition of Terms

Availability: The number of days the buses are actually available compared to the days that the buses are planned for operation, expressed as percent availability.

Average *driving* speed: The average speed of the buses while driving, not including stops and idle time. These data are collected using data loggers.

Clean point: For each evaluation, NREL works with the project partners to determine a starting point—or clean point—for the data analysis period. The clean point is chosen to avoid some of the early and expected operations problems with a new vehicle going into service, such as early maintenance campaigns. In some cases, reaching the clean point may require 3 to 6 months of operation before the evaluation can start.

Deadhead: The miles and hours that a vehicle travels when out of revenue service with no expectation of carrying revenue passengers. Deadhead includes leaving or returning to the garage or yard facility and changing routes.

Miles between roadcalls (MBRC): A measure of reliability calculated by dividing the number of miles traveled by the number of roadcalls. (Also known as mean distance between failures.) MBRC results in the report are categorized as follows:

- Bus MBRC: Includes all chargeable roadcalls. Includes propulsion-related issues as well as problems with bus-related systems such as brakes, suspension, steering, windows, doors, and tires.
- Propulsion-related MBRC: Includes roadcalls that are attributed to the propulsion system. Propulsion-related roadcalls can be caused by issues with the transmission, batteries, and electric drive.
- Energy storage system (ESS)-related MBRC: Includes roadcalls attributed to the energy storage system only.

Revenue service: The time when a vehicle is available to the general public with an expectation of carrying fare-paying passengers. Vehicles operated in a fare-free service are also considered revenue service.

Roadcall: A failure of an in-service bus that causes the bus to be replaced on route or causes a significant delay in schedule. The analysis includes chargeable roadcalls that affect the operation of the bus or may cause a safety hazard. Non-chargeable roadcalls can be passenger incidents that require the bus to be cleaned before going back into service, or problems with an accessory such as a farebox or radio.

Executive Summary

This report summarizes results of a battery electric bus (BEB) evaluation at Foothill Transit, located in the San Gabriel and Pomona Valley region of Los Angeles County, California. Foothill Transit began a demonstration of three Proterra BEBs in October 2010 to evaluate the battery technology and determine if the BEBs could meet Foothill Transit's service requirements. The initial demonstration went well and in 2014, Foothill Transit moved forward with an order of twelve next-generation BEBs from Proterra through a $10.2 million grant under the Federal Transit Administration's (FTA's) Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program. Foothill Transit's project goal was to fully electrify one route in its service area—Line 291—and to investigate the feasibility of the technology for other routes. These electric buses are 35-ft composite-body buses that are capable of being charged quickly on route via Proterra's overhead charging system. The buses are charged midway along the route at a charging station built at the Pomona Transit Center. Foothill Transit began operating the new fleet of electric buses on line 291 in March 2014.

Foothill Transit is collaborating with the California Air Resources Board (CARB) and the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) to evaluate the buses in revenue service. CARB has been gathering data on zero-emission buses (ZBuses) to assess the status of the technology. The majority of ZBus data collected and reported to date are for fuel cell electric buses. CARB would like to have similar analysis and reporting for the other primary ZBus technology being adopted in the state of California, that is, BEBs. NREL has been evaluating advanced technology buses under funding from DOE and the U.S. Department of Transportation's FTA. The objectives of these evaluations are to provide comprehensive, unbiased evaluation results of advanced technology bus development and performance compared to conventional vehicles. CARB has enlisted NREL to conduct a third-party evaluation of Foothill Transit's electric bus fleet.

The focus of this evaluation is to compare the performance and the operating costs of the BEBs to that of the baseline conventional technology buses and to track progress over time. In the commercialization process described by technology readiness levels (TRLs) 1 through 9—from basic research/concept to commercial deployment—NREL considers the BEBs to be at TRL 7. The primary goals of the in-service demonstration are to verify that technical performance targets are met and to identify any issues that need to be resolved. More information regarding TRLs as they relate to advanced technology bus commercialization is provided in Appendix A.

Conventional technology buses that best match the advanced technology buses in terms of size, weight, model year, and intended operation are selected as baseline buses for the evaluation to provide the best possible comparison of performance and cost. The baseline buses selected at Foothill Transit are eight 42-foot NABI compressed natural gas (CNG) buses of the same model year as the Proterra BEBs.

This is the second report summarizing the results of the BEB demonstration at Foothill Transit. The first report covered the initial data period of April 2014 through July 2015. This report provides data and analysis on the twelve Proterra BEBs and eight NABI CNG baseline buses from August 2015 through December 2016. Table ES-1 provides a summary of results for several categories of data presented in this report. The data from the previous report are included for reference. The BEBs have traveled more than 902,000 miles since the start of the demonstration through December 2016. This equates to an average of more than 75,000 miles per BEB during this evaluation.

Table ES-1. Summary of Evaluation Results

Data Item	BEB	BEB	CNG	CNG
Number of buses	12	12	8	8
Data period	4/14–7/15	8/15–12/16	10/14–7/15	8/15–12/16
Number of months	16	17	10	17
Total mileage in data period	401,244	501,037	364,373	656,399
Average odometer	33,437	77,705	45,547	132,405
Average monthly mileage per bus	2,333	2,456	4,555	4,826
Total operating hours	47,462	58,497	—	—
Availability (85% is target)	90	90	94	93
Fuel economy (kWh/mile or miles/gge[a])	2.15	2.17	4.04	3.89
Fuel economy (miles/dge[b])	17.48	17.35	4.51	4.34
Average speed, including stops (mph)	10.6	8.57	17.6	17.6
Miles between roadcalls (MBRC) – bus[c]	9,331	6,180	45,547	29,165
MBRC – propulsion system only[c]	25,078	16,405	91,093	56,710
MBRC – ESS[d] only[c]	133,748	300,760	—	—
Total maintenance ($/mile)[e]	$0.16	$0.21	$0.18	$0.22
Total maintenance ($/mile without tire costs)	$0.12	$0.14	$0.18	$0.20
Maintenance – propulsion system only ($/mile)	$0.02	$0.02	$0.08	$0.07

[a] Gasoline gallon equivalent.
[b] Diesel gallon equivalent.
[c] MBRC data cumulative from the clean point of April 2014 through December 2016.
[d] Energy storage system.
[e] Work order maintenance cost.

For the most recent data period, the average monthly operating mileage per bus for the BEBs was 2,456 miles, which was about half that of the CNG buses (4,826 miles). This large difference in accumulated mileage is expected due to the planned operation of the buses and should not be interpreted as a limitation of the battery technology. The BEBs are operated primarily on Line 291 and the CNG buses are randomly dispatched on all routes out of the Pomona Operations and Maintenance facility, including express and commuter routes that have much higher average speeds. This higher average speed has an impact on the fuel efficiency of the CNG buses and should be taken into consideration when making comparisons.

The average availability for the BEBs during the data period was 90% compared to 93% for the CNG baseline buses. This is consistent with the previous data period (90% and 94%, respectively). The per-bus availability for the BEBs ranged from a low of 84% to a high of 96%. Most of the issues causing downtime were general bus maintenance issues not related to the propulsion system. General bus system issues caused the majority of downtime for the BEBs, followed by electric drive system issues. For the CNG buses, the majority of downtime was caused by general bus system issues, followed by engine issues.

The BEBs had an overall average efficiency of 2.17 kWh per mile, which equates to 17.35 miles per diesel gallon equivalent (mpdge). The CNG buses had an average fuel economy of 3.89

miles per gasoline gallon equivalent (mpgge), which equates to 4.34 mpdge. The operating duty cycle of a bus has a significant effect on fuel economy. Because Foothill Transit operates its BEB and CNG bus fleets differently, the efficiency results presented here are not considered an apples-to-apples comparison. In collaboration with a DOE-funded activity at NREL, the researchers had access to data collected on a selection of Foothill Transit CNG buses using data loggers. The data loggers recorded two days of CNG operation on Line 291 to provide a direct comparison to the BEBs in this evaluation. On Line 291, the average CNG fuel economy was 2.1 mpdge and the average *driving* speed (not including stops and idle time) was 18.1 mph. This is similar to the average *driving* speed (logged) for the BEBs (17.8 mph), providing a more accurate comparison for fuel economy. When comparing the logged data, the BEB fuel economy is more than 8 times higher than that of a CNG bus operating exclusively on Line 291.

During the data period, Foothill Transit paid an average of $0.17/kWh for electricity for the BEBs and $0.96/gge for CNG. Based on actual energy used by the buses, the energy cost for the BEB fleet calculates to $0.37 per mile. When taking into account the total electricity Foothill Transit purchased from the utility to charge the buses, the energy cost is $0.41 per mile. This difference of $0.04 per mile reflects the expected energy loss of approximately 10% during charging. The average per-mile energy cost for the CNG buses operated at a higher average speed was $0.25 per mile. To compare cost between buses in the same service, NREL estimated the cost per mile for the CNG buses if operated only on Line 291. The lower fuel economy would increase the cost of the CNG buses to an overall average of $0.50 per mile, which is higher than the cost of the BEB fleet. This does not reflect the credits from the Low Carbon Fuel Standard program, which results in a greater benefit for using electricity over CNG. CNG buses generate Low Carbon Fuel Standard credits, although not as many as electric vehicles do.

Time of use and demand charges factor into the cost of electricity for Foothill Transit. When the first three BEBs were deployed, Proterra and Foothill Transit were concerned that the maximum demand would exceed 500 kW, moving the agency into an industrial rate schedule, which has high demand charges. This would result in much higher costs for the agency. To help address this issue, the California Public Utilities Commission issued resolution E-4514, which allowed Foothill Transit to stay on the small commercial schedule that has no demand charges. That exemption expired at the end of 2015. Southern California Edison has established additional rate schedules specifically for customers using electric vehicles. TOU-EV-4 is applicable to customers whose monthly demand is between 20 kW and 500 kW. Foothill Transit worked with Proterra to implement charge management software that controls the charging demand to stay under the 500 kW threshold. The combination of rate schedule and charge management resulted in a lower electricity cost for the agency in the most recent data period.

NREL continued to track the bus reliability—measured as miles between roadcalls (MBRC)—during the second data period. The overall bus MBRC for the BEB fleet decreased from more than 9,000 to just over 6,000. This is higher than the target of 4,000 MBRC but much lower than that of the CNG buses, which achieved more than 29,000 MBRC. The propulsion system-related MBRC was 16,405 for the BEBs compared to 56,710 for the CNG buses. There have been only three roadcalls for the energy storage system (ESS) during the evaluation (none in the latest data period). Thus, the ESS-related MBRC for the BEBs continues to climb, now surpassing 300,000.

NREL also analyzed work order data to provide a comparison of maintenance costs between the BEBs and the baseline CNG fleet. After removing accident- and warranty-related items for both fleets, the average per-mile maintenance cost for the data period was $0.21/mi for the BEBs and $0.22/mi for the CNG buses. These combined totals include scheduled and unscheduled maintenance. Although the totals are very similar, the BEBs have lower scheduled maintenance costs ($0.07/mi) than the CNG buses ($0.11/mi). During this period, the BEBs experienced higher unscheduled maintenance costs ($0.14/mi) than the CNG buses ($0.10/mi). The cost for tire damage, which is not related to the technology, accounted for $0.07/mi to the overall cost of the BEBs. Foothill Transit reports that this is likely due to the differing use between the BEBs and CNG buses. The local routes tend to have more road damage, such as potholes and broken curbs. Since the BEBs are operated mainly on local routes, they incur more tire-related damage compared with the CNG buses that are often driven on freeways. The agency expects that the CNG buses would experience similar tire damage as the BEBs if they were only operated on the local routes. Average scheduled and unscheduled maintenance costs for the CNG buses were strongly impacted by a major preventive maintenance inspection (PMI) reached by many of the buses in the middle of the data period. When excluding tire damage, the total maintenance cost is $0.14/mi for BEBs and $0.20/mi for CNG buses. The BEBs had a propulsion-system-only maintenance cost that was 70% lower than that of the CNG buses: $0.02/mi for the BEBs compared to $0.07/mi for the CNG buses.

The top three vehicle systems that accounted for the largest fraction of maintenance for the BEBs were (in order from highest to lowest) tires (34%); PMI (33%); and cab, body and accessories (17%). For the CNG buses, the top three vehicle systems for maintenance were propulsion-related (32%); PMI (24%); and cab, body and accessories (21%).

There have been many achievements for the demonstration, including the following:

- The current fleet of twelve 35-ft BEBs continues to operate well, accumulating more than 902,000 miles (through December 2016). Foothill Transit's combined fleet of 17 Proterra BEBs (including three first-generation BEBs and two new 40-ft BEBs) has operated more than 1,134,000 miles.
- Bus MBRC for the entire evaluation period is more than 6,000, surpassing the target of 4,000 MBRC. Propulsion-related MBRC is more than 16,000.
- The on-route fast chargers operated reliably with minimal issues, none of which resulted in downtime for the buses. Foothill Transit's combined BEB fleet (17 buses) has been charged more than 119,000 times since the fast chargers were installed. Availability of the two charging heads was 98% and 99%.
- Proterra reports that the high voltage batteries are showing little to no signs of capacity degradation to date, and current estimates show they may last for up to 12 years.

Foothill Transit and Proterra report that the project continues to go well. The partners highlight the following key lessons learned since the beginning of the project:

- Short-range, on-route-charged buses are inflexible and cannot be deployed at other service routes that do not connect to an on-route charging location.

- Review potential routes and consider the ones that best fit how BEBs operate based on driving range, duty cycle, and charging opportunities. An agency could benefit from conducting a route analysis and simulating how the BEBs would meet the range requirements.
- Adjust route schedules to accommodate BEB charging time; this is part of the transition from conventional technology buses to electric buses. An agency may need to add deadhead miles prior to the start of the route depending on the location of the in-route charging station and availability of an in-depot charger.
- The higher use of air conditioning lowers the effective range in hotter months; Foothill Transit adjusts its summer schedule to account for more charging time.
- Charger availability is important for successful deployment. Foothill Transit installed two charger heads at its charging station to avoid downtime for charger unavailability.

Foothill Transit reports that there is still a lot of learning as the agency ramps up to a larger BEB fleet. The agency has a goal of transitioning its fleet to 100% electric by 2030. The team needs to consider the operational differences for BEBs and develop plans in achieving this goal.

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Introduction

Beginning in March 2014, Foothill Transit has been operating a fleet of 12 battery electric buses (BEBs) in its service area located in the San Gabriel and Pomona Valley region of Los Angeles County, California. These electric buses, produced by Proterra, are 35-foot, composite body buses that are capable of being charged quickly on route. Foothill Transit is collaborating with the California Air Resources Board (CARB) and the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) to evaluate the buses in revenue service. CARB, primarily through evaluations conducted by NREL, has been monitoring the development progress of zero-emission buses (ZBuses) being demonstrated in California and other parts of the United States. Most of the early NREL evaluations were focused on fuel cell electric buses (FCEBs). The introduction of opportunity fast charging addressed the early range issues that were a challenge for deployment of BEBs and resulted in a number of transit agencies adopting pure electric buses. To allow access to analysis and reporting on BEBs similar to what is available on FCEBs, CARB has enlisted NREL to conduct a third-party evaluation of the Foothill Transit fleet.

NREL has been evaluating advanced technology buses under funding from DOE and the U.S. Department of Transportation's Federal Transit Administration (FTA). NREL uses a standard data collection and analysis protocol originally developed for DOE heavy-duty vehicle evaluations. The objectives of these evaluations are to provide comprehensive, unbiased evaluation results of advanced technology bus development and performance compared to conventional baseline vehicles.

NREL published the first report on the Foothill Transit BEB fleet in January 2016; that report covered the initial data period of April 2014 to July 2015.[1] This report provides an update to the previous report with data from August 2015 through December 2016. Data are provided on a selection of compressed natural gas (CNG) buses as a baseline comparison. However, the CNG buses are operated on different routes at higher speeds, which may affect the ability to compare fuel economy results on an apples-to-apples basis.

Fleet Profile—Foothill Transit Agency

Foothill Transit serves a 327-square-mile area covering the San Gabriel and Pomona Valley region of Los Angeles County. Foothill Transit's administrative office is located in West Covina, California. Foothill Transit is governed by a Joint Powers Authority of 22 member-cities and the County of Los Angeles with representation from the following areas:

Arcadia	Azusa
Baldwin Park	Bradbury
Claremont	Covina
Diamond Bar	Duarte

[1] *Foothill Transit Battery Electric Bus Demonstration Results*, NREL/TP-5400-65274, www.nrel.gov/docs/fy16osti/65274.pdf.

El Monte	Glendora
Industry	Irwindale
La Puente	La Verne
Monrovia	Pasadena
Pomona	San Dimas
South El Monte	Temple City
Walnut	West Covina
Los Angeles County	

Foothill Transit operates 36 local and express routes including commuter runs to downtown Los Angeles. The current bus fleet consists of 353 CNG buses and 17 BEBs. Figure 1 shows the Foothill Transit service area.

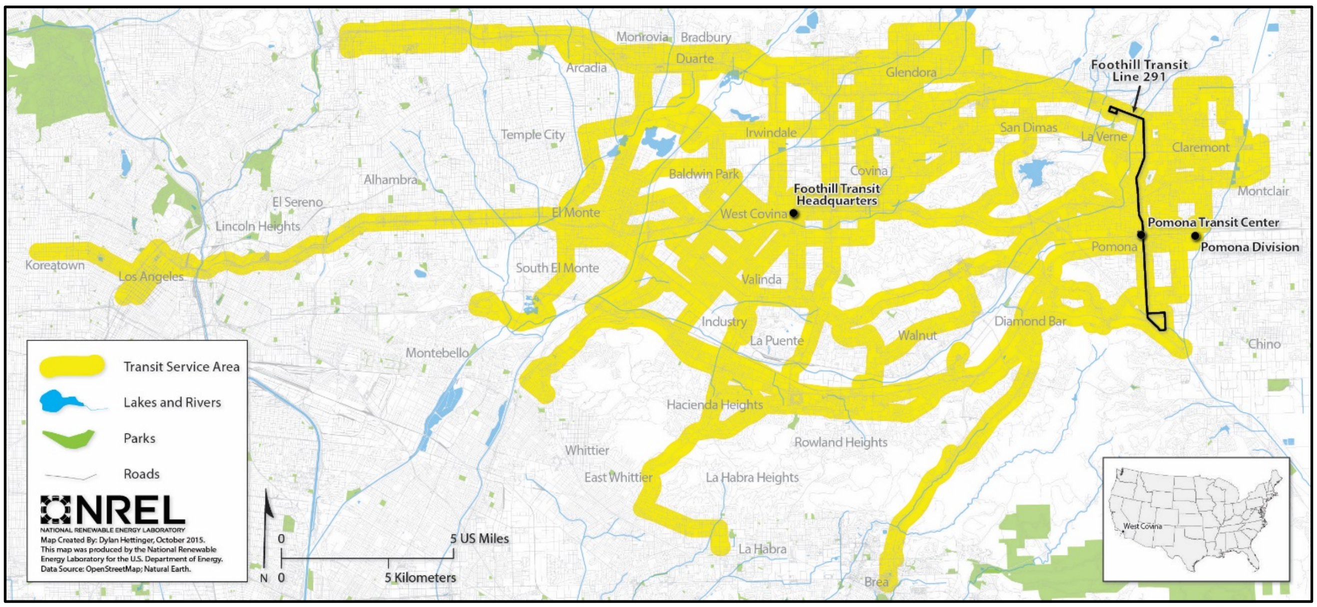

Figure 1. Foothill Transit service area

The agency began a path to cleaner buses in 2002 by adding CNG buses to its fleet. The agency retired its last diesel bus in 2013, making the fleet 100% alternative fuel. Foothill Transit's commitment to clean and efficient technologies has led the agency to initiate additional projects such as adding photovoltaic panels and making efficiency improvements to its facilities, installing a water-saving bus wash, and purchasing zero-emission BEBs.

