Maximize Clean Transit Investment

Natural Gas Outperforms Electric

NGVAMERICA
Natural Gas Vehicles for America

Contents

Executive Summary

The Move Toward Cleaner Transit

This report by NGVAmerica includes a review of recent studies and reports that evaluate natural gas and battery electric transit buses. Much of this report is based on data generated by the National Renewable Energy Laboratory as part of its evaluations of transit bus operations, including Foothill Transit in California, but also included are the findings from a number of other recent reports and studies.

The desire for cleaner air and the urgency of fighting climate change has put additional emphasis on ensuring that transit buses are powered by the cleanest available fuels. Many environmental advocacy and public interest groups contend that state and local governments must mandate the purchase of battery powered electric vehicles, arguing that only zero emission buses adequately address concerns related to urban emissions and climate change. The State of California has responded by mandating all new transit bus purchases be zero emission by 2029. Other government authorities are considering similar mandates.

Advocates for electric or zero emission bus mandates ignore the fact that natural gas-powered buses – including buses that operate on conventional (or geologic) natural gas and renewable natural gas (or natural gas derived above ground from renewable waste streams) – in many cases provide a more viable, proven and cost-effective solution to lowering urban pollution and addressing climate change emissions than battery electric buses.

By leveraging continued investments in new, cleaner natural gas buses communities can actually achieve greater reductions in pollution and generate greater economic savings compared to operating more costly (in all aspects) and unproven electric bus fleets. The savings reaped from continuing to invest in natural gas buses will allow communities to invest the additional funds in expanded public transit services or other worthy public projects.

Flawed Cost Arguments and An Impractical Solution

Battery electric bus (BEB) advocates contend that while electric buses are more costly to purchase today, they are less expensive to operate and maintain over their full lifetime, and that in the future, eventually battery electric buses will be less costly to purchase due to declining battery costs. As demonstrated in this NGVAmerica report, claims of significant lifetime savings are not supported by existing data. In fact, electric buses are not less costly to own and operate over their lifetimes than natural gas buses or diesel buses. Moreover, future demand for batteries driven by electric vehicle mandates in the U.S. and elsewhere for light-duty passenger automobiles combined with limited sources of needed battery components and elements are likely to result in upward, not downward, pressure on future battery prices.

Battery electric buses also have not demonstrated that they are capable of providing the reliable service required of public transit operations. As shown in this report, battery electric buses deployed in the U.S. have largely been operated on shorter, specially selected routes, accumulating far fewer annual miles than natural gas buses. Even in these less-demanding conditions, electric buses have failed to demonstrate the same level of reliability and cost-effectiveness as natural gas buses. Deploying electric buses on longer, more demanding routes will require installing additional batteries on electric buses (or greatly expanding costly on-route charging) resulting in higher costs. Available natural gas buses operated throughout the country have been deployed in numerous types of operations regardless of terrain and are capable of performing on shorter and longer routes without compromise.

While many portray electric buses as being capable of supplanting natural gas buses on a 1:1 basis and make cost comparisons based on this key assumption, several recent reports raise doubts about whether transit agencies will actually be able to completely switch to all-electric bus fleets without reducing service, shortening routes or adding additional numbers of buses into their overall fleets. When factoring in the need for additional buses and costly infrastructure upgrades, the costs for going fully electric can be staggering.

More Affordable, More Reliable, and Greater Environmental Impact

Based on a review of existing studies evaluating natural gas and electric buses, it is apparent that natural gas buses are more affordable, more reliable and deliver greater environmental benefit than electric buses. Compare the Benefits of CNG and Battery Electric Transit Buses Including Key Takeaways from their use in NREL's Foothill Transit Study:[1]

Table 1

	CNG	BEB	Results
Cost			
Unit Cost	X		Electric bus purchase price 57 – 67 percent higher than CNG bus (based on Foothill cost and average 2019 bus prices reported by APTA)
Fuel Purchase Cost	X		Electricity on an energy equivalent basis costs 6x more than CNG at Foothill
Fuel Cost Per Mile	X	X	Efficiency considerations can make this a tossup, but it is important that all relevant costs are considered including cost of maintaining and operating fueling equipment, which is often omitted in reported electricity costs
Repair and Maintenance Costs	X		$0.41/mile (CNG) vs. $0.68/mile (BEB)
Total Cost Per Mile	X		Overall, BEB cost 1.5x more than CNG to operate
1-to-1 Replacement for Diesel	X		Takes more than one new BEB to replace one diesel/CNG bus when considering range, capacity, and performance
Reliability			
Days Available for Service	X		93 percent (CNG) vs. 63 percent (BEB)
Miles Between Road Events	X		CNG performance exceeded BEB by 18,000-20,000 miles between road calls
Resiliency	X		CNG can be refueled quickly and returned to service, BEB needs multiple hours of charging to return to full readiness – difficult during times of emergency or longer- term loss of power
Performance			
Route/Deployment	X		BEB deployed only on carefully selected routes; no such limitations for CNG
Range	X		CNG buses do not require mid-route refueling
Vehicle Efficiency		X	BEB vehicle energy efficiency is higher than CNG, though ratings often do not reflect actual in-use results or sizable energy losses associated with BEB charging
Weather Impact	X		BEB efficiency suffers in extreme cold; no like impact on CNG
Passenger HVAC	X		BEBs have difficulty with battery-powered heating and cooling, requiring a fuel-powered solution
Made in America			
Fuel/battery components	X		100 percent domestic fuel vs. foreign-sourced and controlled battery components (i.e. cobalt)
Technology	X	X	FTA-funded buses required by law to be assembled in USA
Infrastructure	X		CNG refueling contributes to the Federal Highway Trust Fund which supports transportation infrastructure funding including FTA funding for transit buses; EV charging does not, undermining funding to maintain transportation infrastructure and FTA new bus funding programs
Environmental Impact			
Zero tailpipe	X	X	Zero (BEB) vs. 0.02 g/bhp-hr NOx (CNG), a negligible difference, as new CNG buses reduce emissions by 99 percent (NOx) and 96 percent (PM) than pre-2010 transit buses
Well-to-Wheel NOx	X		When considering full well-to-wheel emissions, in most cases CNG buses fueled with RNG beat BEBs on NOx impact due to how power is produced in electric grid mix
Carbon intensity of fuel	X	X	Up to -400 EER-adjusted CI (CNG) vs. up to zero (BEB) if all renewable solar or wind electricity is used
Net-carbon negative	X		When fueled with RNG, CNG bus can offer an emissions result 400 percent better than electric bus, even when BEB powered by 100 percent renewable solar or wind
Delivered Emissions Reductions			
$ for $	X		$105 per lb. of NOx reduced (CNG) versus $159 (BEB) based on acquisition cost of comparable size buses
More Buses and More Emissions Reduced	X		Replace more buses, get more emissions reductions with same $ investment

[1]https://www.nrel.gov/transportation/fleettest-electric-foothill.html

Other Key Findings and Takeaways

Fully Accounting for All Costs is Critical

The reason that transit agencies thus far have been able to deploy more costly electric buses without making significant sacrifices has been the availability of significant federal and state financial support that largely masks the true cost of owning and operating such vehicles. Several recent reports candidly acknowledge that but for these subsidies, electric buses (and really most other types of electric vehicles) would simply not be cost effective to operate as compared to natural gas vehicles. And while these funds can be useful in demonstrating the viability of electric buses for certain applications, there simply are not enough available public funds to fully offset the enormous cost of a wholesale shift to electric buses.

True cost effectiveness comparisons should consider all costs including upfront acquisition costs, operational and maintenance costs, and fueling infrastructure costs. Whether these costs are borne by the transit agency deploying the buses or some other governmental entity, these are still costs that could be deployed to support other technologies or fund different goods and services and therefore they should be properly considered.

Many transit agencies in the U.S. already have natural gas fueling infrastructure, so a true cost comparison should factor the savings associated with continuing to monetize this infrastructure instead of having to invest in new, costly electric charging infrastructure. As part of its compliance with the California Air Resources Board's (CARB) Innovative Clean Transportation (ICT) regulation requiring transit agencies in California to switch exclusively to zero emission buses, Foothill Transit commissioned Burns & McDonald Engineering Company to produce an "In Depot Charging and Planning Study." That study found that Foothill Transit will need to invest $120.6 million in infrastructure development over the next twelve years in order to adequately power a full fleet of 373 mandated electric buses.[2] This figure does not include required investments the local electric utility and its ratepayers must incur to support this transition.

A 2016 study by MJ Bradley & Associates and Ramboll Environ commissioned by the Los Angeles County Metropolitan Transportation Authority (MTA) and the Advanced Transit Vehicle Consortium concluded that the agency would save between $3.5 billion to $5.7 billion over 40 years by continuing to utilize its existing natural gas fueling infrastructure and transitioning 100 percent to all low-NOx natural gas buses fueled by renewable natural gas (RNG). This same study also projected much higher overall and immediate environmental benefits generated by going with natural gas buses over electric or fuel cell buses.[3]

Based on current evaluations and comparisons, it is fair to say that electric buses in most cases will be more expensive to fuel and maintain than natural gas buses and in limited other cases are only slightly less expensive to fuel and maintain. As noted in this report, it is important to consider whether comparisons fully evaluate all factors and adjust accordingly since, to date, no study has evaluated natural gas and electric buses operating in exactly the same conditions on the same routes. It is clear, however, that the savings associated with operating electric buses where they do exist are far from sufficient to offset the higher capital costs for fueling infrastructure or bus acquisition; therefore when all factors are considered, natural gas buses are significantly more cost-effective.