Under California's Low Carbon Fuel Standard (LCFS) program, Foothill Transit benefits from operating the BEBs. The state has a goal of reducing the carbon intensity of transportation fuels ten percent by 2020. The LCFS promotes the use of fuels that reduce greenhouse gas emissions. The program uses a market-based credit trading system that allows entities such as Foothill Transit to generate credits for using low carbon fuels or operating ZBuses that can be sold on the open market to regulated parties to meet requirements. Over the study period (Q3 2015–Q4

2016), Foothill Transit earned approximately $126,000 of LCFS credits. Foothill Transit uses the funds generated by selling credits as extra income to use wherever needed. The funds generated vary depending on the current market.

Bus Technology Descriptions

The BEBs in service at Foothill Transit are 35-foot, composite body buses built by Proterra. In the commercialization process that begins at technology readiness level (TRL) 1—basic research/concept—and ends at TRL 9—commercial deployment, NREL considers the Proterra BEB to be at TRL 7. The design of the bus is a next-generation version based on lessons learned with earlier models and the deployment includes the 12-bus Foothill Transit fleet as well as numerous other fleets around the country. These buses represent a full-scale validation in a relevant environment. (Appendix A provides the TRL guideline table tailored for advanced technology bus commercialization.)

Selecting a comparable baseline bus for a project can be challenging, especially when evaluating a unique design such as the Proterra BEB. Foothill Transit does not operate conventional buses that are similar in size, weight, and year to the BEBs. In addition, the CNG buses are randomly dispatched on all routes whereas the BEBs operate only on a couple of specific local routes. As a result, the BEBs' duty cycle is slower with more stops. The primary baseline buses selected are NABI CNG buses of the same model year as the BEBs. Like the BEBs, the NABI CNG buses are under warranty and should have very low maintenance costs. The NABI CNG buses have Cummins engines with a three-way catalyst. Table 1 provides bus system descriptions for the BEBs and CNG buses that were studied in this evaluation. Figure 2 shows one of the Proterra BEBs and Figure 3 shows one of the NABI CNG baseline buses.

Table 1. Battery Electric and CNG Bus System Descriptions

Vehicle System	BEB	CNG
Number of buses	12	8
Bus manufacturer/model	Proterra/BE35	NABI/BRT-07.03
Model year	2014	2014
Length/width/height	35 ft/102 in./129 in.	42 ft/102 in./137 in.
GVWR/curb weight	37,320 lb/27,680 lb	42,540 lb/33,880 lb
Wheelbase	237 in.	308 in.
Passenger capacity	35 seats, 2 wheelchair positions, 18 standees	38 seats, 2 wheelchair positions, 10 standees
Motor or engine	Permanent magnet, UQM, PP220	CNG engine, Cummins, 8.9 ISL G
Rated power	220 kW peak (295 hp)	280 hp @ 2,200 rpm
Energy storage (BEB) Fuel capacity (CNG)	Lithium-titanate batteries, Altairnano, TerraVolt 368 volts, 88 kWh total energy	7 Type IV cylinders, 22,204 scf at 3,600 psi
Accessories	Electric	Mechanical
Emissions equipment	N/A	3-way catalyst
Transmission/retarder	Regenerative braking	N/A
Bus purchase cost	$904,490	$575,000

Figure 2. Foothill Transit Proterra BEB

Figure 3. Foothill Transit NABI CNG bus

The warranty for the BEBs is included in the bus purchase cost and covers the following:

- Bumper to bumper—2 years
- Powertrain subsystem—5 years
- Major subsystems—3 years
- Main structure—12 years
- Battery warranty—6 years.

Foothill purchased the buses in 2013 with delivery in 2014. The purchase cost for BEBs continues to decrease over time. Foothill reports that the per-bus purchase cost for its orders of BEBs has dropped from $1.2 million to just under $800,000. Table 2 provides costs for the four orders of BEBs for Foothill. Proterra reports that the current base cost of a 40-foot BEB is approximately $730,000 (before taxes).

Table 2. Foothill Transit's BEB Fleet Purchase Cost (nominal dollars)

Order Number	Number of Buses	Bus Description	Purchase Year	Cost per Bus
1	3	35-ft BE35 fast charge buses	2009	$1,200,000
2	12	35-ft BE35 fast charge buses	2013	$904,490
3	2	40-ft Catalyst fast charge buses	2014	$825,000
4	13	40-ft Catalyst extended range buses	2015	$789,000

Charging and Maintenance Facilities

The BEBs and CNG buses are operated out of Foothill Transit's Pomona Operations and Maintenance Facility. Foothill Transit provides operation and maintenance of its fleet through contracts with private firms. Maintenance staff at the division handle all maintenance work on the CNG buses and cover safety inspections, general bus maintenance, and some preventive maintenance for the BEBs. Proterra has two on-site technicians that handle all warranty work on the BEBs. At the end of each day, operators typically charge the BEBs at the Pomona Transit Center (PTC) prior to returning to the depot. Foothill Transit uses an in-depot charger at the operations and maintenance facility for times when a bus needs charging after a going through maintenance or repairs. The installation of this in-depot charger was the only modification needed to allow maintenance of the BEBs inside the facility. A new in-depot charger costs $50,000. Proterra reports that the cost of these chargers continues to drop since adopting the industry standard charger protocol (SAE J1772). Foothill Transit also added a fast charger to this facility at a cost of $665,000 (charger and installation).

Fast-Charge Station

Foothill Transit's fast-charge station is located at the PTC. The station consists of a climate controlled building that holds two Eaton 500 kW chargers, with two charge heads located on opposite sides of the building. The two chargers operate as separate units with a dedicated control system for each. A common communication network serves both units with sensors to detect which charge head a bus is approaching to enable proper bus-to-charger communication for docking. Emergency shut-off switches for each charge head are located on both sides of the building. Figure 4 shows the fast-charge station with two BEBs at the charging heads. The building that houses the chargers and equipment is in the center.

Figure 4. BEB charging station at the PTC

The system can charge two buses simultaneously. Docking a bus with the charging head occurs semi-autonomously and the operator does not have to exit the bus to make any connections. The system is designed to fully charge a bus in less than ten minutes. For Foothill Transit's Line 291, typical charge times are around seven minutes. Foothill Transit built a layover time into the schedule to allow enough time for charging. Foothill Transit has a contract with Proterra to maintain the chargers and associated equipment. The cost for this service is $1,500 per month. The agency is adding another fast charger at the Azusa Intermodal Transit Center. The new charging station will allow the agency to expand the service of the BEBs to additional routes.

Foothill Transit reports that its experience with the charging station has been exceptional and there have been very few issues. Since the project began, the buses have been charged 119,150 times. Because the station has two separate charging heads, there was no time when the buses could not operate. The availability of the two charging heads has been 98% and 99% since the beginning of the project. The biggest challenge was avoiding the higher electricity demand charges that would go into effect if two buses were being charged simultaneously. Proterra solved this issue through a software modification.

In-Service Operations Evaluation Results

The previous report included data from April 2014 through July 2015. The results presented in this section focus on data from August 2015 through December 2016. During the latest data period, the BEBs operated 501,037 miles over 58,497 hours of operation. This indicates an overall operational speed of 8.6 mph. (Appendix B provides a summary of data for this report data period and for the entire in-service period. Appendix C provides a data summary in metric units. Appendix D includes graphs for each evaluation metric that encompasses all data from the beginning of the evaluation.)

Route Assignments

Foothill Transit's BEB fleet operates out of its Pomona Operations and Maintenance Facility. The service consists of 21 routes: fifteen local and six commuter/express routes. The agency operates the BEB fleet primarily on Line 291. This line is a 16.1-mile route that travels between La Verne and Pomona with minimal deadhead distance from the Pomona depot. The line serves a transit dependent community and has high ridership. The route loops through the PTC in both directions, making the PTC an ideal location for the fast charger system. Figure 5 shows the route map for Line 291.

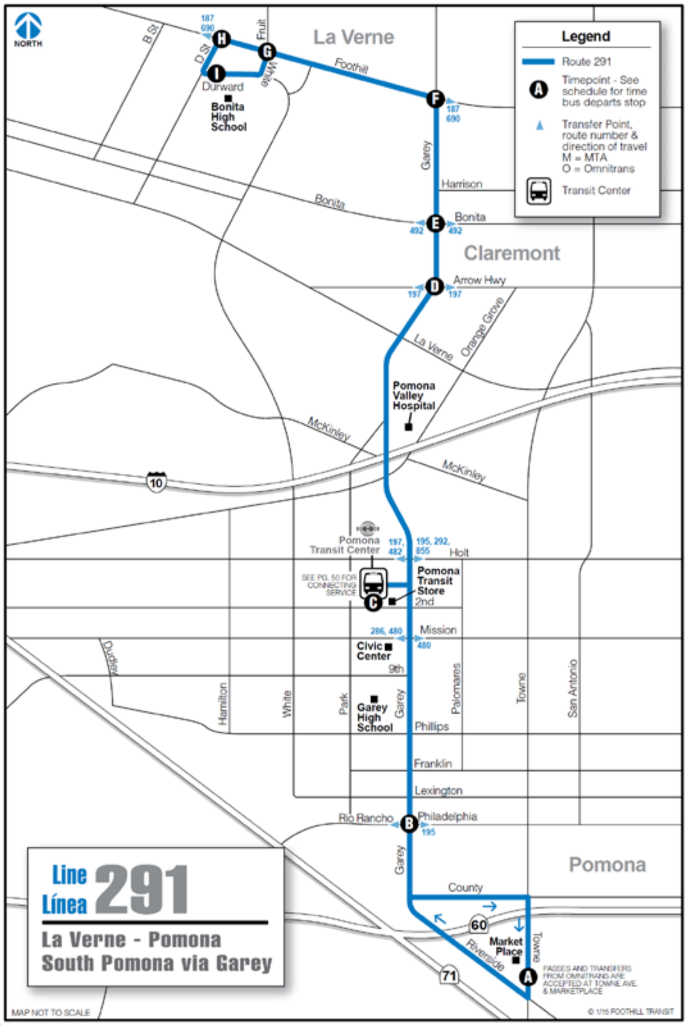

Figure 5. Route map for Line 291 (courtesy of Foothill Transit)

Based on Foothill Transit's schedule for the Pomona operations, in-service speed for Line 291 is 10.6 mph. The agency also operates the BEBs on Line 855 on most mornings. Line 855 runs through the PTC where the charger is located. The BEBs are not operated on Line 855 during the afternoons because those route blocks include service on commuter routes, which is beyond the current range of the buses. The CNG baseline buses are randomly dispatched on all of the routes out of the Pomona operations including commuter routes. Average in-service speed for the Pomona operations as a whole is 17.6 mph. Figure 6 outlines the difference in route assignment between the BEBs and the CNG buses. The routes serviced by the CNG buses include commuter routes that result in a higher average speed and greater mileage accumulation than for local routes. Because fuel economy is highly dependent on duty cycle, this has a significant impact on the fleet-average fuel economy discussed later in this report.

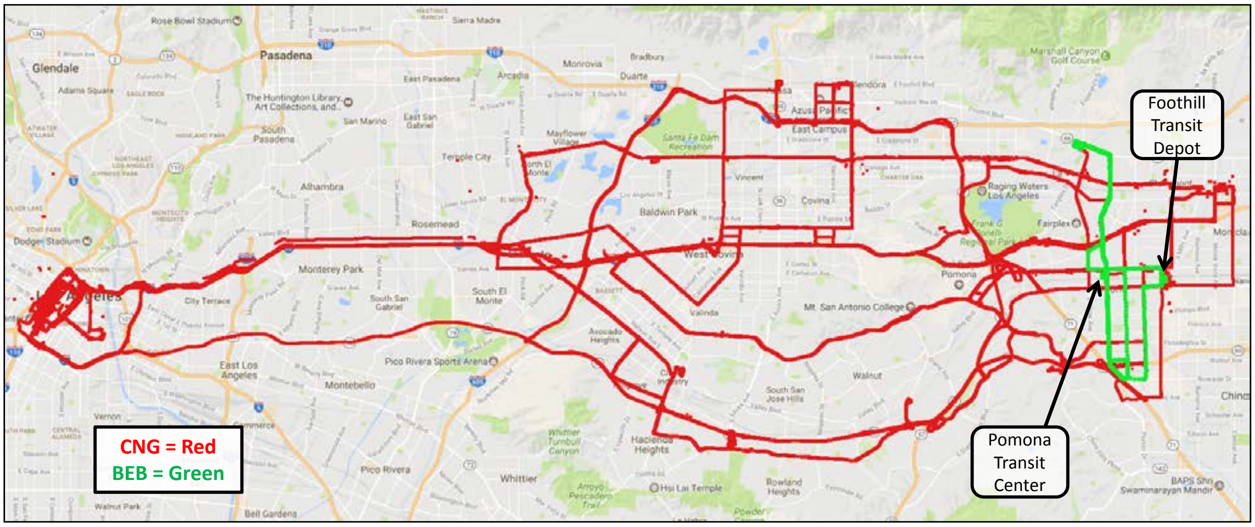

Figure 6. Routes traveled by randomly-dispatched CNG buses (red) and Line 291 traveled by the BEBs (green)

Bus Use and Availability

Bus use and availability are indicators of reliability. Lower bus usage may indicate downtime for maintenance or purposeful reduction of planned work for the buses. This section summarizes bus usage and availability for the BEBs and baseline buses.

Table 3 summarizes the average monthly mileage for the BEBs and CNG baseline buses for the data period. The average monthly operating mileage per bus for the BEBs during the evaluation period is 2,456 miles, which is about half that of the CNG buses. This is expected, considering that the BEBs are operated primarily on Line 291 and the CNG buses are randomly dispatched on all routes out of the Pomona facility, including express and commuter routes that have much higher average speeds. The results presented in this report are based on the planned route for the buses and do not indicate a specific limitation of the technology. Figure 7 tracks the monthly average miles for the BEBs and CNG buses for the data period.

Table 3. Average Monthly Mileage (Evaluation Period)

Bus	Total Mileage	Months	Average Monthly Mileage
BEB Fleet			
2004	42,067	17	2,475
2005	46,987	17	2,764
2006	44,742	17	2,632
2007	43,321	17	2,548
2008	43,666	17	2,569
2009	45,078	17	2,652
2010	42,448	17	2,497
2011	42,710	17	2,512
2012	39,896	17	2,347
2013	36,719	17	2,160
2014	40,384	17	2,376
2015	33,021	17	1,942
BEB Total	**501,039**	**204**	**2,456**
CNG Fleet			
2200	77,696	17	4,570
2201	83,182	17	4,893
2202	82,718	17	4,866
2203	84,575	17	4,975
2204	73,490	17	4,323
2205	82,498	17	4,853
2206	84,474	17	4,969
2207	87,766	17	5,163
CNG Total	**656,399**	**136**	**4,826**

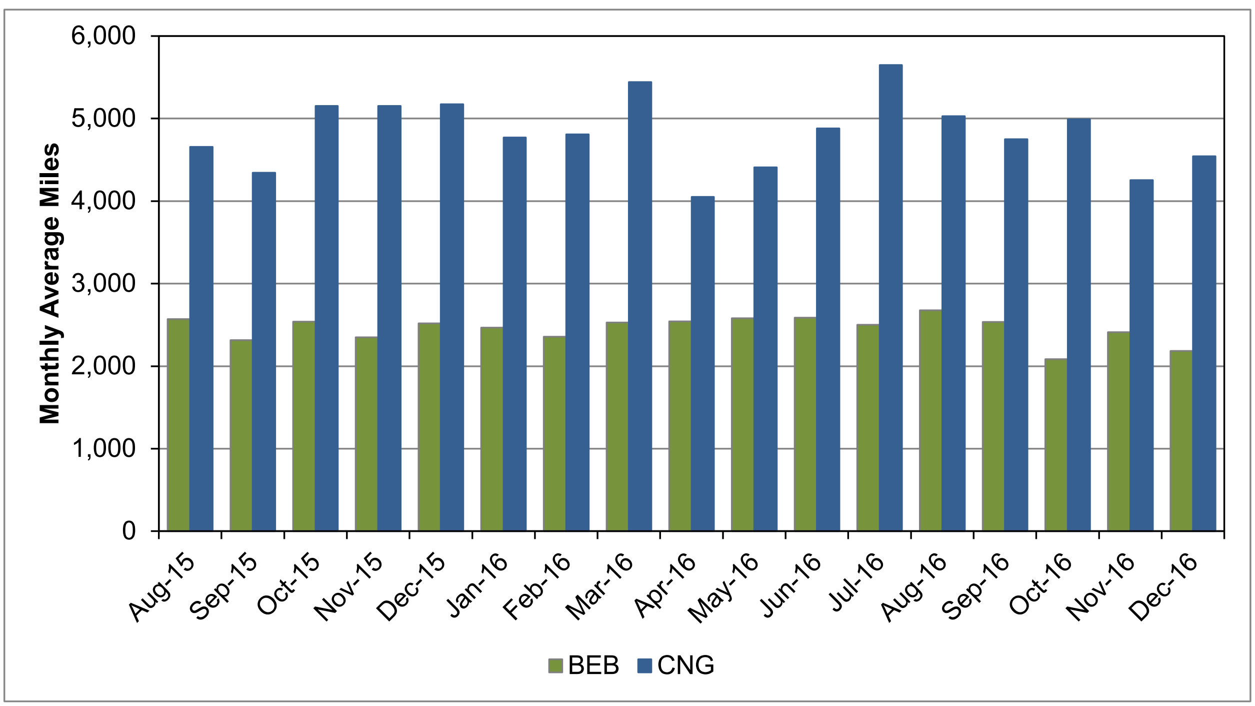

Figure 7. Monthly average miles for the Foothill Transit BEBs and CNG buses

Another measure of reliability is availability—the percentage of days the buses are actually available out of days that the buses are planned for operation. The data presented are based on availability for morning pull-out and don't 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. For the Foothill Transit fleet, the buses are planned to operate every day, including weekends. To calculate availability, NREL collected data from several sources. One source was the daily service reports that Proterra provides to Foothill Transit. These reports list the availability of each BEB for that day and outline any reasons for unavailability. Foothill Transit was able to provide approximately 83% of the daily service reports; this is considered to be a sufficient sample size to be representative of the total. Foothill Transit also provided the daily garage activity sheets for the Pomona facility, which list each bus that is not available for morning pull-out and provide a general reason for unavailability. These activity sheets are for the depot as a whole and include the BEBs as well as the CNG buses. This was the only source of availability data for the CNG buses. The garage activity sheets were not available for every day. During the data period, 61% of the activity sheets were available. Because these are new conventional technology buses, the CNG bus availability is expected to be high. With two data sources for the BEBs, NREL was able to account for more days in the analysis when compared to the CNG buses. As a result, the total planned days for the two fleets is not the same.

Table 4 summarizes the availability for the BEBs during the data period. The per-bus availability ranges from a high of 96% to a low of 84%. The overall average for the group is 90%.