Grid Upgrades

Electric bus advocates fail to evaluate the cost and extent of major utility upgrades needed to accommodate an expected surge in electricity transmission and demand for electric buses, upgrades not needed to fuel natural gas buses. These factors are easily overlooked in the case of demonstration projects involving only a limited number of buses but can quickly become overwhelming when converting an entire fleet to electricity. This is not an issue for natural gas as many bus facilities around the country have been converted entirely or almost entirely to natural gas with hundreds of buses fueling at a single depot. Nearly 100 transit agencies currently operate more than 10,000 natural gas buses with additional natural gas buses successfully in service at many other facilities such as airports and colleges across the United States.

Reliability

In the reports evaluated by NGVAmerica, natural gas buses have demonstrated that they are more reliable than electric buses, accumulating far more service miles, spending fewer days out of service and under-repair than electric buses. A key factor of reliability is availability for pull out. In the studies prepared by NREL evaluating real-world bus fleets, natural gas buses more than exceed the expected rate of 85 percent availability while electric buses struggle to meet the requirement. In the Foothill fleet, during the most recent evaluation period the twelve 35-foot electric buses had an average availability rate of 63 percent. Daily per-bus

[2] "In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Page 13-4, September 9, 2019.

[3] "Zero Emission Bus Options: Analysis of 2015-2055 Fleet Costs and Emissions," MJ Bradley and Associates and Ramboll Environ for Los Angeles County Metropolitan Transportation Authority and the Advanced Transit Vehicle Consortium, September 29, 2016.

availability for electric buses was as low as 46 percent during the first half of 2019. In contrast, CNG buses had an availability rate of 93 percent for the same period and an overall availability rate of 96 percent.[4]

Once out on route, CNG buses had far fewer road calls, or revenue vehicle system failures, than their electric counterparts in the Foothill study. Such incidents require a bus to be replaced on route and/or cause a significant schedule delay affecting system operations. Such reliability in the transit industry is measured in mean distance (miles) between failures (road calls), or MBRC. At Foothill, the average miles between road calls for natural gas buses exceeds that of the BEBs by between 18,000 to almost 20,000 miles.[5]

Fuel Efficiency

Much attention is given to the efficiency of electric buses but very few studies or reports acknowledge efficiency losses associated with charging infrastructure which can increase energy consumption by 10 – 15 percent. And when determining the overall energy efficiency of electric bus transit operations, it is important to consider that more than 60 percent of energy used to generate electricity is lost in conversion. According to the U.S. Department of Energy, U.S. utility-scale generation facilities consumed 38 quadrillion British thermal units (quads) of energy to produce only 14 quads of electricity last year.[6]

Efficiency claims also almost never acknowledge the trade-offs associated with heating and cooling of buses, which is not accounted for in the test cycles used to determine efficiency ratings of transit buses. Another fact that is often omitted is the large percentage of electric buses that are equipped with fossil fueled heaters to reduce the need to draw on electricity to provide heat. Such heaters can be a significant emission source that are not at all considered.

CNG Buses Provides More Work, More Reliability

In the Foothill study, natural gas buses performed more work and were more reliable than the BEBs, two critical metrics for transit agencies. The average miles traveled by the natural gas buses exceeded that of the BEBs each month by between 2,200 and 2,800 miles.[7] While most cost comparison studies assume equivalent mileage for electric and natural gas buses, the reality is that fewer lifetime miles means that these studies greatly underestimate the true cost of operating electric buses.

New Natural Gas Buses are Zero Emissions Equivalent

Natural gas buses today reduce harmful emissions of nitrogen oxides (NOx) and particulate matter (PM) by more than 95 percent compared to transit buses built prior to 2010, thus the emission difference between new natural gas buses and electric buses, which have no tailpipe emissions but do have particulate matter emissions associated with tire wear and braking, are miniscule. Importantly, natural gas buses produce these emission reductions without relying upon costly and cumbersome emission control equipment.

Fueling transit buses with conventional (geologic) natural gas reduces greenhouse gas emissions (GHG) by about 12 percent compared to diesel. But according to the California Air Resources Board, fueling buses with renewable natural gas (biomethane) collected at local landfills, wastewater treatment plants, commercial food waste facilities, and agricultural digesters can yield a carbon-negative lifecycle emissions result. According to CARB data, renewable natural gas (RNG) holds the lowest carbon intensity of any on-road vehicle fuel, including fully renewable electric. On-road natural gas fueling trends show increasing adoption of RNG. According to data from the U.S. Energy Information Administration (EIA) and U.S. Environmental Protection Agency (EPA) Renewable Fuel Standard reporting, 39 percent of all on-road natural gas fuel in 2019 was RNG. In California, 77 percent of all on-road natural gas fuel in 2019 was RNG.

Adding It All Up

When you add it all up, natural gas provides a winning solution for transit agencies looking to lower costs and reduce emissions. As estimated in this report, it could cost billions – as much as $24 billion more – to switch the majority of the U.S. larger bus fleets to an all-electric fleet. Switching the majority of the U.S. bus fleet to an all-CNG fleet powered by RNG would not only save significant capital and operating amounts of money but also would generate much greater annual emission reductions: 10,000 tons of GHG, 25 tons of NOx, and 6.26 tons of PM2.5.

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[4]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 21, October 2019.
[5]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 35, October 2019.
[6]"More than 60 percent of energy used for electricity generation is lost in conversion," Today in Energy series, U.S. Energy Information Administration, July 21, 2020.
[7]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 14, October 2019.

Investing in Natural Gas Buses = More Clean Buses

+

More Cost-Effective Emissions and Climate Impact

+

No Deterioration of Service Due to Technology Limitations

Introduction

The Move Toward Cleaner Transit

An increased desire to address urban air pollution and climate change emissions have put additional emphasis on ensuring that transit buses are powered by the cleanest available fuels.

Many environmental advocacy and public interest groups have urged state and local governments to mandate the purchase of battery powered electric vehicles, arguing that only zero emission buses can address concerns related to urban emissions and climate change. In response, the State of California has adopted rules mandating that all new buses purchased after 2029 by state transit systems must be zero emission. Other government authorities outside California are considering similar mandates.

Advocates of these policies ignore the fact that natural gas-powered buses – including buses that operate on conventional (or geologic) natural gas and renewable natural gas (or natural gas derived above ground from renewable waste streams) – in many cases provide a more viable, proven and cost-effective solution to lowering urban pollution and addressing climate change emissions than their battery electric counterparts. The push to mandate specific technology limits competition unnecessarily drives up costs and slows down the achievement of cleaner air.

A Flawed Cost Argument

Battery electric bus (BEB) advocates contend that although electric buses are more costly to purchase up front, they are less expensive to operate and maintain over their full lifetime, and that soon battery electric buses will be less costly to purchase due to declining battery costs.

However, these claims are not supported by existing data; in fact, electric buses are more expensive to operate than natural gas buses or diesel buses.

Moreover, future demand for batteries driven by electric vehicle mandates is likely to put upward, not downward, pressure on future battery prices and could result in supply constraints for batteries due to limited and restricted access to needed components. One example is the continued delay of Tesla's expected delivery of its commercial Semi Class 8 tractor. A prototype was first unveiled in 2017 with production scheduled to begin in 2019. Tesla pushed delivery back again to 2021; analysts reason the added delay is due, in part, to tightening global battery supply.[1]

A recent paper by the UC Berkeley School of Law and the Natural Resources Governance Institute citing analysis by the scientific journal Nature, shows that "demand for essential battery components could exceed supply within decades (by 2030 for cobalt and 2037 for nickel) without further developments in battery mineral composition" and a World Economic Forum reports of a looming supply crunch for battery materials.[2]

The global COVID-19 pandemic and associated lockdowns could further impact the availability of key metals needed to ramp up production of electric vehicle batteries, according to a June 2020 analysis by BloombergNEF. "Already prone to supply shortages, cobalt could fall into a moderate supply deficit this year that could worsen from 2021 to 2023," reports *E&E News*.[3]

Battery electric buses as shown in this report – even when operated on shorter routes and when accumulating far fewer miles than natural gas buses – have failed to demonstrate the same level of reliability and struggled to provide the same level of cost-effectiveness as natural gas buses. Less reliability requires additional bus purchases to ensure a sufficient number of backup units are available to maintain adequate route coverage. In the Foothill Transit example, the agency deploys a total of 14 battery electric buses to service a route that during peak periods only requires 7 natural gas buses to be in operation.[4]

Based on the current deployment trends, it is not known how efficient electric buses will be when operated on longer, higher speed routes; they are generally deployed on carefully selected, slower speed and shorter range routes which means they can be ordered with fewer batteries than required for longer range routes or with less infrastructure than is needed for on-route recharging. Deploying electric buses on longer, more demanding routes requires installing additional batteries on electric buses thus increasing their cost. If additional battery capacity is not added, electric buses deployed on longer routes will require on route high speed charging.