Table 4. Summary of Availability by Bus for the BEBs

Bus	Planned Days	Available Days	Percent Availability
2004	408	375	92
2005	408	376	92
2006	408	383	94
2007	408	373	91
2008	408	352	86
2009	408	392	96
2010	408	350	86
2011	408	384	94
2012	408	372	91
2013	408	351	86
2014	408	354	87
2015	408	344	84
Total BEB	***4,895***	***4,406***	***90***

Figure 8 tracks the monthly availability for the BEBs (green line) and CNG buses (blue line) for the data period. The figure also provides an indication of the reasons for unavailability for the BEBs. The stacked bars for each month show the number of days the BEBs were not available by six categories. General bus system issues caused the majority of downtime for the BEBs, followed by electric drive system issues. The major drop in availability at the end of the data period was due to issues with three buses: one was involved in an accident and the other two had transmission repairs. The availability of the CNG buses dropped during the months of April and May 2016, and again in December 2016. The downtime during the first of those periods was due to accident repair for one of the baseline buses. The December 2016 downtime was primarily for engine work on three of the baseline buses.

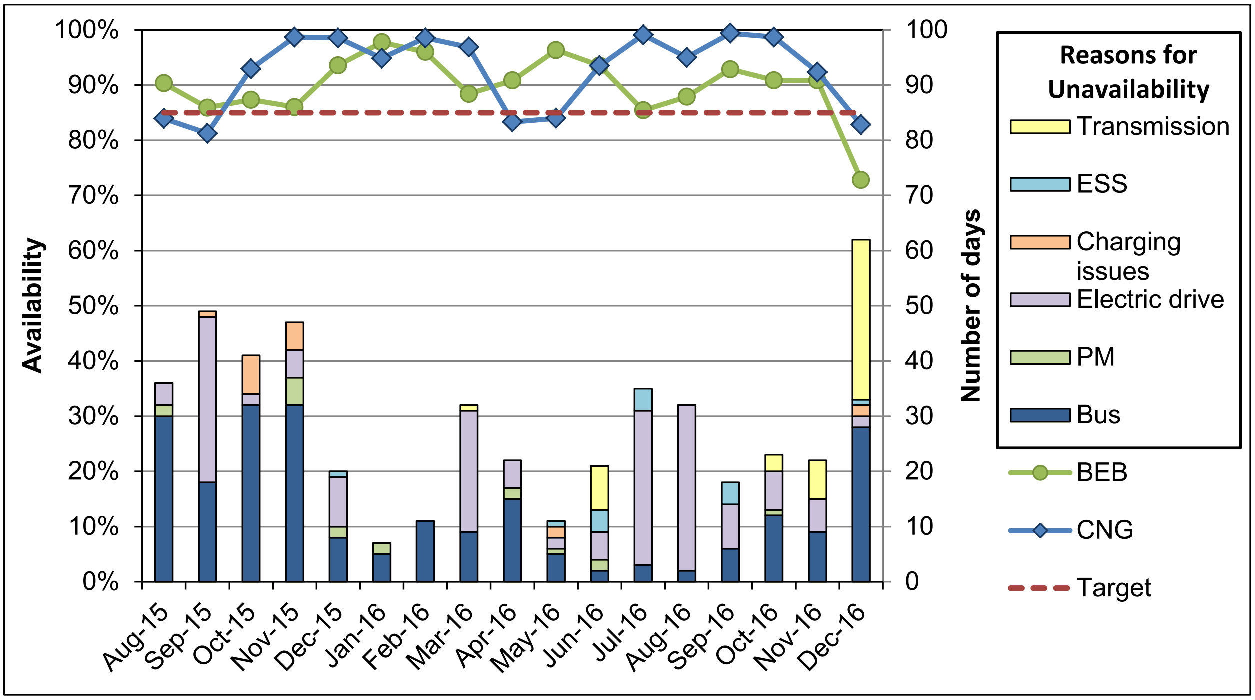

Figure 8. Availability for the BEBs and CNG buses

Table 5 summarizes the reasons for unavailability for the BEBs and CNG buses. During this reporting period, the average availability was 90% for the BEBs and 93% for the CNG buses. Figure 9 graphically presents the availability for the BEBs and Figure 10 presents the availability for the CNG buses.

Table 5. Summary of Availability and Unavailability of Buses for Service

Category	BEB # Days	BEB %	CNG # Days	CNG %
Planned work days	4,895		2,512	
Days available	4,406	90.0	2,326	92.6
Unavailable	**489**	**10.0**	**186**	**7.4**
ESS	15	0.3	—	—
CNG engine	—	—	28	1.1
Electric drive	165	3.4	—	—
Charging issues	17	0.3	—	—
Preventive maintenance	17	0.3	17	0.7
General bus maintenance	227	4.6	136	5.4
Transmission	48	1.0	5	0.2

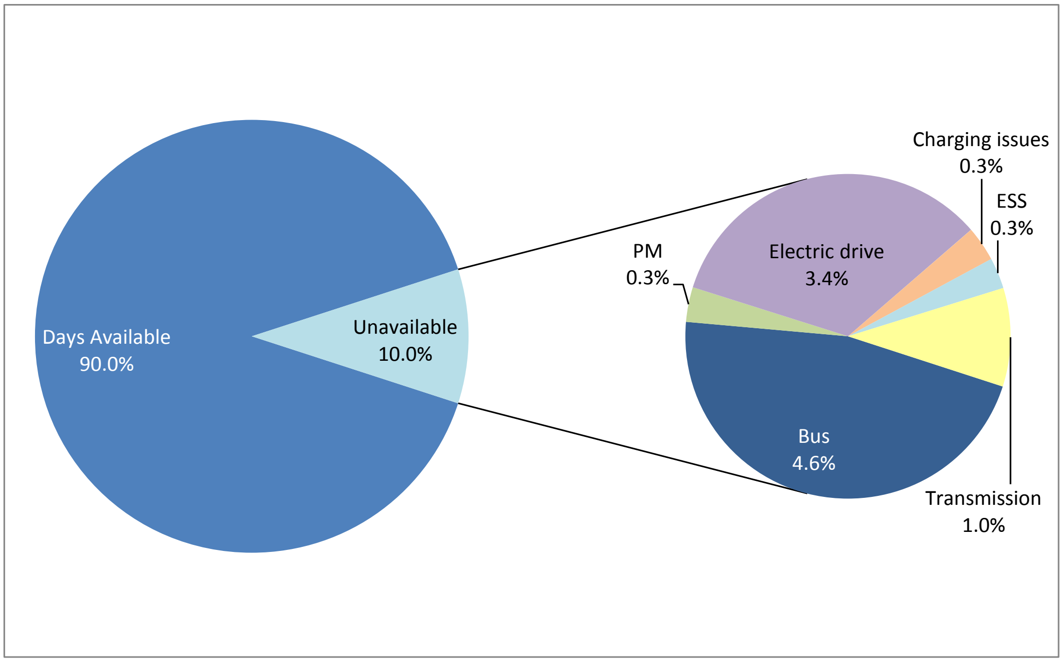

Figure 9. Reasons for unavailability for the Foothill Transit BEBs

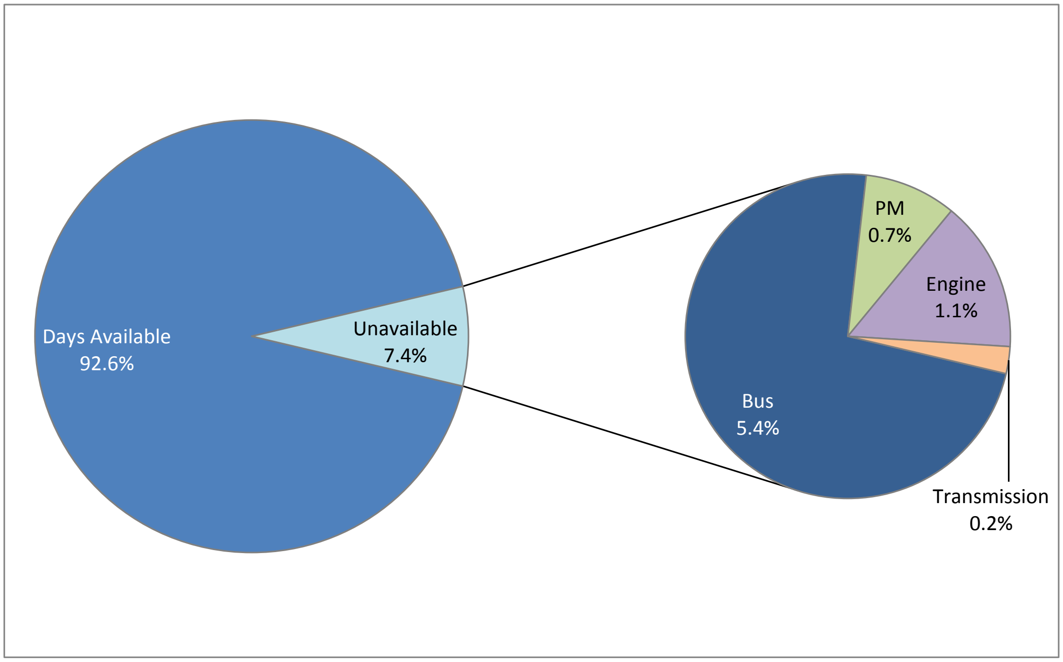

Figure 10. Reasons for unavailability for the Foothill Transit CNG buses

Energy Use, Fuel Economy, and Cost

Each BEB is typically charged every time it stops at the PTC. Figure 11 shows the total energy used and number of charges for the BEB fleet by month. During the data period, the fleet averaged 63,957 kWh and 3,335 charges per month.

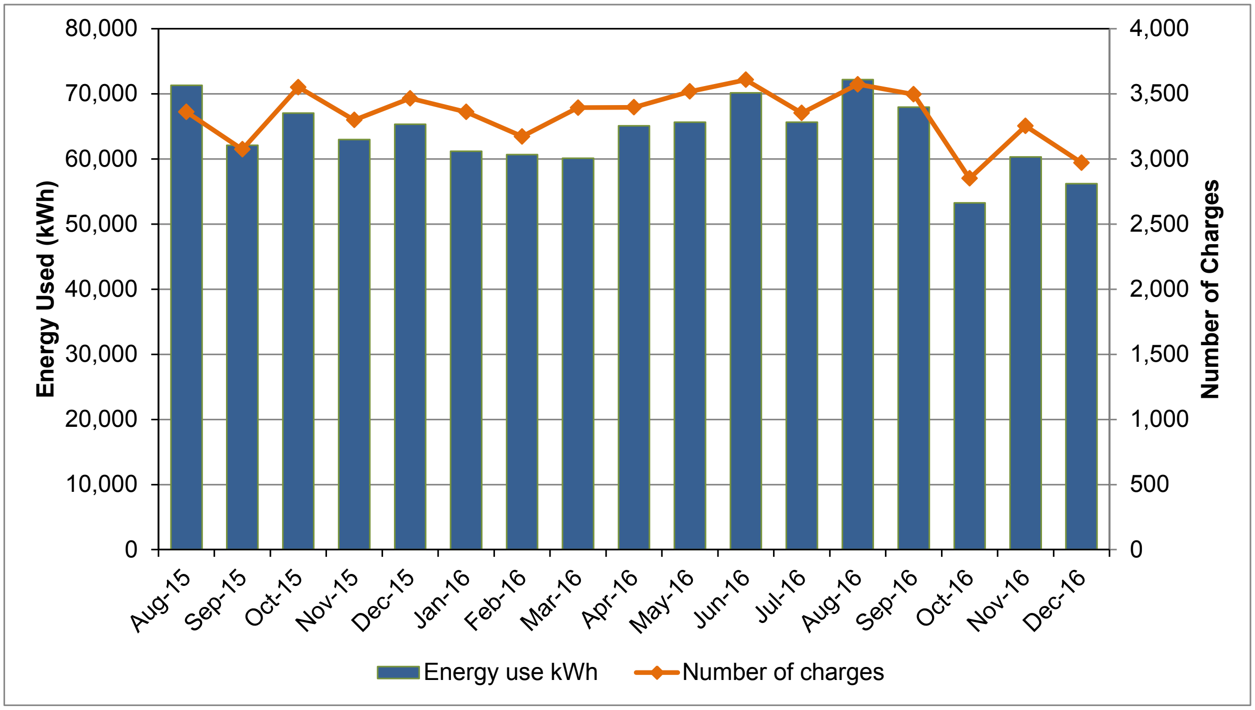

Figure 11. Monthly energy use and number of charges for the BEB fleet

Proterra records and stores data—including total kWh, number of charges, and miles driven—on each of the buses. These data were provided to NREL for calculating efficiency of the buses in kWh per mile. Foothill Transit's CNG buses are normally fueled once each day. Foothill Transit provided individual fueling records for the CNG buses. CNG is typically tracked in units of gasoline gallon equivalent (gge). NREL used these records to calculate the CNG fuel economy in miles per gasoline gallon equivalent (mpgge) as well as miles per diesel gallon equivalent (mpdge). To compare the BEBs to the baseline buses, NREL converted the kWh to diesel gallon equivalent (dge) using a conversion factor of 37.7 kWh/gallon. The explanation of the energy conversion from kWh of electricity to dge appears at the end of Appendix B. (Appendices B and C contain summary statistics for the BEBs and CNG buses.)

Table 6 shows electricity and CNG fuel consumption and equivalent fuel economy for the study buses during the reporting period. The BEBs had an overall average efficiency of 2.17 kWh per mile, which equates to 17.35 mpdge. The CNG buses had an average fuel economy of 3.89 mpgge, which equates to 4.34 mpdge. These results are for the fleets as Foothill Transit operates them, with the CNG buses at a higher average speed compared to the BEBs.

Table 6. Energy Use and Fuel Economy[2] (Evaluation Period)

Bus	Mileage (fuel base)	Electricity (kWh) or CNG (gge)	kWh per Mile or Miles per gge	Diesel Gallon Equivalent (mpdge)	Fuel Economy (mpdge)
BEB Fleet					
2004	42,067	91,699	2.18	2,435	17.28
2005	46,987	103,707	2.21	2,754	17.06
2006	44,742	100,057	2.24	2,657	16.84
2007	43,321	96,698	2.23	2,568	16.87
2008	43,666	95,169	2.18	2,527	17.28
2009	45,078	96,680	2.14	2,567	17.56
2010	42,448	90,619	2.13	2,406	17.64
2011	42,710	89,831	2.10	2,386	17.90
2012	39,896	86,664	2.17	2,301	17.34
2013	36,719	72,131	1.96	1,915	19.17
2014	40,384	86,123	2.13	2,287	17.66
2015	33,021	77,898	2.36	2,069	15.96
BEB Total	**501,037**	**1,087,276**	**2.17**	**28,873**	**17.35**
CNG Fleet					
2200	74,775	18,808	3.98	16,833	4.44
2201	77,607	21,230	3.66	19,001	4.08
2202	79,295	19,955	3.97	17,860	4.44
2203	83,726	21,965	3.81	19,659	4.26
2204	70,939	18,219	3.89	16,306	4.35
2205	81,630	20,135	4.05	18,021	4.53
2206	81,940	21,520	3.81	19,261	4.25
2207	85,006	21,535	3.95	19,274	4.41
CNG Total	**634,918**	**163,367**	**3.89**	**146,215**	**4.34**

Figure 12 shows monthly average fuel economy for the BEBs and CNG buses in mpdge. The monthly average high temperature is included in the graph to track any seasonal variations in the fuel economy due to heating or cooling of the bus, which would require additional energy.

[2] Average speed for the BEBs was 10.7 mph compared to 17.9 mph average speed for the CNG buses.

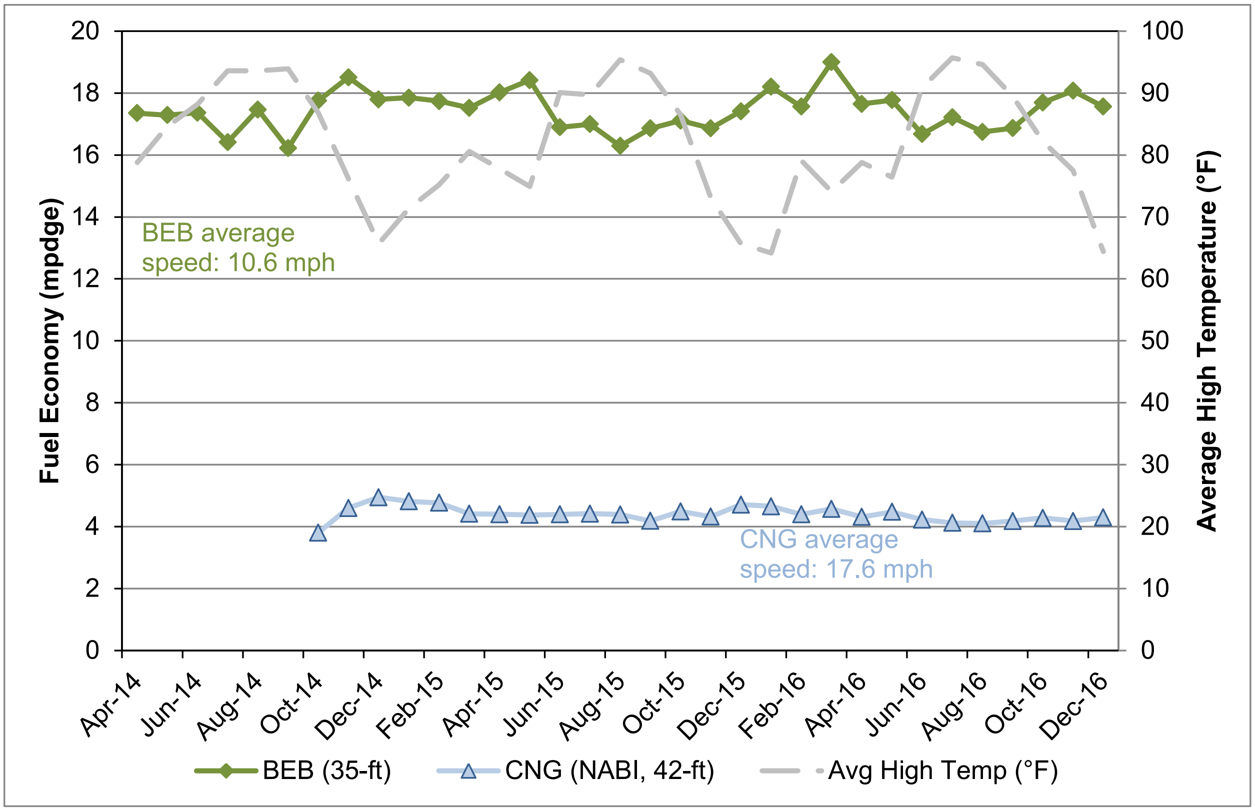

Figure 12. Monthly average fuel economy for the BEBs and CNG buses

Challenge of Comparing Technologies with Different Duty Cycles

The operating duty cycle of a bus has a significant effect on fuel economy. Because Foothill Transit operates its BEB and CNG bus fleets differently, the efficiency results presented above are not considered an apples-to-apples comparison. NREL works with its fleet partners to characterize their experience with advanced technology and does not request changes to the agency's planned operation. Because of this, a perfect comparison is not always possible.

As mentioned in the previous report, researchers on NREL's Fleet Test and Evaluation team were funded by DOE to collect and analyze detailed data on the BEBs to understand the overall use and effectiveness of the BEBs in transit fleet operations compared to operations of conventional counterparts in the same location. The results of the BEB drive cycle analysis were included in the previous report. To characterize the difference in duty cycle between the BEBs and conventional technology buses, the NREL Fleet Test and Evaluation team temporarily instrumented 12 CNG buses at Foothill Transit with data loggers to record detailed in-service drive cycle data in February and March of 2016. This data set contains more than 37,000 miles logged during a total of 212 days of bus operation. Foothill Transit randomly dispatched the instrumented CNG buses on routes throughout the Pomona service area. The data loggers also recorded two days of CNG operation on Line 291 to provide a direct comparison to the BEBs in this evaluation. This collaboration with the DOE-funded activity offers a unique opportunity to make a better comparison of efficiency between the BEB and CNG buses.

Figure 13 shows the daily average CNG fuel economy as a function of daily average *driving* speed from this detailed data set. *Driving* speed includes only the time a bus was in motion; it does not include bus stop or layover time but does include deadhead driving. On Line 291, the average CNG fuel economy was 2.1 mpdge and the average *driving* speed was 18.1 mph. The average CNG fuel economy for all other routes traveled in this data set was 3.5 mpdge and the average *driving* speed was 29.0 mph. Although only two days of CNG operation on Line 291 were recorded, the results follow the general correlation between *driving* speed and fuel economy.

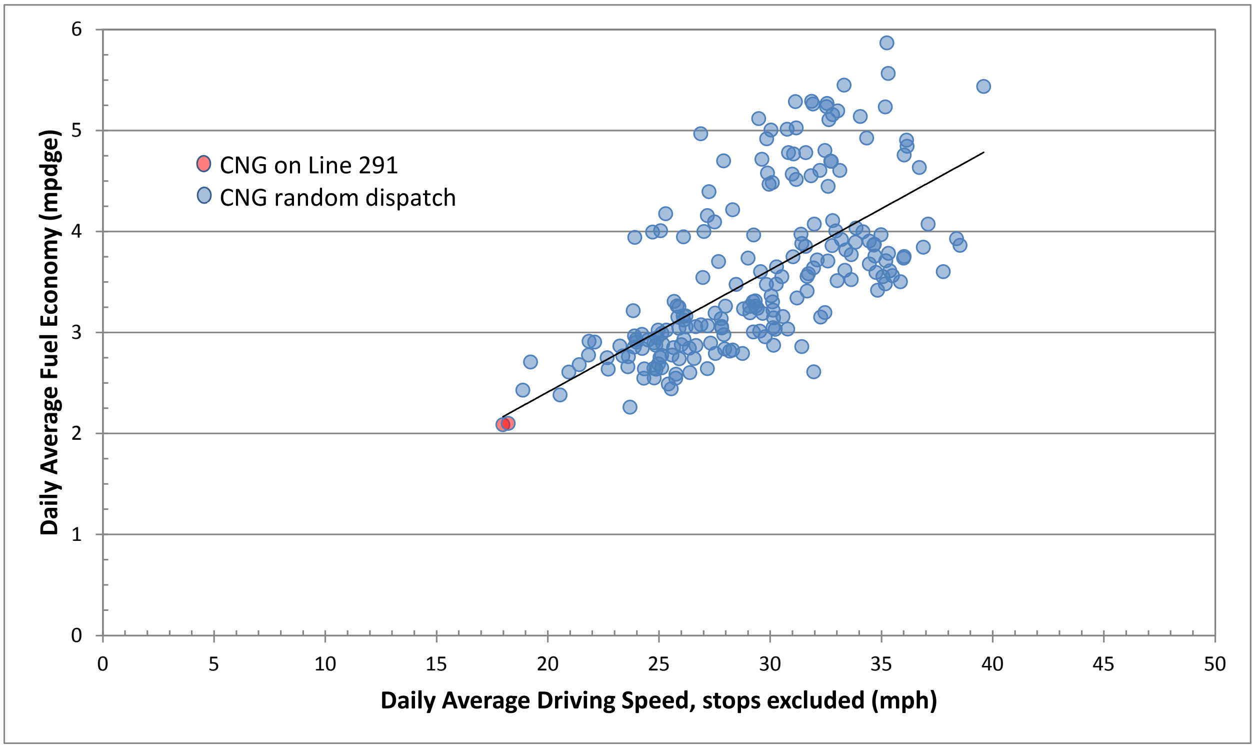

Figure 13. Fuel economy vs. average driving speed for the instrumented CNG buses

Table 7 provides a comparison of duty cycle and fuel economy for the BEBs and CNG buses using both fleet data and logged data. The table includes overall average speed (including stopped time) and average *driving* speed (without stops). The average *driving* speed (logged) for the BEBs and CNG buses is similar, indicating a more accurate comparison for fuel economy. When comparing the logged data, the BEB fuel economy is more than 8 times higher than that of a CNG bus operating exclusively on Line 291. The difference in overall average speed between the BEBs and CNG buses is likely due to the increased dwell time needed to charge the BEBs.

Table 7. Fuel Economy Comparison

Bus Type	Line	Average Speed, including stops (mph)	Average Driving Speed, excluding stops (mph)	Fuel Economy (mpdge)
BEB (fleet)	291, 855	10.6	—	17.35
BEB (logged)	291, 855	7.0	17.8	17.48
CNG (fleet)	Random dispatch	17.6	—	4.34
CNG (logged)	291	9.5	18.1	2.09
CNG (logged)	Random dispatch	19.2	29.0	3.49

The remainder of this report presents the results from the BEBs and baseline buses in this evaluation as they are currently operated by Foothill Transit in real revenue service. Other transit agencies interested in deploying BEBs will likely take a similar approach of first operating BEBs on a shorter, local route before expanding BEB service.

Fuel Cost and Charging Efficiency

Foothill Transit's charging station was installed with a separate utility meter. Foothill Transit provided the monthly utility bills to NREL to determine the energy cost. Time of use and demand charges factor into the cost of electricity for Foothill Transit. When the first three BEBs were deployed, Proterra and Foothill Transit were concerned that the maximum demand would exceed 500 kW. Each of the fast chargers at the Pomona Transit Center is rated at 500 kW, allowing the possibility of exceeding the 500 kW threshold. Customers that exceed the 500 kW limit are moved onto an industrial schedule (TOU-8[3]), which has high demand charges. This would result in much higher costs for the agency. Proterra petitioned the California Public Utilities Commission to help address this issue for Foothill Transit and other transit agencies considering fast-charge buses. The California Public Utilities Commission issued resolution E-4514,[4] which allowed Foothill Transit to stay on the small commercial schedule (TOU-GS-1) that has no demand charges. Typically, this rate schedule is only applicable to customers that demand less than 20 kW. That exemption expired at the end of 2015.

Southern California Edison has established additional rate schedules specifically for customers using electric vehicles. TOU-EV-4[5] is applicable to customers whose monthly demand is between 20 kW and 500 kW. Foothill Transit worked with Proterra to implement charge management software that controls the charging demand to stay under the 500 kW threshold. The combination of rate schedule and charge management resulted in a lower electricity cost for the agency in the most recent data period. Table 8 shows the costs for Foothill Transit during both data periods.

[3] https://www.sce.com/NR/sc3/tm2/pdf/ce54-12.pdf
[4] http://docs.cpuc.ca.gov/publisheddocs/published/g000/m032/k702/32702823.pdf
[5] https://www.sce.com/NR/sc3/tm2/pdf/ce141-12.pdf

Table 8. Foothill Transit Electric Costs

Rate Schedule	TOU-GS-1 Exemption	TOU-EV-4 With Charge Management
Period	4/14–12/15	1/16–12/16
Cost/kWh ($)	$0.175	$0.170
Cost/mi ($)	$0.44	$0.42

During this reporting period, the electricity price averaged $0.17 per kWh. Based on energy used by the buses, the energy cost for the BEB fleet calculates to $0.37 per mile. When taking into account the actual amount of electricity Foothill Transit purchased from the utility, the cost is $0.41 per mile. The difference of approximately 10% reflects the energy lost during charging.

Foothill Transit pays different electricity rates for summer and winter months. During the reporting period, the average price was $0.15 per kWh for the winter months (October–May) and $0.20 per kWh for the summer months (June–September). These electricity rates resulted in average energy costs of $0.37 per mile and $0.52 per mile during the winter and summer, respectively.

The CNG fuel cost during the reporting period averaged $0.96 per gge, which calculates to $0.25 per mile for the NABI CNG buses as operated by Foothill Transit (average speed 17.6 mph). Figure 14 shows the monthly average energy cost per mile for the BEBs and CNG buses, as well as the monthly average high temperature. The gray sections indicate the summer months during which Foothill Transit pays higher seasonal electricity rates. The electricity rates were the primary cause of the increases in per-mile energy costs for the BEBs during the summer. Per-mile fuel costs for the CNG buses remained relatively stable during the reporting period. For comparison, the chart includes an estimate of the cost per mile for the CNG buses if they operated only on Line 291. NREL used the monthly miles for the baseline CNG buses and calculated fuel use with the fuel economy logged from the CNG bus on Line 291. The lower fuel economy would increase the cost to an overall average of $0.50 per mile, which is higher than the cost of the BEB fleet. Because of the seasonal rates for electricity, the cost per mile for the BEBs is lower during the winter months and higher in the summer.

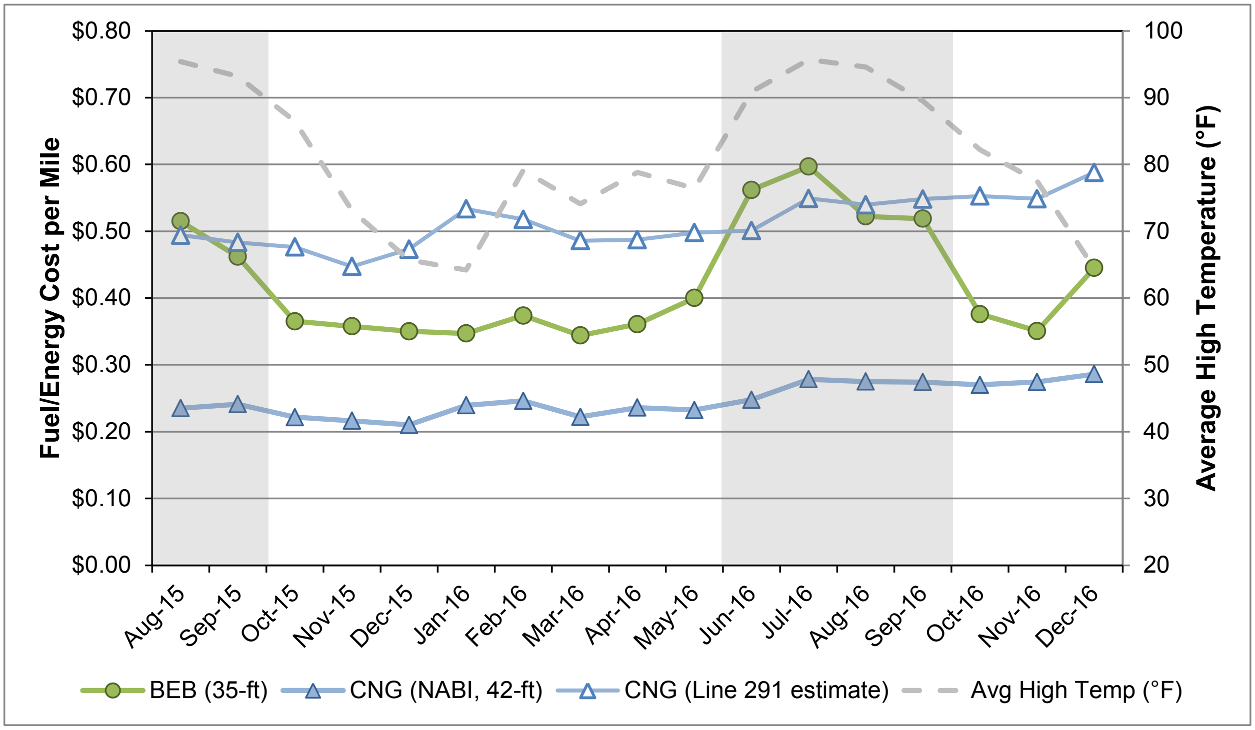

Figure 14. Monthly average energy cost per mile for the BEBs and CNG buses

Figure 15 shows the overall monthly charging efficiency for the BEBs based on the total energy consumption of the fleet (recorded by the buses) and the total energy purchased for the charging station (per the utility bills). These monthly totals are based on the utility billing periods and do not exactly match the calendar months. The overall charging efficiency is normally between 88% and 90%. September 2016 results were omitted from the chart due to insufficient data.

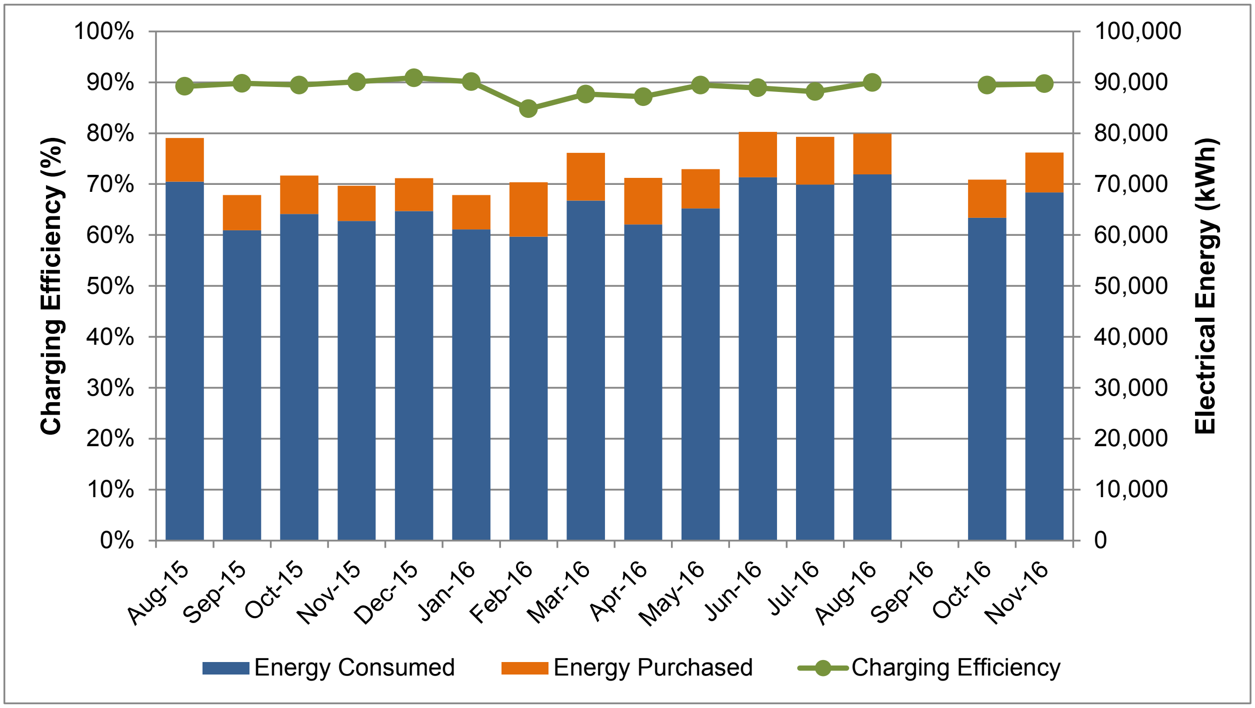

Figure 15. Monthly energy consumption and overall charging efficiency for the BEBs

Roadcall Analysis

A roadcall or revenue vehicle system failure (as named in the National Transit Database[6]) 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, air system), engine, 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 miles between roadcalls (MBRC). Table 9 provides the MBRC for the BEBs and CNG buses categorized by bus roadcalls, propulsion-related roadcalls, and ESS-related roadcalls. Propulsion-related roadcalls include all roadcalls due to propulsion-related systems including the battery system (or engine for a conventional bus), electric drive, fuel, exhaust, air intake, cooling, non-lighting electrical, and transmission systems. The ESS-related roadcalls and MBRC are included for the BEBs. This roadcall analysis includes data accumulated since the clean point of April 2014.

[6] National Transit Database website: www.ntdprogram.gov/ntdprogram/.

Table 9. Roadcalls and MBRC (from Clean Point)

	BEB	CNG
Dates	4/14–12/16	10/14–12/16
Mileage	902,281	1,020,772
Average miles accumulated per bus	75,190	127,597
Bus roadcalls	146	35
Bus MBRC	6,180	29,165
Propulsion-related roadcalls	55	18
Propulsion-related MBRC	16,405	56,710
ESS-related roadcalls	3	
ESS-related MBRC	300,760	

Figure 16 presents the cumulative MBRC by category for the BEBs and CNG baseline buses. DOE and FTA have not established performance targets specific to BEBs, but the MBRC targets established for FCEBs[7] were based on typical conventional buses and the targets could be considered appropriate for any advanced technology. The ultimate target for bus MBRC (4,000) is included in the upper plot of Figure 16 as a red dashed line. The ultimate target for fuel-cell-system-related MBRC is 20,000. This is considered comparable to roadcalls for BEBs that are related to the battery, or ESS. The ESS MBRC target is shown as a red dashed line in the lower plot of Figure 16. At this stage of demonstration, the Foothill Transit BEBs have achieved an ESS MBRC that is significantly higher than the target.

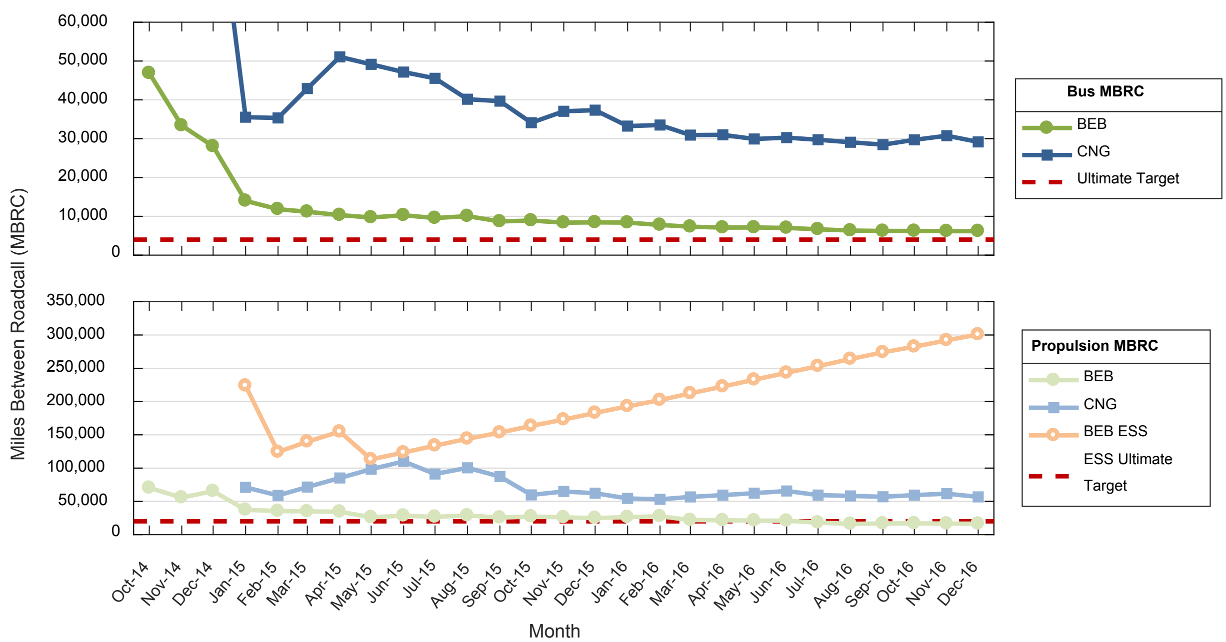

Figure 16. Cumulative MBRC for the BEBs and CNG buses

[7] Fuel Cell Technologies Program Record # 12012, Sept. 2012, www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf.