Available natural gas buses operated throughout the country are deployed in a wide variety of operations and perform equally on short and long routes without compromise. The natural gas buses evaluated in available reports perform on all routes without requiring changes to routing or added downtime during the day for refueling. At the same time, natural gas buses dedicated to operating on shorter routes, as some electric buses are, could be equipped with fewer fuel cylinders at less cost and with less weight and increased efficiency, further improving the economics of operating them.

[1] "Tesla Delays First Deliveries of Electric Semi to 2021," *Transport Topics*, May 5, 2020. Available at: https://www.ttnews.com/articles/tesla-delays-first-deliveries-electric-semi-2021

[2] "Building a Sustainable Electric Vehicle Battery Supply Chain: Frequently Asked Questions," UC Berkeley School of Law's Center for Law, Energy & the Environment and the Natural Resource Guidance Institute, Page 6, April 2020.

[3] Willson, Miranda, "EV Supply Chain Could See Years of Shortages – Report," *E&E News*, June 9, 2020.

[4] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jul. 2019 through Dec. 2019, NREL/PR-5400-75581, National Renewable Energy Laboratory, slide 16, dated March 2020.

More Affordable, More Reliable, and Greater Environmental Impact

Comparing the Benefits of CNG and Battery Electric Transit Buses Including Key Takeaways from their use in NREL's Foothill Transit Study:[5]

Table 1

	CNG	BEB	Results
Cost			
Unit Cost	X		Electric bus purchase price 57 – 67 percent higher than CNG bus (based on Foothill cost and average 2019 bus prices reported by APTA)
Fuel Purchase Cost	X		Electricity on an energy equivalent basis costs 6x more than CNG at Foothill
Fuel Cost Per Mile	X	X	Efficiency considerations can make this a tossup, but it is important that all relevant costs are considered including cost of maintaining and operating fueling equipment, which is often omitted in reported electricity costs
Repair and Maintenance Costs	X		$0.41/mile (CNG) vs. $0.68/mile (BEB)
Total Cost Per Mile	X		Overall, BEB cost 1.5x more than CNG to operate
1-to-1 Replacement for Diesel	X		Takes more than one new BEB to replace one diesel/CNG bus when considering range, capacity, and performance
Reliability			
Days Available for Service	X		93 percent (CNG) vs. 63 percent (BEB)
Miles Between Road Events	X		CNG performance exceeded BEB by 18,000-20,000 miles between road calls
Resiliency	X		CNG can be refueled quickly and returned to service, BEB needs multiple hours of charging to return to full readiness – difficult during times of emergency or longer- term loss of power
Performance			
Route/Deployment	X		BEB deployed only on carefully selected routes; no such limitations for CNG
Range	X		CNG buses do not require mid-route refueling
Vehicle Efficiency		X	BEB vehicle energy efficiency is higher than CNG, though ratings often do not reflect actual in-use results or sizable energy losses associated with BEB charging
Weather Impact	X		BEB efficiency suffers in extreme cold; no like impact on CNG
Passenger HVAC	X		BEBs have difficulty with battery-powered heating and cooling, requiring a fuel-powered solution
Made in America			
Fuel/battery components	X		100 percent domestic fuel vs. foreign-sourced and controlled battery components (i.e. cobalt)
Technology	X	X	FTA-funded buses required by law to be assembled in USA
Infrastructure	X		CNG refueling contributes to the Federal Highway Trust Fund which supports transportation infrastructure funding including FTA funding for transit buses; EV charging does not, undermining funding to maintain transportation infrastructure and FTA new bus funding programs
Environmental Impact			
Zero tailpipe	X	X	Zero (BEB) vs. 0.02 g/bhp-hr NOx (CNG), a negligible difference, as new CNG buses reduce emissions by 99 percent (NOx) and 96 percent (PM) than pre-2010 transit buses
Well-to-Wheel NOx	X		When considering full well-to-wheel emissions, in most cases CNG buses fueled with RNG beat BEBs on NOx impact due to how power is produced in electric grid mix
Carbon intensity of fuel	X	X	Up to -400 EER-adjusted CI (CNG) vs. up to zero (BEB) if all renewable solar or wind electricity is used
Net-carbon negative	X		When fueled with RNG, CNG bus can offer an emissions result 400 percent better than electric bus, even when BEB powered by 100 percent renewable solar or wind
Delivered Emissions Reductions			
$ for $	X		$105 per lb. of NOx reduced (CNG) versus $159 (BEB) based on acquisition cost of comparable size buses
More Buses and More Emissions Reduced	X		Replace more buses, get more emissions reductions with same $ investment

[5]https://www.nrel.gov/transportation/fleettest-electric-foothill.html

About this Report

This NGVAmerica document is based largely on data presented in the Foothill Transit Electric Bus Evaluation, a project by the National Renewable Energy Laboratory (NREL) – a national laboratory of the U.S. Department of Energy. The Foothill Evaluation was selected as the primary focus for this document because it includes real-world operational and cost data and, to date, is the longest and most extensive study of its kind in North America. However, several other recent studies including an on-going evaluation of Long Beach Transit by NREL, a report by the Rocky Mountain Institute for Seattle City Light, a 2019 ICF report on Medium- and Heavy-Duty Technologies in California, as well as a number of other sources are referenced and cited throughout this document.

The purpose of the Foothill project is to evaluate the in-service performance of 14 fast-charge battery electric buses (BEBs) compared to 8 conventional compressed natural gas (CNG) buses in order to assess their cost and reliability of operation. The buses in this study – with the exception of two electric buses – are of similar age but are operated on different routes by Foothill Transit Agency in West Covina, California. Foothill Transit purchased the BEBs with grant funding from the Federal Transit Administration's Transit Investments for Greenhouse Gas and Energy Reduction Program.

Foothill Transit is a medium-sized municipal operator in Los Angeles County, California, second in fleet size only to regional provider LA Metro. It operates 376 buses in service on 39 local and express routes in a 327 square area of the San Gabriel and Pomona Valley. On average, Foothill Transit serves more than 48,000 riders per weekday and approximately 14 million riders per year.[6]

The study was launched in 2015 in conjunction with a previously funded California Air Resources Board research project with the aim of improving the understanding of the overall usage and effectiveness of fast-charge electric buses and associated charging infrastructure in transit operation.

Foothill Transit has fully electrified one route in its service area and recently completed an investigation of the feasibility of electrifying its entire fleet. The electric buses include twelve 35 foot and two 42.5-foot Proterra buses. The 35-foot buses are equipped with seating for 35 persons and powered by eight 368 V lithium-titanate battery packs offering 88 kWh of energy. The 42.5-foot buses are equipped with 40 seats and powered by 331V lithium-titanate batteries that provide 106 kWh total energy.[7] The electric buses can be completely charged in less than 10 minutes via two 500kW fast chargers located mid-way along the route. The natural gas buses include eight 42-foot buses manufactured by NABI and equipped with seating for 38 persons (APTA's 2019 Public Transportation Vehicle Database indicates these buses have seating for 40). All of the buses in this evaluation were Model Year 2014 except for the two 42.5-foot electric buses which are listed as Model Year 2016.

NREL publishes study data every six months beginning in January 2016 through 2020. Data in this evaluation is based off the report released October 2019.[8] In July 2020, NREL released an update of this report that includes data for the second half of 2019, The report is dated March 2020 but made available in July 2020 just as this white paper was finalized.[9]

[6]http://foothilltransit.org/about/fast-facts/.
[7]https://www.nrel.gov/transportation/fleettest-electric-foothill.html.
[8]https://www.nrel.gov/docs/fy20osti/73516.pdf.
[9]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jul. 2019 through Dec. 2019, NREL/PR-5400-75581, National Renewable Energy Laboratory, dated March 2020.

Key Findings and Takeaways

Natural Gas Buses are Less Expensive to Purchase

Foothill Study Reported Bus Pricing

The chart below details the vehicles included in the Foothill study. Of the buses purchased in 2014, the natural gas version cost considerably less than the electric buses – about $329,000 saved or 36 percent less in acquisition costs per bus than the electric counterpart.[10]

[a]*Includes amenities such as painting of bus and livery, surveillance system, PA system, radio, safety vision monitor. Range based on 100% fuel utilization for both CNG and battery-electric and in case of natural gas based on NABI/NewFlyer literature (https://www.newflyer.com/buses/xcelsior-cng/)."*

Table 2

Vehicle System	BEB 35FC	BEB 40FC	CNG
Number of Buses	12	2	8
Bus manufacturer/model	Proterra/BE35	Proterra/Catalyst Fast Charge	NABI/BRT-07.03
Model year	2014	2016	2014
Bus purchase cost[a]	$904,490	$879,845	$575,000
Length/width/height	35 ft/102 in/129 in	42.5 ft/102 in/ 134 in	42 ft/ 102 in/137 in
GVWR/curb weight	37,320 lb/27,680 lb	39,050 lb/27,000 lb	42,540 lb/ 33,880 lb
Wheelbase	237 in	296 in	308 in
Passenger capacity	35 seats, 2 wheelchair positions, 18 standees	40 seats, 2 wheelchair positions, 18 standees	38 seats, 2 wheelchair positions, 10 standees
Motor or engine	Permanent Magnet, UQM, PP220	Permanent Magnet, UQM, PP220	CNG engine, Cummins Westport, 8.9 ISL G
Rated power	220 kW peak (295 hp)	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	Lithium-titanate batteries, Toshiba, TerraVolt 331 volts, 106 kWh total energy	7 Type IV cylinders, 22,204 scf at 3,600 psi
Maximum Range	41 miles	49 miles	400
Accessories	Electric	Electric	Mechanical
Emissions equipment	N/A	N/A	3-way catalyst
Transmission/retarder	Regenerative braking	Regenerative braking	N/A

[10]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 11, October 2019. APTA's 2019 Public Transportation Vehicle Database lists the purchase price for the Proterra BEB 40FC bus at $890,000. It also lists the 2014 NABI CNG bus as having 40 seats, not 38.

Long Beach Study Reported Bus Pricing

A similar study comparing BEBs and CNG transit buses in Long Beach, California completed by NREL for the Federal Transit Administration reports an almost two-to-one cost difference between 40-foot BEBs and 40-foot CNG buses – $1,002,550 versus $546,314.[11] **See Table 3**

American Public Transportation Association Reported Bus Pricing

Figures from the American Public Transportation Association's 2019 Public Transportation Vehicle Database are shown at right.[12] By identifying buses of the same or very similar size and seating and evaluating the same years of manufacture, it is apparent that newer natural gas buses continue to retain a sizable average price advantage over new electric buses. Note – "MB" stands for "Motor Bus". **See Table 4**

Many pro-BEB studies cite lower costs for battery electric buses, likely because a 30- or 35-foot bus price point is used. But there is a significant cost differential between 30- and 35-foot BEBs and 40-foot and larger BEBs. APTA's 2019 database shows just how significant this average cost differential is for buses delivered to California transit agencies.[13] **See Table 5**

Table 3

Vehicle System	BEB	CNG
Number of Buses	10	8
Bus manufacturer	BYD	Gillig
Bus year and model	2015 6120 LGEV	2014 G27B102N4
Length (ft.)	40.2 Ft.	40 Ft.
GVWR (lb.)	43,431	41,600
ESS	LiFePO4 (LFP) Ferro type Lithium Iron Phosphate	N/A
Electric drive motor or engine	BYD-TYC90A, Traction Motor 90 kW	Cummins ISL G280 280 hp
Accessories	Electric	Mechanical
Energy storage or fuel capacity	324 kWh (original) 360 kWh (ESS upgrade)	25,304 SCF @ 3,500 psi
Charging equipment	50 kW WAVE induction charging system	N/A
Bus purchase cost	$1,002,550	$546,314

Table 4

MB 40 foot Built	2017	2018	2019
CNG	$530,909	$538,394	$551,055
Diesel	$470,384	$495,435	$498,971
EB 40 foot	$836,333	$869,451	$919,289
EB 41 foot	$800,000		
EB 42 foot	$789,000	$836,100	$794,500

Table 5

CA Average Price Paid for BEB MB 40 - 42 foot		
2017	Build Years	$869,500.00
2018	Build Years	$873,460.67
2019	Build Years	$903,679.00
2020	Build Years	$927,000.00
CA Average Price Paid for BEB MB 30 - 35 foot		
2017	Build Years	$399,000.00
2018	Build Years	$580,000.00
2021	Build Years	$618,000.00

[11] "Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses," Federal Transit Administration, FTA Report No. 0163; Table 2-1, Page 7; April 2020. http://foothilltransit.org/about/fast-facts/.
[12] "Public Transportation Vehicle Database," American Public Transportation Association (APTA), 2019
[13] "Public Transportation Vehicle Database," American Public Transportation Association (APTA), 2019. There were no 35-foot electric buses delivered in the years shown.

And when considering what BEB price to use in evaluating overall operational cost, it is important to note that the vast majority of transit buses deployed in the United States are 40-foot or larger.[14] **See Table 6**

Table 6

APTA Bus Count 2019 Report	Active	40' or Greater	40' or Greater
Commuter Buses	1,549	1,480	96%
Motor Buses	54,606	45,444	83%
Bus Rapid Transit	500	472	94%
Combined	56,655	47,396	84%

ICF Study Estimated Bus Pricing

A 2019 ICF report prepared for the California Electric Transportation Coalition and the Natural Resources Defense Council includes conclusions on current costs that are based on unrealistically low prices for electric buses and offers conflicting data on other bus pricing.

Table II-1, "2019 Bus Initial Purchase Price Assumptions in 2019$" within the report's Part II copy cites prices as in[15] **See Table 7**

Table 7

Vehicle System	Diesel	CNG	Electric	Hydrogen
Bus Purchase Cost	$476,000	$544,000	$753,000	$1,100,00

But more detailed data presented in the Total Cost of Ownership Technology Analysis appendix – Table VI-11, "Transit Bus Details Results" – cites different numbers for all but the electric technology.[16] **See Table 8**

Table 8

Vehicle System	Diesel	CNG	Electric	Hydrogen
Bus Purchase Cost	$435,000	$500,000	$753,000	$1,200,00

Assuming its more detailed data presented in the appendix is correct, the ICF study estimates that natural gas buses – while only slightly more expensive than diesel – are 34 percent less expensive than battery electric buses.

Transit agencies deploying electric buses have depended on extremely costly funding programs to underwrite their costs. The ICF report notes, "The HVIP incentive is the most critical for current electric trucks and buses to be competitive on a TCO (total cost of ownership) basis. Without this incentive for electric technologies, diesel and/or natural gas options for almost all categories have a lower TCO."[17]

ICF estimates that total incentive funding (including HVIP, LCFS, and utility incentives) for electric buses in California to be over $235,000 per bus, but just over $16,000 for natural gas buses.[18] Outside of California a large number of transit agencies deploying electric buses have benefited from the Federal Transit Administration's Low or No Emission Bus Program[19], which to date has provided several hundred million dollars in federal aid for electric buses.

ICF's conclusion regarding the need for funding for electric buses to be competitive with natural gas buses is all the more stunning given the unrealistically low price it uses for electric buses and the fact that ICF assumes costs related to natural gas fueling infrastructure even though a large number of California transit agencies already have natural gas fueling infrastructure and would not need to make major investments to continue future deployment of new natural gas buses. It also is significant that the ICF report assumes lower fuel costs and operational and maintenance costs for electric buses that are not supported by the real-world data in the NREL Foothill Transit study.

Federal Transit Administration (FTA) funding – where available – will pay 80 to 85 percent of the cost of a new transit bus purchased by a transit agency. Funding for transit comes from a number of different programs funded by the federal excise tax on motor fuels. The vast majority of funding is formula grant money that is apportioned to the states based on statutory criteria.

[14]"Public Transportation Vehicle Database," American Public Transportation Association (APTA), 2019.
[15]"Comparison of Medium- and Heavy-Duty Technologies in California," Prepared for California Electric Transportation Coalition and the Natural Resources Defense Council by ICF; Part 2, Table II-1, Page 2; December 2019.
[16]"Comparison of Medium- and Heavy-Duty Technologies in California," Prepared for California Electric Transportation Coalition and the Natural Resources Defense Council by ICF; Part 2, Table VI-11, Page 45; December 2019.
[17]"Comparison of Medium- and Heavy-Duty Technologies in California," Prepared for California Electric Transportation Coalition and the Natural Resources Defense Council by ICF; Part 2, Page 33; December 2019.
[18]"Comparison of Medium- and Heavy-Duty Technologies in California," Prepared for California Electric Transportation Coalition and the Natural Resources Defense Council by ICF; Part 2, Table VI-11, Page 45; December 2019.
[19]https://cms7.fta.dot.gov/funding/grants/lowno

Table 9: Active Transit Vehicles by Source of Federal Funding from 2013 National Transit Database Revenue Vehicle Inventory for Urbanized Areas (Vehicles only in Urbanized Areas)

	Type of Vehicle				
Funding Source	All Bus	Vans and Automobile Based	All Rail	Ferry Boat	All Vehicles
Number of Vehicles					
Urbanized Area Formula Program	54,825	7,271	8,213	59	70,368
Other Federal Programs	13,375	4,638	5,928	12	23,953
Subtotal All Federal Programs	*68,200*	*11,909*	*14,141*	*71*	*94,321*
No Federal Funding	15,408	29,689	8,171	86	53,354
Total	83,608	41,598	22,312	157	147,675
Percent of Each Column					
Urbanized Area Formula Program	65.6%	17.5%	36.8%	37.6%	47.7%
Other Federal Programs	*16.0%*	*1.1%*	*26.6%*	*7.6%*	*16.2%*
Subtotal All Federal Programs	81.6%	28.6%	63.4%	45.2%	63.9%
No Federal Funding	18.4%	71.4%	36.6%	54.8%	36.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: National Transit Database, 2013

A significant amount of funding also is transferred to the states by discretionary programs administered by the FTA.[20] As shown above, large urban areas rely on federal funding for their transit bus purchases with federal dollars offsetting more than 80 percent of the funding needed to acquire new buses and states contributing only about 18 percent for new buses. **See Table 9**

Higher Vehicle Costs Impact Bus Replacement Rates

The higher costs of new electric buses regardless of replacement rates mean that transit agencies purchasing electric buses will not be able to purchase as many new buses as agencies purchasing diesel or natural gas buses and therefore a greater number of more polluting, older vehicles will remain in service for longer periods of time. This approach of prioritizing the purchase of more costly buses can result in fewer buses on the road, which in turn reduces service and negatively impacts job growth in communities where residents greatly rely upon public transportation to access them.