Maintenance Analysis

NREL collected all work orders for the study buses for this evaluation. Costs for accident-related repair, which are extremely variable from bus to bus, were eliminated from the analysis for both BEB and CNG bus fleets. Warranty costs were also removed from the cost-per-mile calculations. For consistency, NREL uses a constant maintenance labor rate of $50 per hour; this does not reflect an average rate for Foothill Transit. This section first covers total maintenance costs and then maintenance costs by bus system.

At the beginning of the project, Proterra technicians performed all maintenance on the BEBs. In January 2015, the Foothill Transit contractor staff took over the preventive maintenance inspections (PMI) and general bus work. This has remained constant throughout the report data period.

Total Work Order Maintenance Costs

Total maintenance costs include the price of parts and labor rates at $50 per hour. Cost per mile is calculated as follows:

Cost per mile = [(labor hours * 50) + parts cost] / mileage

Table 10 shows total maintenance costs for the BEBs and CNG buses. Scheduled and unscheduled maintenance cost per mile is provided for each bus and study group of buses. During the reporting period, the BEBs had a maintenance cost per mile that was slightly lower (4.9% less) than that of the CNG buses.

Table 10. Total Work Order Maintenance Costs (Evaluation Period)

Bus	Mileage	Parts ($)	Labor Hours	Total Cost per Mile ($)	Scheduled Cost per Mile ($)	Unscheduled Cost per Mile ($)
BEB Fleet						
2004	42,067	$5,428.16	101.2	$0.25	$0.07	$0.18
2005	46,987	$3,407.96	87.4	$0.17	$0.07	$0.10
2006	44,742	$4,676.79	106.8	$0.22	$0.07	$0.15
2007	43,321	$4,695.32	104.2	$0.23	$0.07	$0.16
2008	43,666	$5,446.82	93.0	$0.23	$0.07	$0.16
2009	45,078	$2,889.02	104.7	$0.18	$0.07	$0.11
2010	42,448	$2,744.76	100.1	$0.18	$0.07	$0.11
2011	42,710	$4,575.00	92.9	$0.22	$0.07	$0.15
2012	39,896	$2,053.03	115.7	$0.20	$0.07	$0.13
2013	36,719	$1,462.05	82.7	$0.15	$0.07	$0.08
2014	40,384	$4,395.14	100.8	$0.23	$0.07	$0.17
2015	33,021	$3,814.02	76.4	$0.23	$0.06	$0.17
Average BEB	***41,753***	***$3,799.01***	***97***	***$0.21***	***$0.07***	***$0.14***
CNG Fleet						
2200	77,696	$14,027.80	177.9	$0.30	$0.12	$0.17
2201	83,182	$8,275.39	182.0	$0.21	$0.11	$0.10
2202	82,718	$7,364.37	169.0	$0.19	$0.11	$0.08
2203	84,575	$12,465.90	153.9	$0.24	$0.12	$0.12
2204	73,490	$8,340.69	141.3	$0.21	$0.10	$0.11
2205	82,498	$8,360.75	175.7	$0.21	$0.11	$0.10
2206	84,474	$7,286.81	139.2	$0.17	$0.13	$0.04
2207	87,766	$9,996.05	178.9	$0.22	$0.12	$0.09
Average CNG	***82,050***	***$9,514.72***	***165***	***$0.22***	***$0.11***	***$0.10***

The monthly scheduled and unscheduled maintenance cost per mile for the BEBs and CNG buses are shown as stacked columns in Figure 17. Scheduled maintenance for the BEBs was fairly consistent over the data period. The CNG buses typically have higher scheduled maintenance costs per mile than the BEBs and lower unscheduled costs per mile.

The average monthly odometer reading for each fleet is included in the figure. In April 2016, six of the CNG buses reached the mileage target for a major PMI, resulting in a spike for both scheduled and unscheduled maintenance costs for that month. Also during that month, Foothill Transit conducted tune-ups on five of the CNG buses.

The higher unscheduled maintenance costs for the BEBs in October and November 2016 were primarily due to tire replacements, troubleshooting for a low voltage electrical issue, and towing charges. The cost for tire damage, which is not related to the electric drive technology, accounted for $0.07/mi of the overall cost of the BEBs.

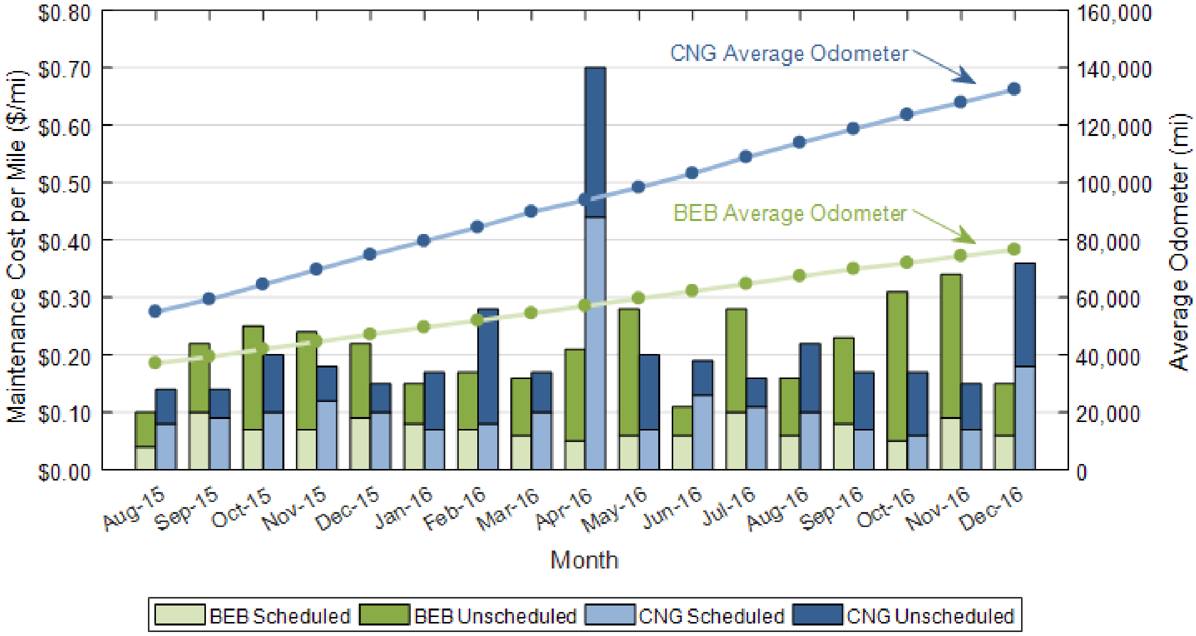

Figure 17. Monthly scheduled and unscheduled maintenance costs per mile for the BEBs

Work Order Maintenance Costs Categorized by System

Table 11 shows maintenance costs by vehicle system and bus study group (without warranty costs). The vehicle systems shown in the table are as follows:

- **Cab, body, and accessories**: Includes body, glass, cab and sheet metal, seats and doors, and accessory repairs such as hubodometers and radios
- **Propulsion-related systems**: Repairs for exhaust, fuel, engine, electric motors, battery modules, propulsion control, non-lighting electrical (charging, cranking, and ignition), air intake, cooling, and transmission
- **PMI**: Labor for inspections during preventive maintenance
- **Brakes:** Includes brake pads, disks, calipers, anti-lock braking system, and brake chambers
- **Frame, steering, and suspension**
- **HVAC**
- **Lighting**
- **Air system, general**
- **Axles, wheels, and drive shaft**
- **Tires**
- **Towing charges.**

Table 11. Work Order Maintenance Cost per Mile by System (Evaluation Period)

System	BEB		CNG	
	Cost per Mile ($)	Percent of Total (%)	Cost per Mile ($)	Percent of Total (%)
Propulsion-related	0.02	10	0.07	32
Cab, body, and accessories	0.03	17	0.04	21
PMI	0.07	33	0.05	24
Brakes	0.00	0	0.00	2
Frame, steering, and suspension	0.00	0	0.00	0
HVAC	0.00	1	0.01	4
Lighting	0.00	1	0.00	0
Air, general	0.00	0	0.02	7
Axles, wheels, and drive shaft	0.00	1	0.00	1
Tires	0.07	34	0.02	9
Towing charges	0.01	3	0.00	1
Total	***0.21***	*100*	***0.22***	*100*

The top three systems with the highest percentage of maintenance costs for the BEBs were (in order from highest to lowest) tires; PMI; and cab, body, and accessories. For the CNG buses the three systems with the highest percentage of maintenance costs were propulsion-related; PMI; and cab, body, and accessories. Figure 18 shows the monthly maintenance cost per mile by system for the BEBs. Figure 19 presents the same data for the CNG buses.

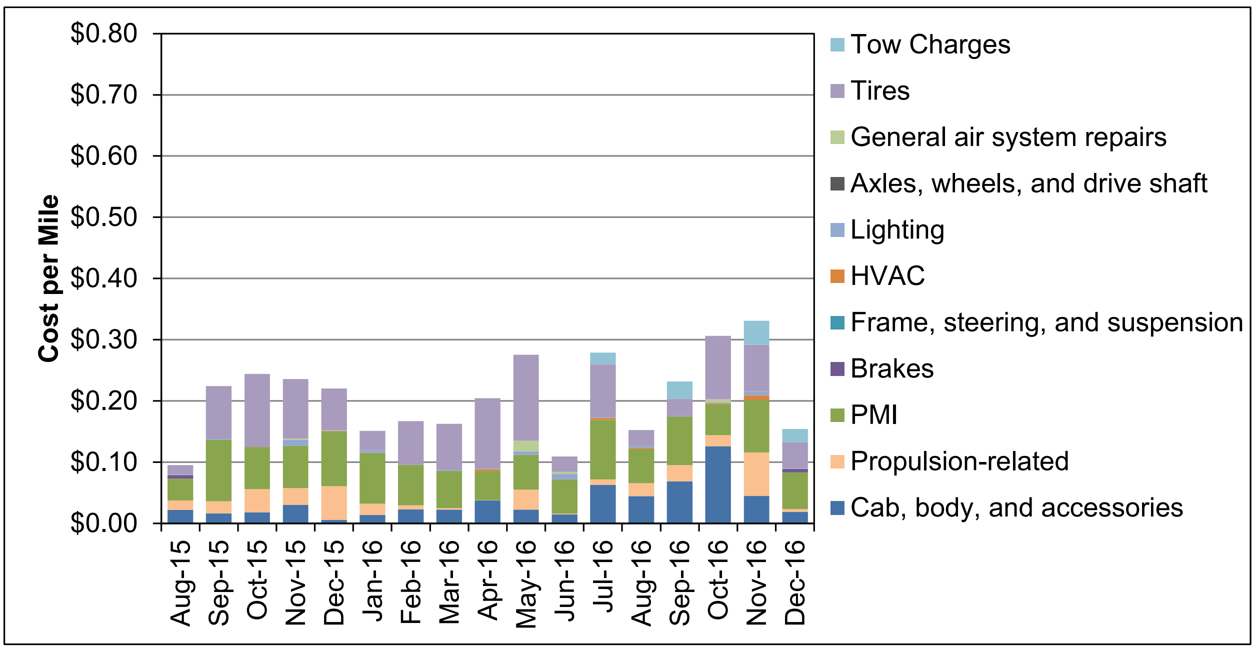

Figure 18. Monthly maintenance cost per mile by vehicle system for the BEBs

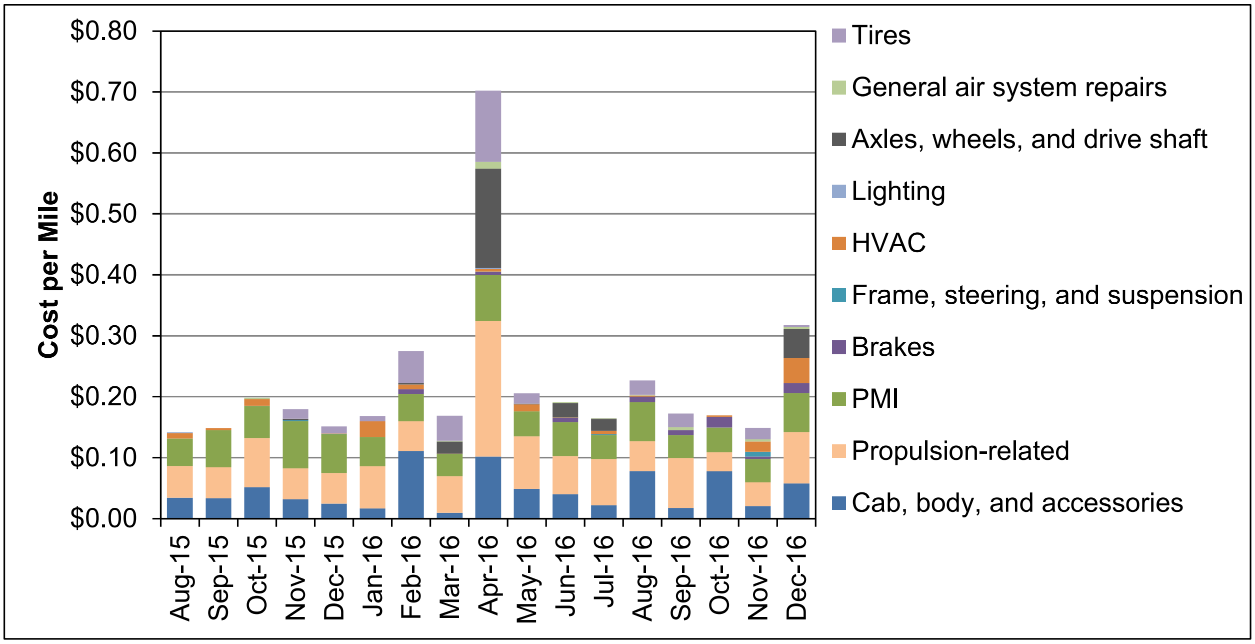

Figure 19. Monthly maintenance cost per mile by vehicle system for the CNG buses

Propulsion-Related Work Order Maintenance Costs

Propulsion-related vehicle systems include the exhaust, fuel, engine, battery modules, electric propulsion, air intake, cooling, non-lighting electrical, and transmission systems. These vehicle subsystems have been separated to highlight how maintenance costs for the propulsion system are affected by the change from conventional technology (CNG) to advanced technology (batteries).

Table 12 shows the propulsion-related system maintenance by category. During the data period, the propulsion-related maintenance costs for the BEBs were 68% lower than that of the CNG buses; however, the costs for both groups were low overall. 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 subsystem parts costs, while air filters are included in the air intake subsystem parts costs.

Table 12. Propulsion-Related Work Order Maintenance Costs by System (Evaluation Period)

Maintenance System		BEB	CNG
Total mileage		501,037	656,399
Average miles per bus		75,190	127,597
Total propulsion-related systems (roll-up of subsystems below)	Parts cost ($)	6,842.25	34,141.06
	Labor hours	80.3	220.1
	Total cost ($)	10,855.75	45,146.06
	Total cost ($) per mile	**0.02**	**0.07**
Exhaust system repairs	Parts cost ($)	0.00	157.20
	Labor hours	0.0	1.5
	Total cost ($)	0.00	232.20
	Total cost ($) per mile	**0.00**	**0.00**
Fuel system repairs	Parts cost ($)	0.00	487.89
	Labor hours	0.0	18.7
	Total cost ($)	0.00	1,422.89
	Total cost ($) per mile	**0.00**	**0.00**
Power plant system repairs (battery system or CNG engine)	Parts cost ($)	0.00	16,344.60
	Labor hours	1.5	63.8
	Total cost ($)	75.00	19,534.60
	Total cost ($) per mile	**0.00**	**0.03**
Electric motor and propulsion system repairs	Parts cost ($)	0.00	0.00
	Labor hours	21.4	0.0
	Total cost ($)	1,070.00	0.00
	Total cost ($) per mile	**0.00**	**0.00**
Non-lighting electrical system repairs (general electrical, charging, cranking, ignition)	Parts cost ($)	6,818.43	4,765.93
	Labor hours	50.3	50.6
	Total cost ($)	9,331.93	7,295.93
	Total cost ($) per mile	**0.02**	**0.01**
Air intake system repairs	Parts cost ($)	0.00	7,817.69
	Labor hours	3.9	0.0
	Total cost ($)	195.00	7,817.69
	Total cost ($) per mile	**0.00**	**0.01**
Cooling system repairs	Parts cost ($)	23.82	4,348.08
	Labor hours	2.5	73.8
	Total cost ($)	148.82	8,038.08
	Total cost ($) per mile	**0.00**	**0.01**
Transmission system repairs	Parts cost ($)	0.00	219.67
	Labor hours	0.7	11.7
	Total cost ($)	35.00	804.67
	Total cost ($) per mile	**0.00**	**0.00**
Hydraulic system repairs	Parts cost ($)	0.00	0.00
	Labor hours	0.0	0.0
	Total cost ($)	0.00	0.00
	Total cost ($) per mile	**0.00**	**0.00**

Potential PMI Cost Savings for BEBs

Over time, Foothill Transit expects to save on PMI costs for BEBs compared to conventional buses. Proterra has established a PMI schedule for the BEBs based on mileage at intervals similar to that of conventional buses. Safety inspections and preventive maintenance for the bus-related systems on the BEBs are the same as that of conventional buses. The primary differences are related to the advanced components for the propulsion system. The PMI schedule for the BEBs has recommended intervals of 6,000 and 48,000 miles, while the PMI schedule for the CNG buses has recommended intervals of 6,000; 12,000; 18,000; 24,000; 30,000; and 36,000 miles.

The majority of time and materials costs for maintaining the CNG buses involve fluid and filter change outs. During PMIs for conventional buses, maintenance staff typically change out the oil, oil filter, fuel filter, air filter, and coolant filter. Fluid changes for the BEBs include motor coolant at 80,000 miles and transmission fluid at 100,000 miles. In addition to materials and labor cost savings for the BEBs compared to conventional buses, Foothill Transit reports that there are other potential savings for BEB operation. Operating conventional buses often requires many other costs that can be difficult to quantify, such as:

- Storage, handling, and proper disposal of used oil and other fluids
- Storage and disposal of used containers and oily rags
- Paperwork required for hazardous waste disposal
- Supplies and labor for cleaning the shop.