[20] "Public Transportation Investment Background Data," American Public Transportation Association, Page 21; November 2015.

Natural Gas Refueling is More Affordable, Efficient, and Convenient

Electric bus advocates fail to accurately account for the massive costs involved with constructing and maintaining the charging infrastructure required to regularly charge a large fleet of electric buses.

While a typical natural gas bus refueling event is most like traditional diesel bus refueling, lasting roughly 10 minutes for a complete fill, battery electric bus charging times vary according to the load provided. And like their diesel counterparts, typical natural gas buses have roughly a 400-plus-mile range on a complete fill. That means there is no down time during the day for natural gas buses or breaks in service for refueling while buses are in route as is often the case with electric buses.

Further, differences in energy efficiency exist between the types of charging: in-depot versus on-route. An NREL BEB study of the Central Contra Costa Transit Authority in the East Bay of San Francisco area reports charging efficiency for depot charging at 92.8 percent while the efficiency of the inductive charging lags behind at 85.2 percent, bringing a system average of 86.9 percent. Overall monthly charging efficiency for BEBs is based on the total energy consumption of the fleet (recorded by the buses) and the total energy purchased for the charging stations (per the utility bills). These results are shown in **See Table 10**.[21]

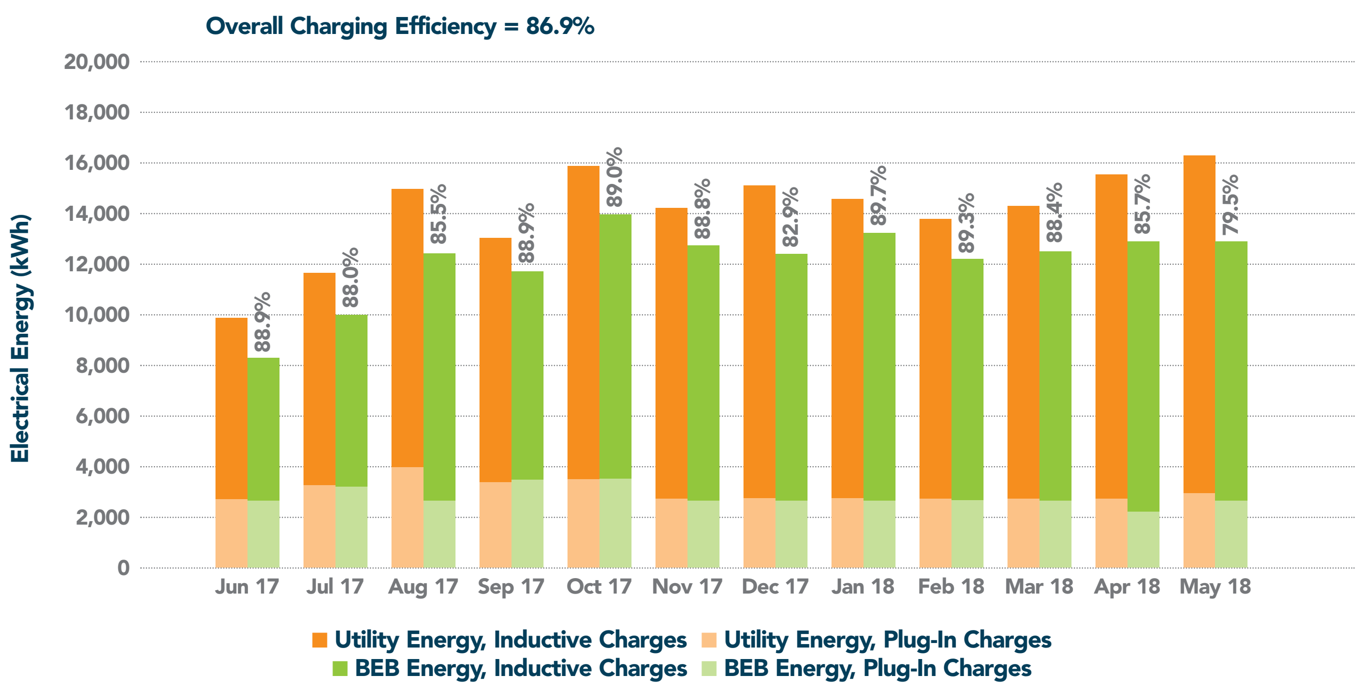
Systems that will require more BEB recharging by induction technologies on-route will face increasing levels of electricity loss during charging events.

And when determining the overall energy efficiency of electric bus transit operations, it is important to consider that more than 60 percent of energy used to generate electricity is lost in conversion. According to the U.S. Department of Energy, U.S. utility-scale generation facilities consumed 38 quadrillion British thermal units (quads) of energy to produce only 14 quads of electricity last year.[22]

CNG Bus Refueling Infrastructure Less Expensive

As part of its compliance with the California Air Resources Board's (CARB) Innovative Clean Transportation (ICT) regulation requiring large transit agencies in California to purchase increasing numbers of zero emission buses over a scheduled time period, Foothill Transit commissioned Burns & McDonald Engineering Company to produce an "In Depot Charging and Planning Study," made final in September 2019. The results are startling.

Table 10: Monthly utility energy, bus energy, and charging efficiency



1. Data labels indicate the overall charging efficiency for each month (Inductive charging and Plug-In charging combined)

[21]Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses, NREL/TP-5400-72864, National Renewable Energy Laboratory, Pages 20-21, 2018
[22]"More than 60 percent of energy used for electricity generation is lost in conversion," Today in Energy series, U.S. Energy Information Administration, July 21, 2020.
[23]"In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Page 13-4, September 9, 2019.

According to the experts, Foothill Transit will need to invest $120.6 million in infrastructure development over the next twelve years in order to adequately power a full fleet of 373 mandated electric buses.[23] In addition, it is important to note these costs do not include required investments the local electric utility – Southern California Edison (SCE) – will incur to upgrade its infrastructure in order to supply the added electric load needed to charge vehicles at Foothill's two bus depots in Arcadia and Pomona.

Burns & McDonald estimates that the Arcadia and Pomona depots – once supporting a fully electrified fleet – will require a total electric energy load of 29,222 MWh/year and 16,486 MWh/year with peak demands of 13.9 MW and 7.8 MW respectively.[24]

The study further states, "SCE will pay 100 percent of the electrical costs for the distribution line modifications, distribution service transformers, and service drop leading up to the electric charges located within the depot. Capital expenditures incurred by SCE will be applied to the distribution system rate base through typical rate proceedings."[25]

In addition to the $120.6 million incurred by Foothill Transit for charging infrastructure, all needed grid upgrades will be incurred by SCE ratepayers for an unspecified length of time at a total cost not currently made public.

A similar ICT required report prepared for Omnitrans transit system in San Bernadino County, California found the cost to transition its complete fleet to BEBs to be "very expensive," citing costs of approximately $100,000 per bus for charging equipment (DC cabinets and dispensers) and $50,000 per bus for support equipment (conduit, trenching, cabling, etc.).[26]

ICF's report includes cost estimates for infrastructure investments for different technologies including for transit agencies using diesel, CNG and electric. Table 11 is taken from data presented by ICF and is based on their underlying assumptions that include 12-year life and 34,000 miles per year for transit buses:[27] Note, however, that the ICF capital cost figures for infrastructure listed in Table 11 are nearly $125,000 less than those estimated in the Omintrans' report. **See Table 11**

Table 11: ICF Report December 2019, $2019 Costs per Bus

	Diesel	CNG	Electric
Infrastructure	**$3,886**	**$35,076**	**$44,127**
Capital	$0	$18,000	$26,400
O&M	$3,886	$17,076	$17,727
Infrastructure Cost per Mile	$0.01	$0.09	$0.11
100 Bus Fleet Station Cost	**$388,600**	**$3,507,600**	**$4,412,700**

Despite the use of very low costs for electric charging infrastructure, ICF's report indicates that transit agencies switching to electric buses can expect to pay quite a bit more for fueling infrastructure than if they chose to go with a natural gas bus fleet. To put this in perspective, the costs also are shown for a fleet of 100 buses. As noted later in this report, it is important to acknowledge that many large transit agencies already own natural gas fueling equipment, so the capital portion of the costs shown would not be incurred by those entities if they choose to continue to deploy more CNG buses in the future.

A 2016 study by MJ Bradley & Associates and Ramboll Environ commissioned by the Los Angeles County Metropolitan Transportation Authority (MTA) and the Advanced Transit Vehicle Consortium concluded that the agency would save between $3.5 billion to $5.7 billion over 40 years by continuing to utilize its existing natural gas fueling infrastructure and transitioning 100 percent to all low-NOx natural gas buses fueled by RNG instead of replacing its fleet with all electric buses. This same study also projected much higher overall and immediate environmental benefits generated by going with natural gas buses over electric or fuel cell buses.[28]

The aforementioned studies for Foothill Transit and Omnitrans do not discuss savings to each agency if able to continue to upgrade and improve their existing CNG fleets. Other than the cost to regularly replace aging buses with new models, additional costly refueling infrastructure investments are not required for transit agencies continuing their CNG bus operations if allowed.