Summary of Achievements and Challenges

This section focuses on the achievements and challenges for Foothill Transit and its partners in implementing BEBs into the fleet. As with all new technology development, lessons learned during this project could aid other agencies considering BEB technology. There have been many achievements for the demonstration, including the following:

- The current fleet of twelve 35-ft BEBs continues to operate well, accumulating more than 902,000 miles (through December 2016). Foothill Transit operated its fleet of three first-generation Proterra BEBs from 2010 through 2013, accumulating more than 190,000 miles. In 2016, the agency received two 40-foot, fast charge buses. Foothill Transit's combined fleet of 17 Proterra BEBs has operated more than 1,134,000 miles.
- Bus MBRC for the entire evaluation period is more than 6,000, surpassing the ultimate target of 4,000. Propulsion-related MBRC is more than 16,000.
- The on-route fast chargers operated reliably with minimal issues, none of which resulted in downtime for the buses. Since installation of the chargers, Foothill Transit's combined BEB fleet (17 buses) has been charged 119,150 times. Availability of the two charging heads was 98% and 99%.
- Proterra reports that the high voltage batteries are showing little to no signs of capacity degradation to date, and current estimates show they may last for up to 12 years.

- Foothill Transit generates LCFS credits by operating the BEBs. Over the study period (Q3 2015–Q4 2016), Foothill Transit earned approximately $126,000 in LCFS credits. The agency uses the funds as an additional revenue source to be applied wherever needed.

Advanced technology demonstrations typically experience challenges and issues that need to be resolved. The remainder of this section summarizes the primary issues that affected the demonstration as a whole.

Local monitor unit (LMU) failures—The LMU is part of the battery management system (BMS) for the BEBs. During the data period, a resistor within the LMU on three buses failed. Proterra has investigated the failures and believes they are due to stressing the board during previous electrical connection rework. As Proterra replaces the overstressed boards, the rate of failure has decreased. This failure is not related to the high-voltage batteries themselves. Proterra expects the part to last the life of the bus.

Tire damage—While not related to the advanced technology, tire damage continues to account for a significant portion of the maintenance costs for the BEBs at Foothill Transit. Since the buses went into service, Foothill Transit has replaced 100 tires at a parts cost of more than $37,800 and 99.3 labor hours. Average cost per bus is $3,154 and 8.3 labor hours. The CNG buses also had significant tire costs during the data period. The agency replaced 53 tires at a cost of more than $10,700 and 68 labor hours. The per-bus average cost for the eight-bus CNG fleet is $1,346 and 8.5 labor hours. Foothill Transit reports that this is likely due to the differing use between the BEBs and CNG buses. The local routes tend to have more road damage, such as potholes and broken curbs. The agency expects that the CNG buses would experience similar tire damage as the BEBs if they were only operated on the local routes.

Transmission issues—Several BEBs experienced transmission problems during the data period. Proterra has sent one of the failed transmissions to the supplier to determine the cause. A transmission replacement typically takes less than a day. One bus was out of service for an extended time because the new transmission was damaged during the installation and the agency had to wait for a new one to be shipped.

Lessons Learned

Foothill Transit and Proterra report that the project continues to go well. The partners highlighted the following key lessons learned since the beginning of the project:

- Short-range, on-route-charged buses are inflexible and cannot be deployed at other service routes that do not connect to an on-route charging location.
- Review potential routes and consider the ones that best fit how fast-charge BEBs operate based on driving range, duty cycle, and charging opportunities. An agency could benefit from conducting a route analysis and simulating how the BEBs would meet the power requirements.
- Adjust route schedules to accommodate BEB charging time; this is part of the transition from conventional technology buses to electric buses. An agency may need to add

deadhead miles prior to the start of the route depending on the location of the in-route charging station and availability of an in-depot charger.

- Work with the local utility to address potential costs for demand and time-of-use charges.
- The higher use of air conditioning lowers the effective range in warmer months; Foothill Transit adjusts its summer schedule to account for more charging time.
- Charger availability is important for successful deployment. Foothill Transit installed two charger heads at its charging station to avoid downtime due to charger unavailability.
- Agencies operating BEBs can generate LCFS credits.

Foothill Transit reports that there is still a lot of learning as the agency ramps up to a larger BEB fleet. The agency has a goal of transitioning its fleet to 100% electric by 2030. The team needs to develop plans in achieving this goal. As the technology improves to include longer range BEBs, Foothill Transit expects to manage more buses through overnight charging. To accomplish this, the agency is investigating options for charging a large number of buses in a limited space.

What's Next

Foothill Transit will continue operating the 12 BEBs on Line 291 and is evaluating other routes that might be well suited for electric buses. The agency has orders for Proterra's new Catalyst 40-foot BEB. The first two BEBs, which have been received and placed in service, are fast-charge buses. The remaining 13 BEBs will be the Catalyst E2 extended range model with a nominal range of 251 miles on a single charge.

The agency plans to operate the buses on Line 280—a 22-mile round trip. Foothill Transit built a transit center (Azusa Intermodal Transit Center) which was completed in 2016 in partnership with the City of Azusa. The transit center serves Foothill Transit lines and the Metro Goldline station in Azusa. The underground infrastructure is installed for a charging station with two fast-charging heads, which will be built out in 2017 in conjunction with the BEB delivery schedule. Foothill Transit is looking at other potential routes for the 40-foot buses as part of its fleet electrification initiative by 2030.

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References and Related Reports

All NREL hydrogen and fuel cell-related evaluation reports can be downloaded from the following website: www.nrel.gov/hydrogen/proj_fc_bus_eval.html.

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Eudy, L.; Post, M.; Jeffers M. (2016). *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2016*. NREL/TP-5400-67097. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy17osti/67097.pdf.

Appendix A: TRL Guideline Table

Technology Readiness Levels for Advanced Technology Bus Commercialization[a]

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
Deployment	TRL 9	Actual system operated over the full range of expected conditions	The technology is in its final form. Deployment, marketing, and support begin for the first fully commercial products.
Technology Demonstration/ Commissioning	TRL 8	Actual system completed and qualified through test and demonstration	The last step in true system development. Demonstration of a limited production of 50 to 100 buses at a small number of locations. Beginning the transition of all maintenance to transit staff.
	TRL 7	Full-scale validation in relevant environment	A major step up from TRL 6 by adding larger numbers of buses and increasing the hours of service. Full-scale demonstration and reliability testing of 5 to 10 buses at several locations. Manufacturers begin to train larger numbers of transit staff in operation and maintenance.
	TRL 6	Engineering/pilot-scale validation in relevant environment	First tests of prototype buses in actual transit service. Field testing and design shakedown of one to two prototypes. Manufacturers assist in operation and typically handle all maintenance. Begin to introduce transit staff to technology.
Technology Development	TRL 5	Laboratory scale, similar system validation in relevant environment	Integrated system is tested in a laboratory under simulated conditions based on early modeling. System is integrated into an early prototype or mule platform for some on-road testing.
	TRL 4	Component and system validation in laboratory environment	Basic technological components are integrated into the system and begin laboratory testing and modeling of potential duty cycles.
Research to Prove Feasibility	TRL 3	Analytical and experimental critical function and/or proof of concept	Active research into components and system integration needs. Investigate what requirements might be met with existing commercial components.
Basic Technology Research	TRL 2	Technology concept and/or application formulated	Research technology needed to meet market requirements. Define strategy for moving through development stages.
	TRL 1	Basic principles observed and reported	Scientific research and early development of concepts.

[a] This guideline considers the bus as a whole and does not account for differing TRLs for separate components or subsystems. Some subsystems may include off-the-shelf components that are considered commercial, while other subsystems may feature newly designed components at an earlier TRL.

Appendix B: Foothill Transit Fleet Summary Statistics

BEB and CNG Fleet Operations and Economics

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Number of vehicles	12	12	8	8
Period used for fuel and energy op analysis	4/14–12/16	8/15–12/16	10/14–12/16	8/15–12/16
Total number of months in period	33	17	27	17
Fuel and energy analysis base fleet mileage	902,281	501,037	929,451	634,918
Period used for maintenance op analysis	1/15–12/16	8/15–12/16	10/14–12/16	8/15–12/16
Total number of months in period	24	17	27	17
Maintenance analysis base fleet mileage	706,078	501,037	1,020,772	656,399
Average monthly mileage per vehicle	2,400	2,456	4,726	4,826
Availability (%)	90	90	93	93
Fleet energy usage in kWh (BEB) or gge (CNG)	1,951,862	1,087,276	236,345	163,368
Roadcalls	146	104	35	27
Total MBRC	6,180	4,818	29,165	24,311
Propulsion-related roadcalls	55	40	18	14
Propulsion-related MBRC	16,405	12,526	56,710	46,886
Average speed, including stops (mph)	10.6	10.6	17.6	17.6
Fleet kWh/mile (BEB) or miles/gge (CNG)	2.16	2.17	3.93	3.89
Fleet average fuel economy (mpdge)	17.41	17.35	4.39	4.34
CNG fleet average fuel economy (mpdge) at similar average driving speed as BEB fleet			2.09	2.09
Energy cost per kWh	$0.17	$0.17		
CNG cost per gge			$0.95	$0.96
Energy/fuel cost per mile (based on purchased energy)	$0.43	$0.41	$0.24	$0.25
CNG fuel cost per mile at similar average driving speed as BEB fleet			$0.45	$0.46
Total scheduled repair cost per mile	$0.07	$0.07	$0.12	$0.11
Total unscheduled repair cost per mile	$0.12	$0.14	$0.08	$0.10
Total maintenance cost per mile	$0.19	$0.21	$0.20	$0.22
Total operating cost per mile (as operated)	***$0.62***	***$0.62***	***$0.45***	***$0.46***
Total operating cost per mile at similar average driving speed, excluding tire costs	***$0.56***	***$0.55***	***$0.65***	***$0.66***

Maintenance Costs

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Fleet mileage	706,078	501,037	1,020,772	656,399
Total parts cost ($)	54,932.79	45,588.07	108,879.49	76,117.76
Total labor hours	1,647.9	1,165.5	1,997.2	1,317.8
Average labor cost (@ $50.00 per hour) ($)	82,397.00	58,277.00	99,860.00	65,887.50
Total maintenance cost ($)	137,329.79	103,865.07	208,739.49	142,005.26
Total maintenance cost per bus ($)	11,444.15	8,655.42	26,092.44	17,750.66
Total maintenance cost per mile ($)	***0.19***	***0.21***	***0.20***	***0.22***
Total maintenance cost per mile, excluding tire costs ($)	***0.13***	***0.14***	***0.19***	***0.20***

Breakdown of Maintenance Costs by Vehicle System

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Fleet mileage	706,078	501,037	1,020,772	656,399
Total Engine/Fuel-Related Systems (ATA VMRS 27, 30, 31, 32, 33, 41, 42, 43, 44, 45, 46, 65)				
Parts cost ($)	9,263.26	6,842.25	57,194.31	34,141.06
Labor hours	116.27	80.27	311.35	220.10
Average labor cost ($)	5,813.50	4,013.50	15,567.50	11,005.00
Total cost (for system) ($)	15,076.76	10,855.75	72,761.81	45,146.06
Total cost (for system) per bus ($)	456.87	328.96	2,204.90	1,368.06
Total cost (for system) per mile ($)	**0.02**	**0.02**	**0.07**	**0.07**
Exhaust System Repairs (ATA VMRS 43)				
Parts cost ($)	0.00	0.00	157.20	157.20
Labor hours	0.0	0.0	1.5	1.5
Average labor cost ($)	0.00	0.00	75.00	75.00
Total cost (for system) ($)	0.00	0.00	232.20	232.20
Total cost (for system) per bus ($)	0.00	0.00	7.04	7.04
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**
Fuel System Repairs (ATA VMRS 44)				
Parts cost ($)	0.00	0.00	552.57	487.89
Labor hours	0.0	0.0	25.2	18.7
Average labor cost ($)	0.00	0.00	1,260.00	935.00
Total cost (for system) ($)	0.00	0.00	1,812.57	1,422.89
Total cost (for system) per bus ($)	0.00	0.00	54.93	43.12
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**
Power Plant (Engine or ESS) Repairs (ATA VMRS 45)				
Parts cost ($)	0.00	0.00	31,934.86	16,344.60
Labor hours	11.0	1.5	89.3	63.8
Average labor cost ($)	550.00	75.00	4,465.00	3,190.00
Total cost (for system) ($)	550.00	75.00	36,399.86	19,534.60
Total cost (for system) per bus ($)	16.67	2.27	1,103.03	591.96
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.04**	**0.03**
Electric Propulsion Repairs (ATA VMRS 46)				
Parts cost ($)	0.00	0.00	0.00	0.00
Labor hours	22.9	21.4	0.0	0.0
Average labor cost ($)	1,145.00	1,070.00	0.00	0.00
Total cost (for system) ($)	1,145.00	1,070.00	0.00	0.00
Total cost (for system) per bus ($)	34.70	32.42	0.00	0.00
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**

Breakdown of Maintenance Costs by Vehicle System (continued)

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)				
Parts cost ($)	9,239.44	6,818.43	5,924.77	4,765.93
Labor hours	74.8	50.3	79.6	50.6
Average labor cost ($)	3,738.50	2,513.50	3,980.00	2,530.00
Total cost (for system) ($)	12,977.94	9,331.93	9,904.77	7,295.93
Total cost (for system) per bus ($)	393.27	282.79	300.14	221.09
Total cost (for system) per mile ($)	**0.02**	**0.02**	**0.01**	**0.01**
Air Intake System Repairs (ATA VMRS 41)				
Parts cost ($)	0.00	0.00	12,057.79	7,817.69
Labor hours	3.9	3.9	0.8	0.0
Average labor cost ($)	195.00	195.00	37.50	0.00
Total cost (for system) ($)	195.00	195.00	12,095.29	7,817.69
Total cost (for system) per bus ($)	5.91	5.91	366.52	236.90
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.01**	**0.01**
Cooling System Repairs (ATA VMRS 42)				
Parts cost ($)	23.82	23.82	6,158.30	4,348.08
Labor hours	2.5	2.5	98.3	73.8
Average labor cost ($)	125.00	125.00	4,915.00	3,690.00
Total cost (for system) ($)	148.82	148.82	11,073.30	8,038.08
Total cost (for system) per bus ($)	4.51	4.51	335.55	243.58
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.01**	**0.01**
Hydraulic System Repairs (ATA VMRS 65)				
Parts cost ($)	0.00	0.00	0.00	0.00
Labor hours	0.0	0.0	0.0	0.0
Average labor cost ($)	0.00	0.00	0.00	0.00
Total cost (for system) ($)	0.00	0.00	0.00	0.00
Total cost (for system) per bus ($)	0.00	0.00	0.00	0.00
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**
General Air System Repairs (ATA VMRS 10)				
Parts cost ($)	54.04	54.04	1,269.07	713.20
Labor hours	25.8	15.5	15.9	7.9
Average labor cost ($)	1,287.50	775.00	795.00	395.00
Total cost (for system) ($)	1,341.54	829.04	2,064.07	1,108.20
Total cost (for system) per bus ($)	40.65	25.12	62.55	33.58
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**

Breakdown of Maintenance Costs by Vehicle System (continued)

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Brake System Repairs (ATA VMRS 13)				
Parts cost ($)	0.00	0.00	2,281.00	2,281.00
Labor hours	6.7	6.7	11.2	11.2
Average labor cost ($)	335.00	335.00	560.00	560.00
Total cost (for system) ($)	335.00	335.00	2,841.00	2,841.00
Total cost (for system) per bus ($)	10.15	10.15	86.09	86.09
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**
Transmission Repairs (ATA VMRS 27)				
Parts cost ($)	0.00	0.00	408.82	219.67
Labor hours	1.2	0.7	16.7	11.7
Average labor cost ($)	60.00	35.00	835.00	585.00
Total cost (for system) ($)	60.00	35.00	1,243.82	804.67
Total cost (for system) per bus ($)	1.82	1.06	37.69	24.38
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**
Inspections Only - no parts replacements (101)				
Parts cost ($)	0.00	0.00	0.00	0.00
Labor hours	979.4	684.2	1119.1	680.6
Average labor cost ($)	48,970.00	34,210.00	55,955.00	34,030.00
Total cost (for system) ($)	48,970.00	34,210.00	55,955.00	34,030.00
Total cost (for system) per bus ($)	1,483.94	1,036.67	1,695.61	1,031.21
Total cost (for system) per mile ($)	**0.07**	**0.07**	**0.05**	**0.05**
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)				
Parts cost ($)	3,749.39	3,562.03	15,590.95	14,654.88
Labor hours	384.0	272.0	412.7	296.9
Average labor cost ($)	19,198.50	13,601.00	20,635.00	14,845.00
Total cost (for system) ($)	22,947.89	17,163.03	36,225.95	29,499.88
Total cost (for system) per bus ($)	695.39	520.09	1,097.76	893.94
Total cost (for system) per mile ($)	**0.03**	**0.03**	**0.04**	**0.04**
HVAC System Repairs (ATA VMRS 01)				
Parts cost ($)	55.59	55.59	4,454.57	3,935.89
Labor hours	10.0	9.5	41.0	29.6
Average labor cost ($)	500.00	475.00	2,050.00	1,480.00
Total cost (for system) ($)	555.59	530.59	6,504.57	5,415.89
Total cost (for system) per bus ($)	16.84	16.08	197.11	164.12
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.01**	**0.01**

Breakdown of Maintenance Costs by Vehicle System (continued)

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Lighting System Repairs (ATA VMRS 34)				
Parts cost ($)	173.74	173.74	20.52	20.52
Labor hours	26.6	25.6	2.0	2.0
Average labor cost ($)	1,327.50	1,277.50	97.50	97.50
Total cost (for system) ($)	1,501.24	1,451.24	118.02	118.02
Total cost (for system) per bus ($)	45.49	43.98	3.58	3.58
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)				
Parts cost ($)	0.00	0.00	387.02	352.30
Labor hours	0.0	0.0	6.7	2.7
Average labor cost ($)	0.00	0.00	335.00	135.00
Total cost (for system) ($)	0.00	0.00	722.02	487.30
Total cost (for system) per bus ($)	0.00	0.00	21.88	14.77
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.00**	**0.00**
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)				
Parts cost ($)	0.00	0.00	15,703.90	9,600.96
Labor hours	0.0	0.0	8.0	6.0
Average labor cost ($)	0.00	0.00	400.00	300.00
Total cost (for system) ($)	0.00	0.00	16,103.90	9,900.96
Total cost (for system) per bus ($)	0.00	0.00	488.00	300.03
Total cost (for system) per mile ($)	**0.00**	**0.00**	**0.02**	**0.02**
Tire Repairs (ATA VMRS 17)				
Parts cost ($)	38,501.77	31,765.42	10,775.15	9,214.95
Labor hours	99.3	71.8	68.3	59.8
Average labor cost ($)	4,965.00	3,590.00	3,415.00	2,990.00
Total cost (for system) ($)	43,466.77	35,355.42	14,190.15	12,204.95
Total cost (for system) per bus ($)	1,317.17	1,071.38	430.00	369.85
Total cost (for system) per mile ($)	**0.06**	**0.07**	**0.01**	**0.02**
Towing Charges				
Parts cost ($)	3,135.00	3,135.00	1203	1,203.00
Labor hours	0.00	0.00	1.0	1.0
Average labor cost ($)	0.00	0.00	50.00	50.00
Total cost (for system) ($)	3,135.00	3,135.00	1,253.00	1,253.00
Total cost (for system) per bus ($)	95.00	95.00	37.97	37.97
Total cost (for system) per mile ($)	**0.00**	**0.01**	**0.00**	**0.00**

Notes

1. To compare the charging energy to CNG fuel and diesel equivalent, the energy and CNG were converted into diesel energy equivalent gallons. Actual energy content will vary by location, but the general energy conversions are based on the following:

Lower heating value (LHV) for diesel = 128,488 Btu/gal (Alternative Fuels Data Center, fuel properties database[8])

U.S. average energy content of electricity = 3,412 Btu/kWh (Energy Information Administration)

Conversion factor for calculations = 37.7 kWh/gal

CNG fuel is reported as gasoline gallon equivalent (gge). The gasoline LHV is 115,000 Btu/gal. Gasoline/Diesel = 115,000 Btu/gallon / 128,400 Btu/gallon = 0.896 gge/gal

2. The propulsion-related systems were chosen to include only those systems of the vehicles that could be affected directly by the selection of a fuel or advanced technology.