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[23] "In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Page 13-4, September 9, 2019.
[24] "In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Page 12-1, September 9, 2019.
[25] "In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Pages 11-4 and 11-5, September 9, 2019.
[26] "Omnitrans Zero Emission Bus Rollout Plan," Prepared by WSP USA, Inc. for Omnitrans, Page 31, April 8, 2020.
[27] "Comparison of Medium- and Heavy-Duty Technologies in California," Prepared for California Electric Transportation Coalition and the Natural Resources Defense Council by ICF; Part 2, Table VI-11, Page 45; December 2019.
[28] "Zero Emission Bus Options: Analysis of 2015-2055 Fleet Costs and Emissions," MJ Bradley and Associates and Ramboll Environ for Los Angeles County Metropolitan Transportation Authority and the Advanced Transit Vehicle Consortium, September 29, 2016.

CNG Bus Refueling More Resilient

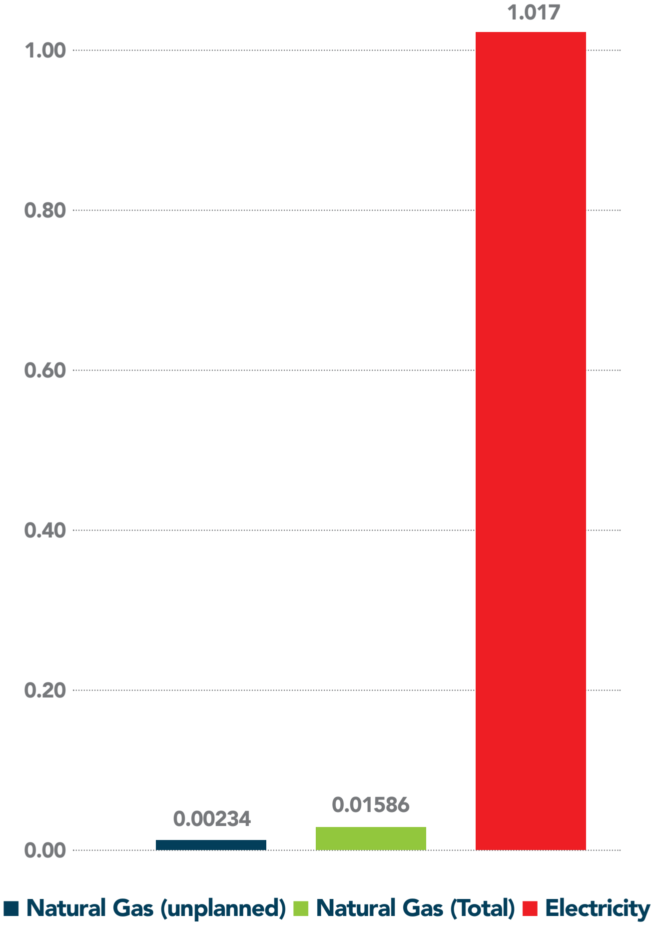
Multiple redundancies are always built into natural gas refueling infrastructure, ensuring refuelability in any weather or condition. Natural gas buses are relied upon during times of storms and natural disasters. And natural gas bus refueling is not impacted by short- or long-term electric grid blackouts for weather-related or fire prevention purposes.

A recent study by Portland State University concludes that the natural gas system is a resource for resilience in disasters and an earthquake-compromised city, and that renewable and compressed natural gas presents a strong case for a "least cost, least risk framework" for efforts to diversify the transportation fuel network.[29]

A report released by the International Association for Energy Economics evaluated the reliability and resiliency of natural gas and electricity transmission systems with telling conclusions stating, "Natural gas outages are relatively rare. Major outages that have the potential to cause downstream disruptions are even rarer.... failures are infrequent despite the size of the system. By contrast, the electric industry has relatively more frequent outages as well as 'major' outage events."[30]

A 2018 Gas Technology Institute (GTI) report found that while all electric customers typically have one outage per year, on average only one in 112 gas customers is expected to experience an outage in any given year. And while most natural gas outages are for planned equipment replacement, unplanned outages only affect about one in 800 natural gas customers per year.[31] **See Table 12**

Table 12: Average Energy Distribution Annual Outage Rate



[29] "NW Natural Energy System Resilience Initiative, Renewable/Compressed Natural Gas for Transportation System Resilience," Portland State University Center for Public Service Prepared for NW Natural, Page 39, October 4, 2019.
[30] Page, C. "How Reliable is Natural Gas? An Historical Overview of Natural Gas Transmission's Outage Track Record," U.S. Department of Energy, Office of Energy Policy & Systems Analysis, 2017.
[31] "Assessment of Natural Gas and Electric Distribution Service Reliability," Gas Technology Institute, July 19, 2018.

Disruptions to the electric grid are growing. Notwithstanding rolling blackouts experienced in places like California due to wildfire concerns where outages last not hours but days, system reliability for customers across the United States has decreased.

According to the U.S. Energy Information Administration, electric power for U.S. customers was interrupted for an average of 7.8 hours in 2017, nearly double the average total experienced in 2016. Analysts cited more major events such as hurricanes and winter storms, and the total duration of interruptions caused by major events was longer in 2017 than the prior year.[32] **See Table 13**

And some experts warn the growing number of electric vehicles and public charging units adds a new level of electric grid vulnerability: cybersecurity and the risk of a hack that could result in major system outages. A 2018 report by the National Motor Freight Traffic Association (NMFTA) found that the impact from a cyberattack on extreme fast charging (XFC) infrastructure could "cause widespread systemic and societal issues." Furthermore, charging outlets "for light passenger vehicles and heavy-duty electric trucks present major vulnerability points also to the grid that supplies power to the XFC systems."[33]

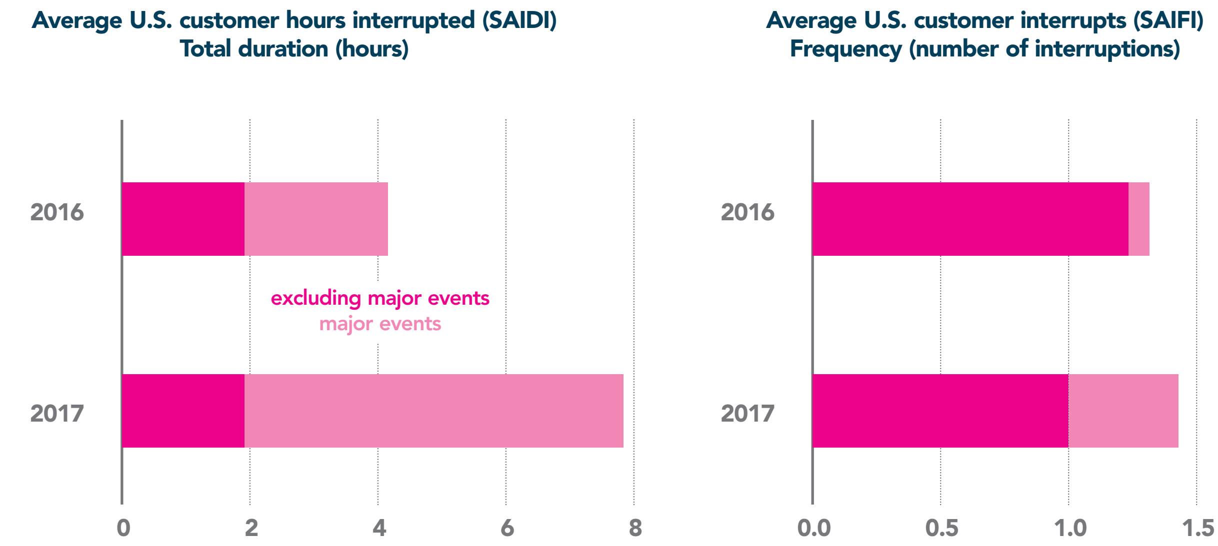
The Electric Power Research Institute's Rish Ghatikar adds, "With power levels of 200 (kilowatts) or higher, the malfunction of an individual or a fleet has the potential to impact the local distribution system, especially when multiple EVs are charging simultaneously."[34]

Major Grid Upgrades Not Needed for CNG Buses

Electric bus advocates also fail to articulate the cost and extent of major utility upgrades needed to accommodate an expected surge in electricity transmission and demand, upgrades not needed to fuel natural gas buses. The complexity and extent to which system upgrades can become necessary was highlighted in a report prepared by the Rocky Mountain Institute (RMI) for Seattle. In the report, RMI assumes Seattle "buses will primarily charge overnight at centralized bus bases. Most buses will travel a daily route of 100-140 miles with a battery size of 300-450 kWh.[35] Overnight charging will occur at existing Metro bus bases. Metro will also install 'opportunity chargers' for short, on-route charging events located at transit hubs, major transfer points, and the ends of major routes."[36]

The Seattle study showed constrained new electric load capacity throughout its service territory if required to serve a system of 250 electric buses. Further significant study and financial investment are needed. Only 2 of the identified 20 feeders that currently serve Metro bus bases and transit centers have the necessary peak load capacity (between 10 and 30 MW) available.[37]

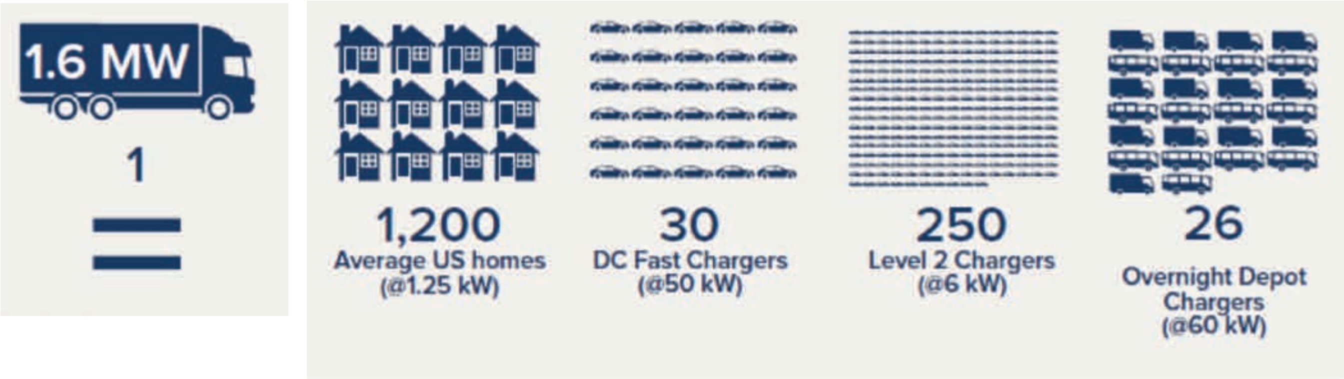
Table 13: Average U.S. electricity customer interruptions totaled nearly 8 hours in 2017



Source: U.S. Energy Information Administration, *Annual Electric Power Industry Report* (EIA-861 data file)

[32] "Average U.S. Electricity Customer Interruptions Totaled Nearly 8 Hours in 2017," U.S. Energy Information Administration, Today in Energy series, November 30, 2018.
[33] "Medium- and Heavy-Duty Electric Vehicle and Charging Infrastructure Cyber Security Baseline Reference Document," National Motor Freight Traffic Association, Inc. in conjunction with GRIMM and USDOT/Volpe Center Advanced Vehicle Technology Division, May 30, 2018.
[34] Vasquez, Christian, "'Major Vulnerability': EV Hacks Could Threaten Power Grid," *E&E News*, June 17, 2020.
[35] Note the battery size used here is more than 3 – 4 times larger than the batteries on the Foothill buses, which is likely required if on-route charging is not an option.
[36] "Seattle City Light Transportation Electrification Strategy," Rocky Mountain Institute; Page 32; July 2019.
[37] "Seattle City Light Transportation Electrification Strategy," Rocky Mountain Institute; Page 32; July 2019.

Table 14: Power Requirements (kW) of One Class-8 Truck "Mega-charging Event (1,600 kW) Compared with Power Requirements of Other Vehicles and Homes



See Table 14 for an exhibit in the Rocky Mountain Institute report detailing just how much power is involved in a single "mega-charging" event.[38]

The Burns & McDonald study for Foothill describes the $120.6 million in costs to be incurred by the transit agency for the installation of in-route and in-depot charging infrastructure on its property but fails to detail how much associated grid upgrades beyond depot fences will cost SCE ratepayers and users.[39]

Electric Utilities Not Prepared for Surge in Demand

An October 2019 study by the Smart Electric Power Alliance (SEPA) found that 24 percent of utility respondents were not preparing at all for growing EV adoption and only 34 percent were planning for EV needed utility infrastructure upgrades.[40]

Unlike electric buses, natural gas buses need no mid-route refueling. In the Foothill study, the battery electric buses currently deployed require on-route fast charging. Designed to fully charge the bus in under 10 minutes, Foothill was required to build layover time into Line 291's schedule to allow time for recharging on-route both outbound and inbound, essentially every time the limited-range BEB encounters an on-route charger. Further, software controls are needed to prevent charging events from surpassing the kWh limit that triggers expensive high demand charges.[41]

Consideration of Investments Made

While battery electric buses are certainly part of the clean transportation solution, mandating their exclusive use by transit authorities ignores very real operational realities. Today more than 170+ transit agencies, airports, and universities throughout the U.S. operate natural gas-powered transit buses. In addition to the acquisition costs of the buses, transit agencies and the communities they serve have invested significant capital in natural gas fueling infrastructure, garage upgrades and training for their workforces.

The American Public Transportation Association's 2019 annual survey shows deep penetration of natural gas bus usage across the country.[42] **See Table 15**

Table 15: Combined Percentages - 2019
Includes Bus, Commuter Bus and Rapid Transit

	Existing	Built in 2018	Ordered	Potential
NG Total	10,724	778	689	578
All Bus Total	38,778	2104	2,500	2,122
NG%	28%	37%	28%	27%

Demand Response Vehicles - 2019

	Existing	Built in 2018	Ordered	Potential
NG	871	102	73	279
Total	9,899	925	426	592
NG%	9%	11%	17%	47%

[39] "In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Pages 11-4 and 11-5, September 9, 2019.
[40] "Preparing for an Electric Vehicle Future: How Utilities Can Succeed," Smart Electric Power Alliance, Page 8, October 2019.
[41] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 18, October 2019.
[42] "Public Transportation Vehicle Database," American Public Transportation Association, 2019.

And the Federal Transit Administration reports natural gas buses are in use by transit agencies in every region of the nation. The top 25 transit authorities by CNG fuel usage are in Table 16.[43] **See Table 16**

Economic comparisons of electric and natural gas buses often completely ignore these investments and start by assuming that an agency will have to make these investments, driving up the cost of natural gas acquisitions and providing misleading comparisons. Moreover, emission comparisons often do not account for the fact that an increasing amount of the fuel consumed by natural gas buses is sourced from renewable natural gas that provides significant reductions of greenhouse gas emissions.

Volatile Demand Charges Add to BEB Recharging Costs

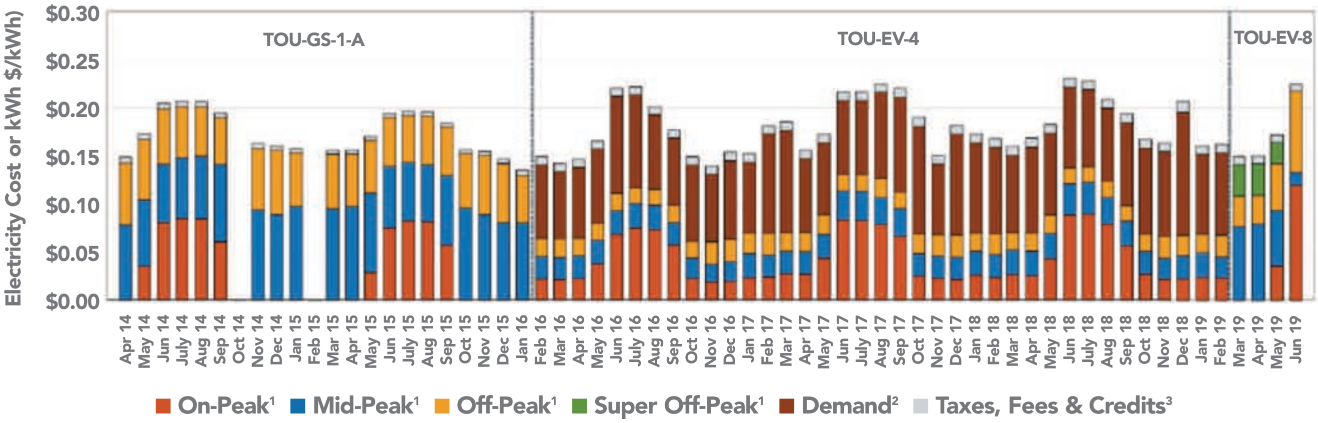
In order to fully charge a large number of buses while avoiding costly electric utility demand charges, electric buses need a lengthy down time in order to achieve a full fleet charge. The Rocky Mountain Institute report for Seattle City Light warns, "The higher upfront cost of electric buses - $750,000 compared with a diesel bus at $435,000 – can potentially be offset by lower fuel and maintenance costs. However, the structure of electricity tariffs, in particular demand charges, strongly influences total cost of ownership for electric buses, and in some cases, can make them more expensive than diesel."[44]

Table 16

Agency	City	State	CNG Fuel	CNG Buses
Los Angeles County Metropolitan Transportation Authority, dba: Metro	Los Angeles	CA	37,761,044	2,409
Dallas Area Rapid Transit	Dallas	TX	8,685,511	638
Orange County Transporation Authority	Orange	CA	7,595,144	515
San Diego Metropolitan Transit System	San Diego	CA	7,313,641	582
Regional Transportation Commission of Southern Nevada	Las Vegas	NV	6,208,757	276
MTA New York City Transit	New York	NY	6,110,199	749
Metropolitan Atlanta Rapid Transit Authority	Atlanta	GA	5,919,091	391
Foothill Transit	West Covina	CA	5,518,289	343
VIA Metropolitan Transit	San Antonio	TX	4,809,837	370
County of Nassau, dba: Nassau Inter County Express	Garden City	NY	4,322,919	269
City of Phoenix Public Transit Department, dba: Valley Metro	Phoenix	AZ	4,313,696	293
Washington Metropolitan Area Transit Authority	Washington	DC	4,144,729	551
Omnitrans	San Bernadino	CA	3,519,903	195
Regional Public Transportation Authority, dba: Valley Metro	Phoenix	AZ	3,225,424	196
City of Los Angeles, dba: City of Los Angeles Department of Transportation	Los Angeles	CA	3,064,666	161
City of El Paso, dba: Sun Metro	El Paso	TX	2,822,950	168
Sacramento Regional Transit District	Sacramento	CA	2,488,371	198
Riverside Transit Agency	Riverside	CA	2,401,984	175
MTA Bus Company	New York	NY	2,139,592	213
Forth Worth Transportation Authority, dba: Trinity Metro	Fort Worth	TX	2,122,332	154
Central Ohio Transit Authority	Columbus	OH	1,998,699	150
Golden Empire Transit District	Bakersfield	CA	1,898,945	64
Massachusetts Bay Trasportation Authority	Boston	MA	1,842,320	175
New Jersey Transit Corporation	Newark	NJ	1,664,875	147
City of Santa Monica, dba: Big Blue Bus	Santa Monica	CA	1,621,332	176