3. ATA VMRS coding is based on parts that were replaced. If there was no part replaced in a given repair, then the code was chosen by the system being worked on.

4. In general, inspections (with no part replacements) were included only in the overall totals (not by system). Category 101 was created to track labor costs for PMIs.

5. ATA VMRS 02-Cab and Sheet Metal represents seats, doors, etc.; ATA VMRS 50-Accessories represents things like fire extinguishers, test kits, fareboxes, etc.; ATA VMRS 71-Body represents mostly windows and windshields.

6. Average labor cost is assumed to be $50 per hour.

7. Warranty costs are not included.

[8] http://www.afdc.energy.gov/fuels/fuel_properties.php

Appendix C: Foothill Transit Fleet Summary Statistics—SI Units

BEB and CNG Fleet Operations and Economics

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Number of vehicles	12	12	8	8
Period used for fuel and energy op analysis	4/14–12/16	8/15–12/16	10/14–12/16	8/15–12/16
Total number of months in period	33	17	27	17
Fuel and energy analysis base fleet mileage	1,452,041	806,319	1,495,765	1,021,774
Period used for maintenance op analysis	1/15–12/16	8/15–12/16	10/14–12/16	8/15–12/16
Total number of months in period	24	17	27	17
Maintenance analysis base fleet kilometers	1,136,291	806,319	1,642,728	1,056,343
Average monthly kilometers per vehicle	3,862	3,953	7,606	7,767
Availability (%)	90	90	93	93
Fleet fuel usage in kWh/CNG liter equiv.	1,951,862.0	1,087,276.0	894,663.1	618,415.2
Roadcalls	149	107	35	27
Total KMBRC	7,626	7,536	46,935	39,124
Propulsion-related roadcalls	55	40	18	14
Propulsion-related KMBRC	20,660	20,158	91,263	75,453
Rep. fleet fuel consumption (L/100 km)	13.50	13.54	53.53	54.17
CNG fleet fuel consumption at similar average driving speed as BEB fleet (L/100 km)			100.73	100.73
Energy cost per kWh	$0.18	$0.18		
CNG cost/liter			$0.25	$0.25
Energy/fuel cost per kilometer (based on purchased energy)	**$0.27**	**$0.26**	**$0.15**	**$0.15**
CNG fuel cost per kilometer at similar average driving speed as BEB fleet			**$0.28**	**$0.28**
Total scheduled repair cost per kilometer	$0.04	$0.04	$0.08	$0.07
Total unscheduled repair cost per kilometer	$0.08	$0.09	$0.05	$0.06
Total maintenance cost per kilometer	**$0.12**	**$0.13**	**$0.13**	**$0.13**
Total operating cost per kilometer (as operated)	***$0.39***	***$0.39***	***$0.28***	***$0.29***
Total operating cost per mile at similar average driving speed, excluding tire costs	***$0.35***	***$0.34***	***$0.40***	***$0.41***

Maintenance Costs

	BEB All Data	BEB Report Period	CNG All Data	CNG Report Period
Fleet mileage	1,136,291	806,319	1,642,728	1,056,343
Total parts cost ($)	54,932.79	45,588.07	108,879.49	76,117.76
Total labor hours	1,647.94	1,165.54	1,997.20	1,317.75
Average labor cost (@ $50.00 per hour) ($)	82,397.00	58,277.00	99,860.00	65,887.50
Total maintenance cost ($)	137,329.79	103,865.07	208,739.49	142,005.26
Total maintenance cost per bus ($)	11,444.15	8,655.42	17,394.96	11,833.77
Total maintenance cost per kilometer ($)	***0.12***	***0.13***	***0.13***	***0.13***
Total maintenance cost per kilometer, excluding tire costs ($)	***0.08***	***0.08***	***0.12***	***0.12***

Appendix D: Charts for Entire In-Service Period (All Data)

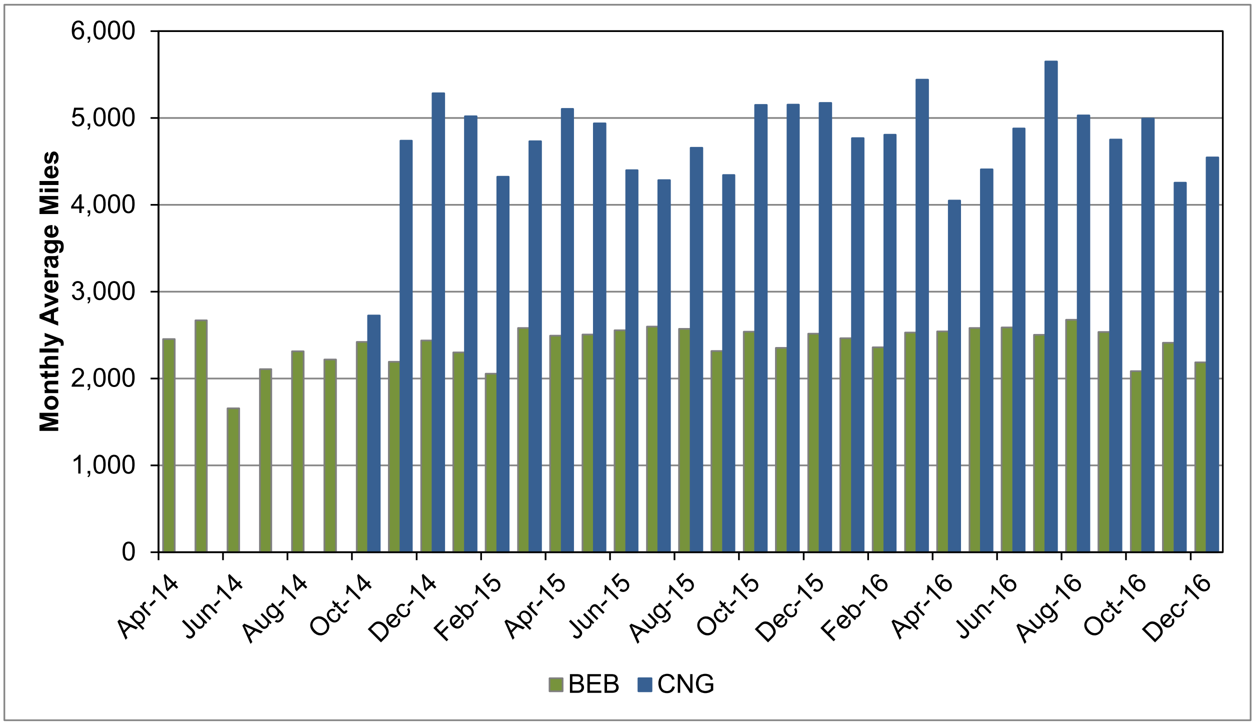

Figure D-1. Monthly average miles for the BEBs and CNG buses

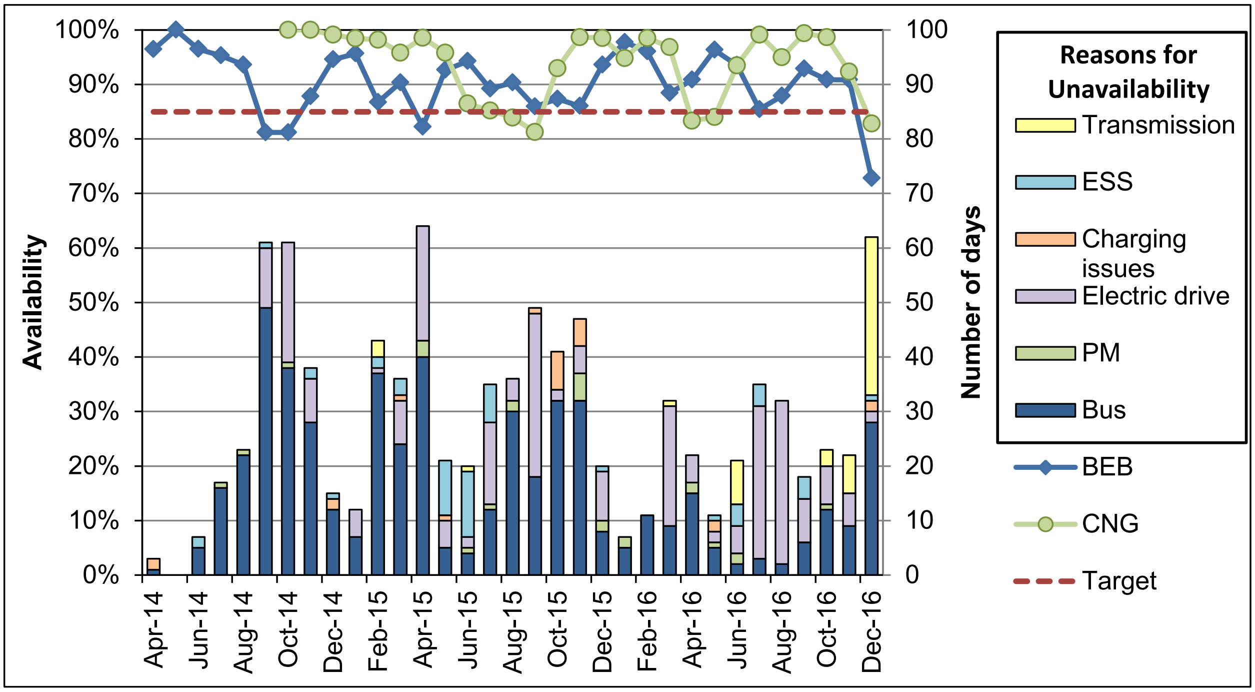

Figure D-2. Monthly availability for the BEBs and CNG buses

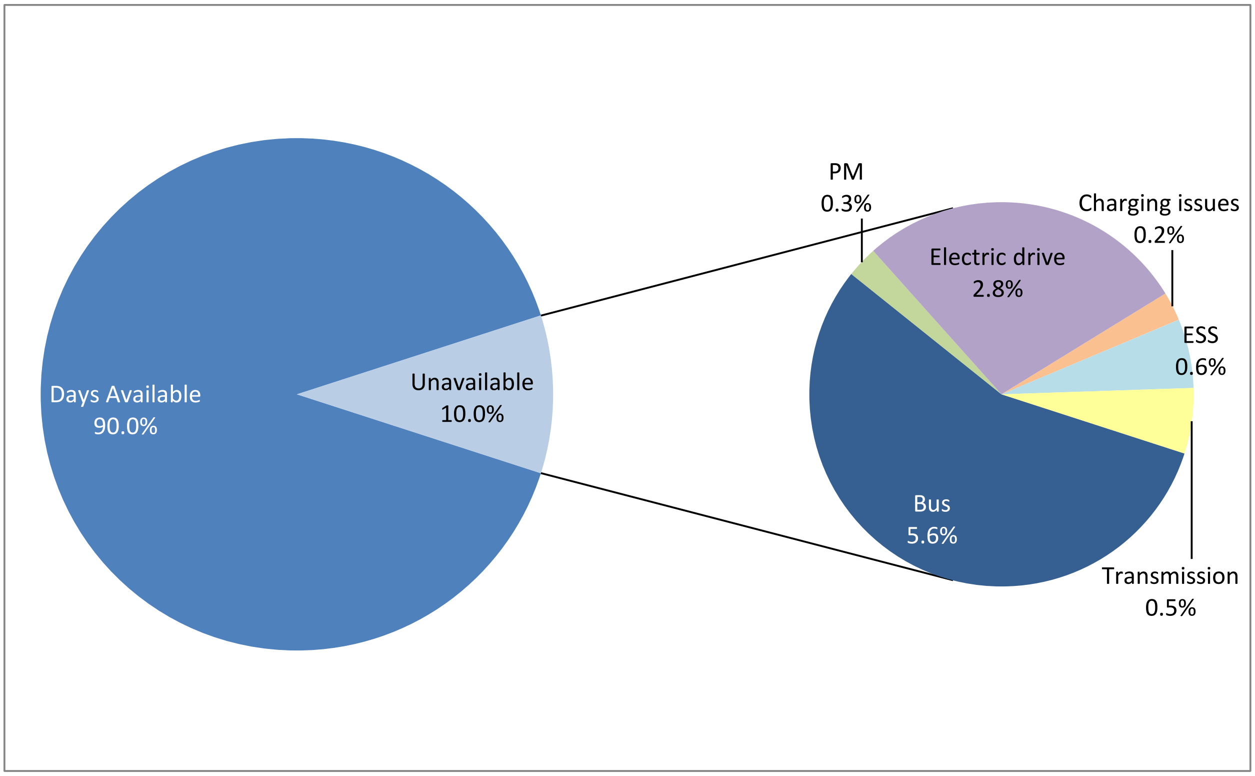

Figure D-3. Overall availability and reasons for unavailability for the BEBs

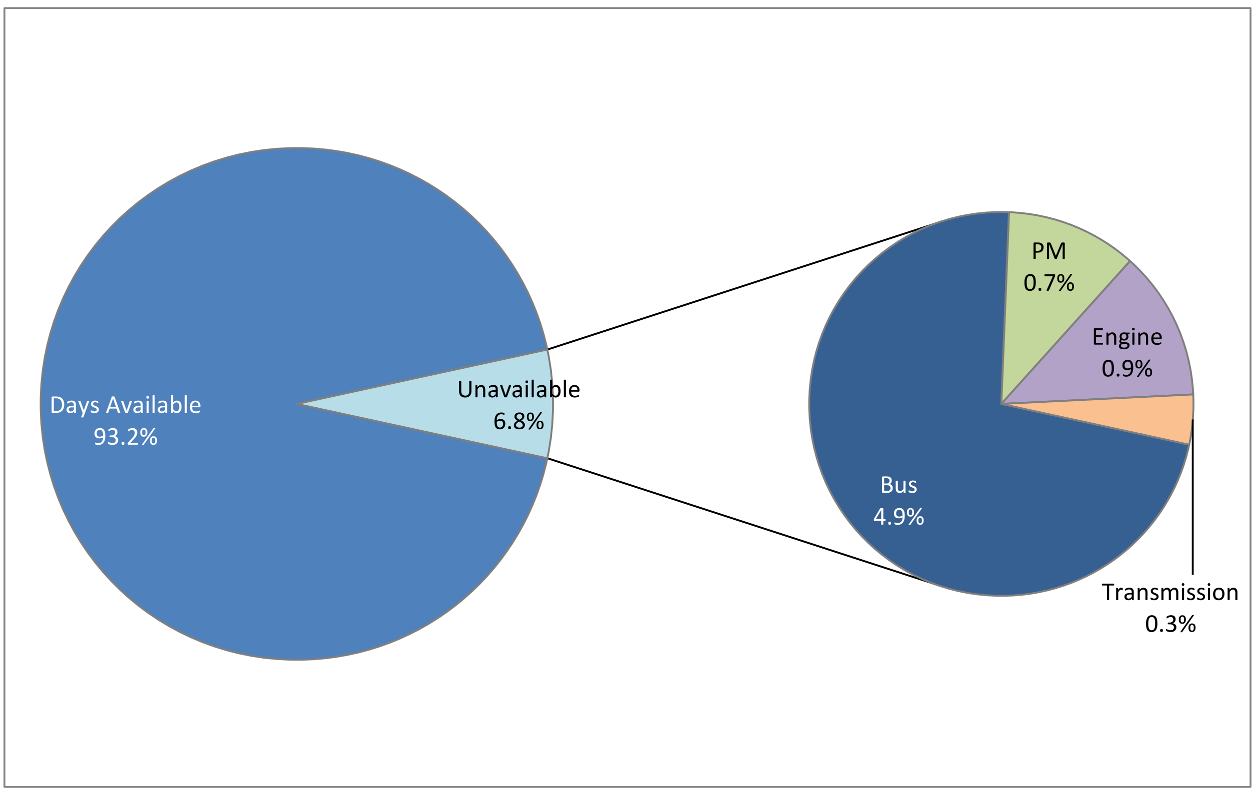

Figure D-4. Overall availability and reasons for unavailability for the CNG buses

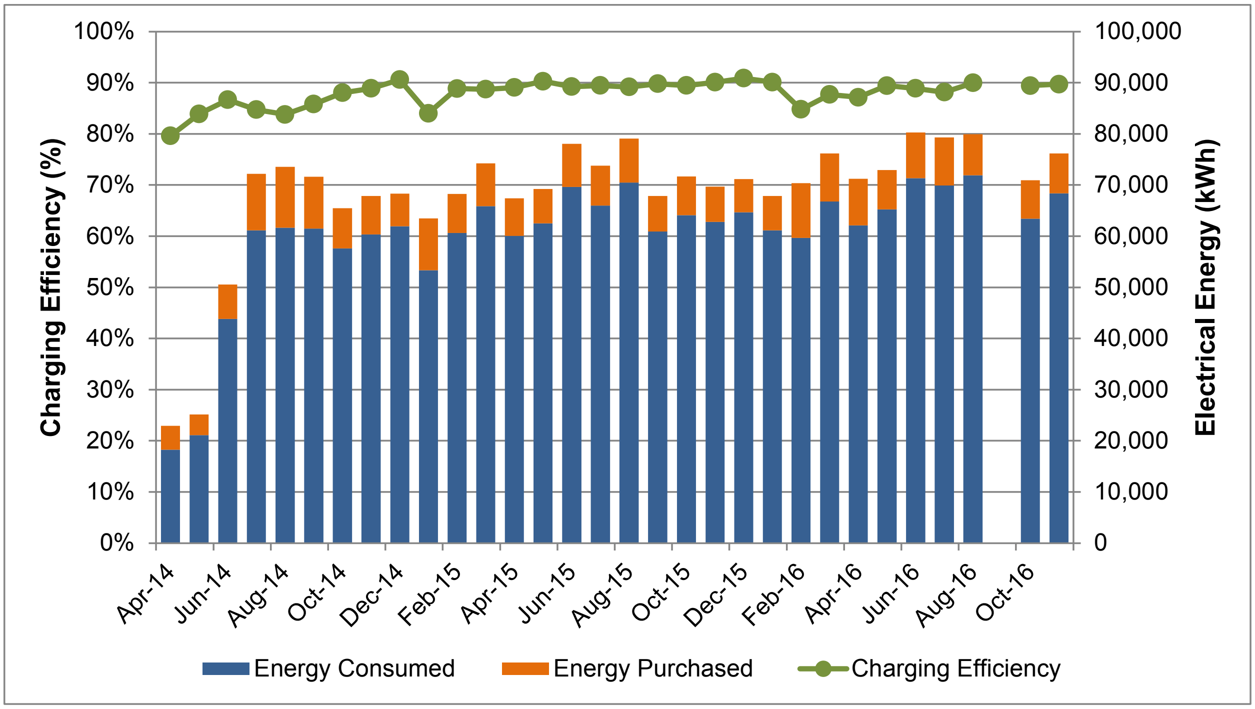

Figure D-5. Monthly energy consumption and overall charging efficiency for the BEBs

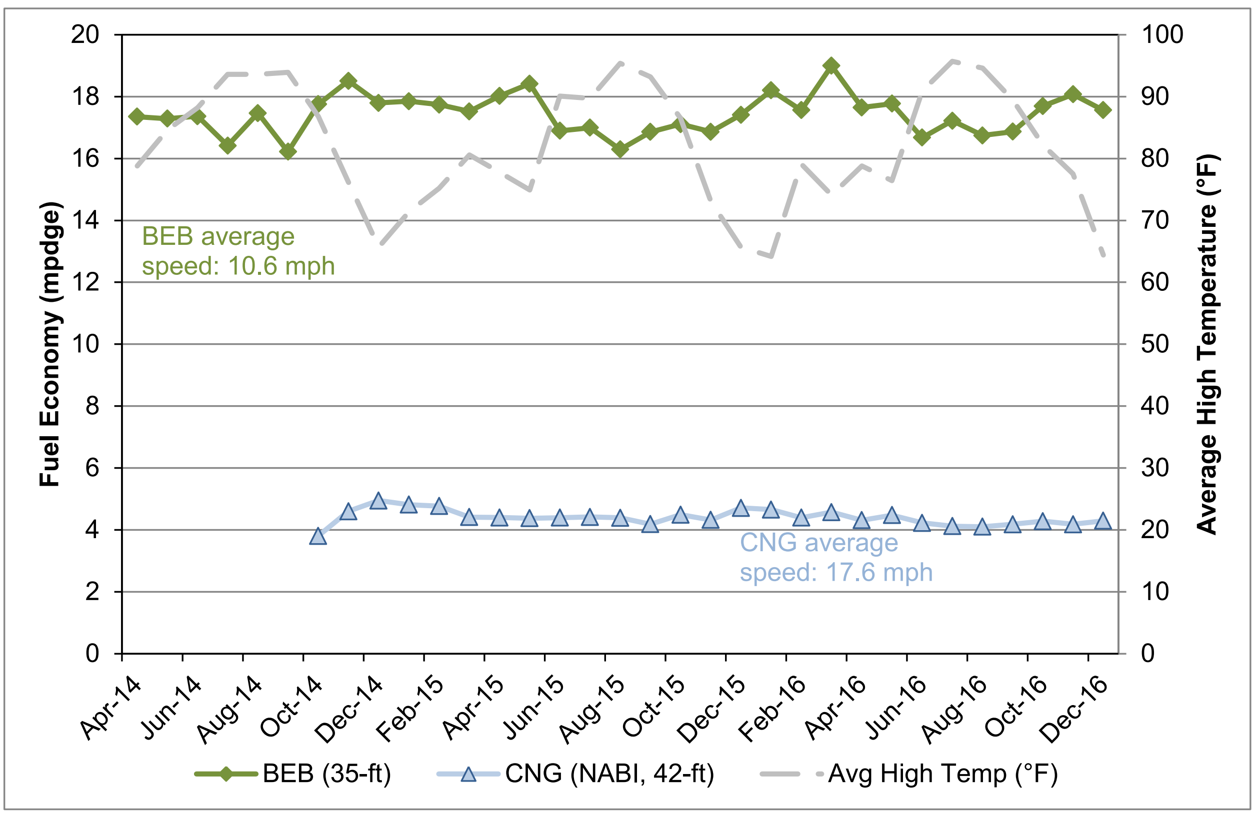

Figure D-6. Monthly average fuel economy for the BEBs and CNG buses

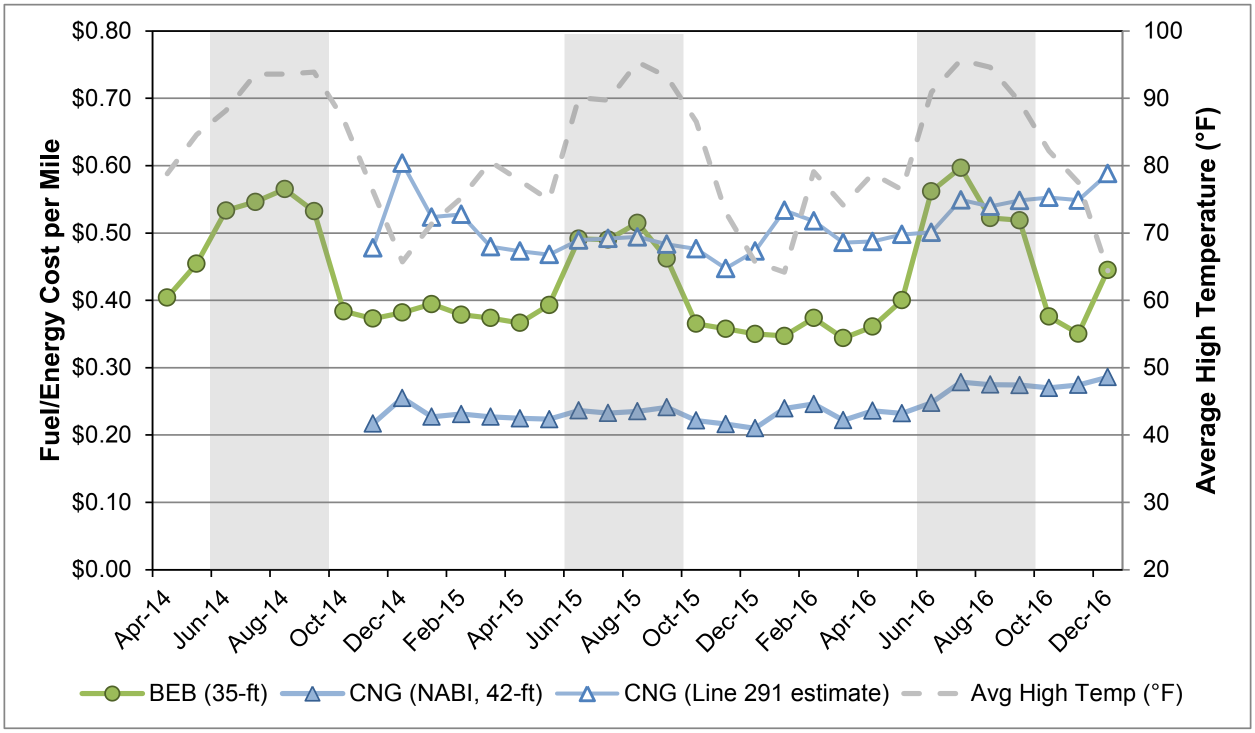

Figure D-7. Monthly average energy cost per mile for the BEBs and CNG buses

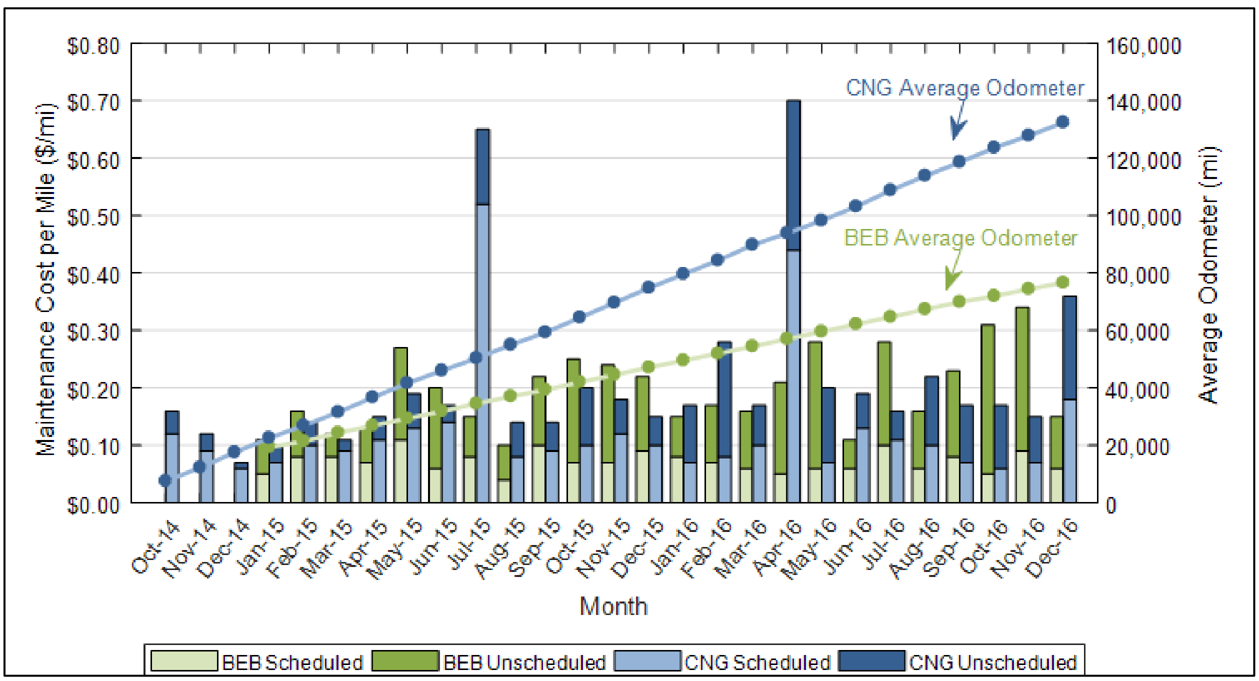

Figure D-8. Monthly scheduled and unscheduled maintenance costs per mile for the BEBs and CNG buses

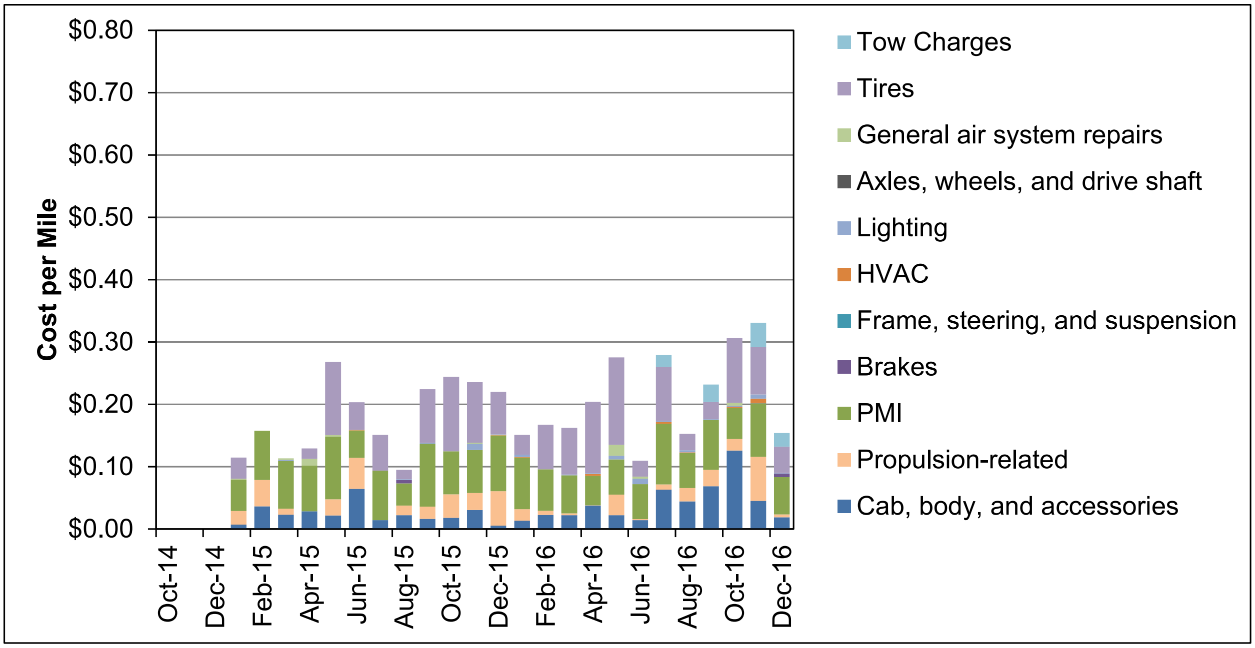

Figure D-9. Monthly maintenance cost per mile by vehicle system for the BEBs

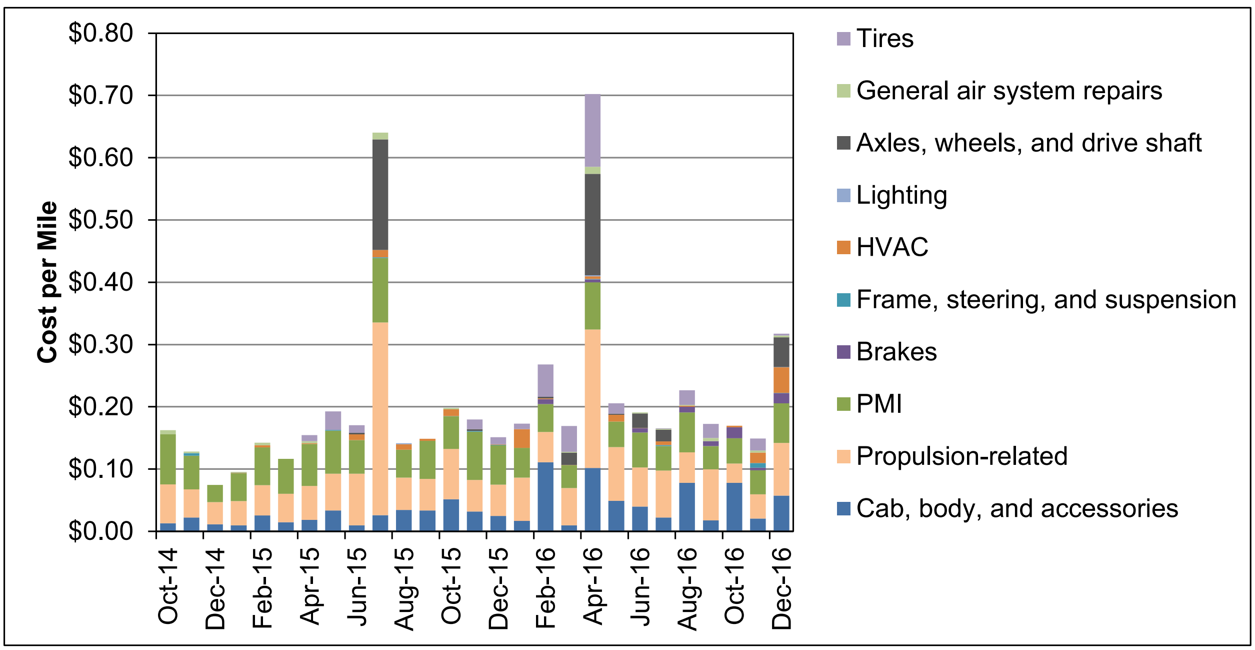

Figure D-10. Monthly maintenance cost per mile by vehicle system for the CNG buses

April 27, 2018

To: Executive Board

Subject: **Contract Award - Mobile Fare Payment System**

Recommendation

Authorize the Executive Director to negotiate final contract terms and conditions and enter into a sole source agreement in the amount of $515,000, including all merchant processing fees with AmericanEagle.com for a Mobile Ticketing and Retail Point-of-Sale system. The agreement has a three-year term.

Analysis

Foothill Transit received an Unsolicited Proposal for a Mobile Ticketing and Retail Point-of-Sale (POS) system project from AmericanEagle.com. The proposal provides a unique validating method that solves common concerns with current popular mobile ticketing solution providers. The proposed validating method will not require Foothill Transit to install and maintain additional on-board equipment, but will be able to validate fares by service type without Coach Operator intervention. In addition to providing the mobile payment solution, the AmericanEagle.com approach also includes a complete POS system with all hardware, and integrates with other Foothill Transit financial systems.

After reviewing the proposal, to determine whether there were other vendors capable of providing equivalent features and functionality, Foothill Transit released a Request for Information and Qualifications (RFIQ) to provide all vendors an opportunity to comment or submit competing fare collection technology solutions. The RFIQ was available from March 2 to March 23, 2018. Foothill Transit received eight proposals in response to the RFIQ. After a thorough review of all eight proposals, it was determined that the unsolicited proposal from AmericanEagle.com offered a unique combination of fare collection improvements not available from any other RFIQ respondent.

The validation methods most commonly proposed by the RFIQ respondents are listed below:

- <u>Electronic validators:</u> This would require Foothill Transit to invest in and install electronic validators on board every bus and requires wireless communication subscription services. The electronic validator requires Coach Operators to log on to capture accurate data and collect the appropriate fares, or it would require complex integration through an extensive software redesign of our Computer Aided Dispatch and Automatic Vehicle Location (CAD/AVL) system.

- Bluetooth beacons: This approach would require Foothill Transit to install a passive Bluetooth device, known as a beacon, powered by a coin-size battery on every bus. This method of validation captures data when the mobile phone is in range of the beacon and for this to work, it requires the mobile phone to have the Bluetooth feature turned on at all times. This method collects limited data and does not have the ability to accurately charge fares for different levels of service.
- Visual validation: Using this approach, the mobile application acts as a flash pass where the customer presents his/her phone to the Coach Operator and the Coach Operator validates the ticket visually based on several built-in security features. The coach operator would then use a tally key on the farebox to record the ride manually. This method of validation collects limited data and limits our ability to respond effectively to customer comments regarding fares and fare collection. This method also adds more complexity to the fare collection responsibilities for our Coach Operators.

The methods described above are used in various combinations throughout the transit industry in the United States, including in Los Angeles County. In contrast, the Unsolicited Proposal from AmericanEagle.com proposes a solution to Foothill Transit that is unique and, heretofore, untried in the United States.

AmericanEagle.com has designed a solution that uses a radio frequency identification (RFID)/Two-dimensional barcode for validation. The RFID/barcode tag is passive and does not require a power source, and the various form factor of the tag allows flexible options for placement. After downloading the free mobile application on their mobile phones, customers can purchase Foothill Transit's fare products and retrieve real-time bus arrivals. Each time the customer boards, he/she will need to open the application, and depending on the make and model of the customer's phone, they will either tap or scan the RFID/barcode tag. The application will default to tapping, but if the phone does not have the tapping capability, then the application will launch the scanning function. Once the customer taps or scans the tag, the application will determine its validity through the provided data from the CAD/AVL system. After the application validates the mobile ticket, the validated ticket appears as a screen on their phone, at which point the customer will show the Coach Operator the mobile ticket. The validated screen will display several unique security features to help Coach Operators easily and accurately identify validated tickets. The Coach Operator will not need to interact with the farebox to capture ridership data since the mobile application collects all ridership, boarding location, route, and bus number data.

In addition to the mobile application and validating mechanism, the RFIQ also asked for responses on providing an integrated POS system equivalent to that of AmericanEagle.com, and none of the eight proposers was able to provide a similar or better system. Some of the proposers were able to provide a simple standard POS system, but the integration was limited for integrating to Foothill Transit's accounting software and mobile application data collection methodology.

The Unsolicited Proposal submitted by AmericanEagle.com is clearly a unique solution that provides originality of thought for mobile ticket validation with the inclusion of the POS system. The integrated POS system integrates with Foothill Transit's existing systems in a way that will streamline business processes and improve overall efficiencies. The proposed solution enhances our ability to learn more about our customers, which enables us to provide a better experience on Foothill Transit services.

Budget Impact

Funding for this capital project is included in the approved Fiscal Year 2017-2018 Business Plan and Budget for fare revenue collection system improvements and enhancements.

Sincerely,

M Caldwell for

John Xie
Revenue Manager

Doran J. Barnes
Executive Director