[43]National Transit Database, Federal Transit Administration, U.S. Department of Transportation, 2018. CNG bus counts are taken from NTD and APTA Transit Vehicle Database. Fuel consumption shown is mostly from transit buses but in some cases includes fuel used by demand response vehicles.
[44]"Seattle City Light Transportation Electrification Strategy," Rocky Mountain Institute; Page 22; July 2019.

Table 17



1. On-Peak, Mid-Peak, Off-Peak and Super Off-Peak charge categories include respective costs for delivery and generation.
2. Rate structure changed to TOU-EV-4 February 2016, introducing demand charges, and changed to TOU-EV-8 March 2019, eliminating demand charges
3. "Taxes, Fees & Credits" category includes all remaining utility bill items (positive & negative charges)

With electric buses, demand charges in some cases could double the cost of electricity. This appears to be supported by the NREL data from the Foothill and Long Beach Transit studies. Fuel prices in the Foothill analysis – although higher than the national average (e.g. 17 cent kWh versus 10 cent) – might actually be fairly close to what a transit agency outside of California could expect to pay since the national average price does not include demand charges. Long Beach Transit is paying 27 cent per kWh.

Consumers in California pay higher electricity rates, but the Foothill study shows waived demand charges for a period of time. Foothill Transit has benefited from special rates intended to encourage the switch to BEBs, so its costs are likely to be lower than what others transit agencies could expect to pay if they cannot secure similar incentive pricing.

Total electricity refueling costs can include utility base rates, demand charges, time of use charges, and varying summer versus winter rates.

According to NREL, total BEB recharging costs include a variety of charges in two main categories – actual electricity consumption charges and electricity demand charges. Consumption charges can include seasonal rates, time of use rates, and tiered rates. Demand charges include seasonal levies as well as their own time of use charges and can be calculated a variety of ways, including "ratchet clauses that raise the demand charge of low-demand months to a certain percentage of the month with the highest demand. These are particularly impactful if a fleet pilots BEBs for a few months and then has to pay additional ratcheted demand charges for the rest of the year."[45]

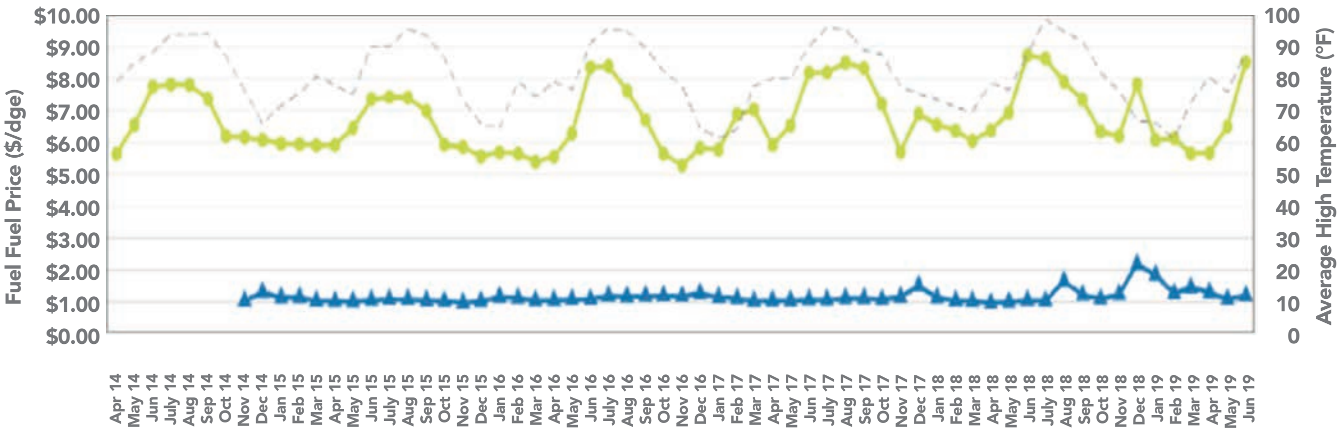
Many electric bus refueling cost claims fail to include the entirety of charges which vary greatly from utility to utility. Consider this: Tesla charges $0.28 to its customers using its supercharging stations – that might be a fair or representative price to consider.[46] Because BEBs consume 2 or more kWh per mile, a 10-cent increase in cost per kWh increases the cost per mile by 20 cents.

CNG Offers Stable and Consistent Fuel Pricing

Across the nation, utility rate structures are varied. The Foothill study highlights the irregularity of electricity costs. On-peak, mid-peak, off-peak, and super-off-peak impact overall fueling costs.[47] **See Table 17**

[45] "Financial Analysis of Battery Electric Transit Buses," NREL/TP-5400-74832, National Renewable Energy Laboratory, Pages 27-28, June 2020.
[46] Accessed at: https://www.tesla.com/support/supercharging; July 10, 2020.

Table 18



	Electricity Price (dge)[1]	CNG Price (dge)[2]	Temperature
Overall average fuel price	$6.73/dge	$1.14/dge	
Date period average fuel price	$6.46/dge	$1.37/dge	

1. Electrical energy converted from kWh to diesel gallon equivalent (dge); conversion factor = 37.64 kWh/dge
2. CNG fuel energy from gasoline gallon equivalent (gge) to diesel gallon equivalent (dge); conversion factor = 1.146 gge/dge
3. Average daily temperatures at Ontario International Airport CA; data acquired from: https://www.ncdc.noaa.gov.

The NREL report found that electricity costs on an energy equivalent basis during the ongoing Foothill study period is approximately 6 times the cost of CNG. Even the most efficient electric bus operating in an extremely forgiving duty cycle will have a difficult time being less expensive to operate per mile if the cost of the electricity it is purchasing is 6 times that of natural gas or diesel fuel. Even more, the reported CNG cost is all inclusive, comprising the price of fuel, transmission, and operations and maintenance costs for the station. And while electricity prices vary seasonally, CNG prices are relatively consistent (exclusive of two temporary disruptions in regional CNG supply).[48] **See Table 18**

Confirmed Lower Fuel Cost Per Mile with CNG

In the October 2019 NREL Foothill study update for data period January 2019-June 2019, natural gas buses reported a lower fuel cost per mile. The BEB fleet had a fuel cost of $0.39/mi (at $0.17/kWh) and the CNG fleet had a fuel cost of $0.33/mi (at $1.19/gge).[49]

In the previous six-month reporting period from July 2018-December 2018, natural gas buses bested electric buses even more. The BEB fleet had a fuel cost of $0.46/mi (at $0.20/kWh) and the CNG fleet had a fuel cost of $0.28/mi (at $1.24/gge). This six-month data period reflects the higher electricity rates charged during the summer months.[50]

It is important to note also that the CNG fuel costs assembled by NREL at Foothill are fully loaded, meaning the price cited not only includes the cost of the fuel, but any associated costs to fully service, maintain and operate the refueling equipment/station.[51] This is not the case with the electric charges which only capture the cost of the kilowatts delivered (e.g. cost of the fuel).

[48] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 32, October 2019.

[49] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 6, October 2019.

[50] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jul. 2018 through Dec. 2018, NREL/PR-5400-72209, National Renewable Energy Laboratory, slide 6, May 2019.

[51] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jul. 2019 through Dec. 2019, NREL/PR-5400-75581, National Renewable Energy Laboratory, slide 32, dated March 2020.

Table 19

Category %	BEB 35FC # Days	BEB 35FC %	BEB 40FC # days	BEB 40FC %	CNG # days	CNG %
Planned work days	1,317		220		880	
Days available	835	63.4	195	88.6	815	92.6
Unavailable	482	36.6	25	11.4	65	7.4
ESS	45	3.4	0	0.0	—	—
CNG engine	—	—	—	—	11	1.3
Electric drive	158	12.0	5	2.3	—	—
Charging issues	0	0.0	0	0.0	—	—
Preventative maintenance	2	0.2	1	0.5	6	0.7
General bus maintenance	248	18.8	19	8.6	35	4.0
Transmission	29	2.2	0	0.0	13	1.5

Natural Gas Buses are More Reliable

Natural gas bus technology is proven, and engine technology and bus performance continue to advance. Conversely, electric bus technology remains in its infancy on performance, cost, and reliability in real world applications.

CNG Buses Spend Fewer Days Out of Service

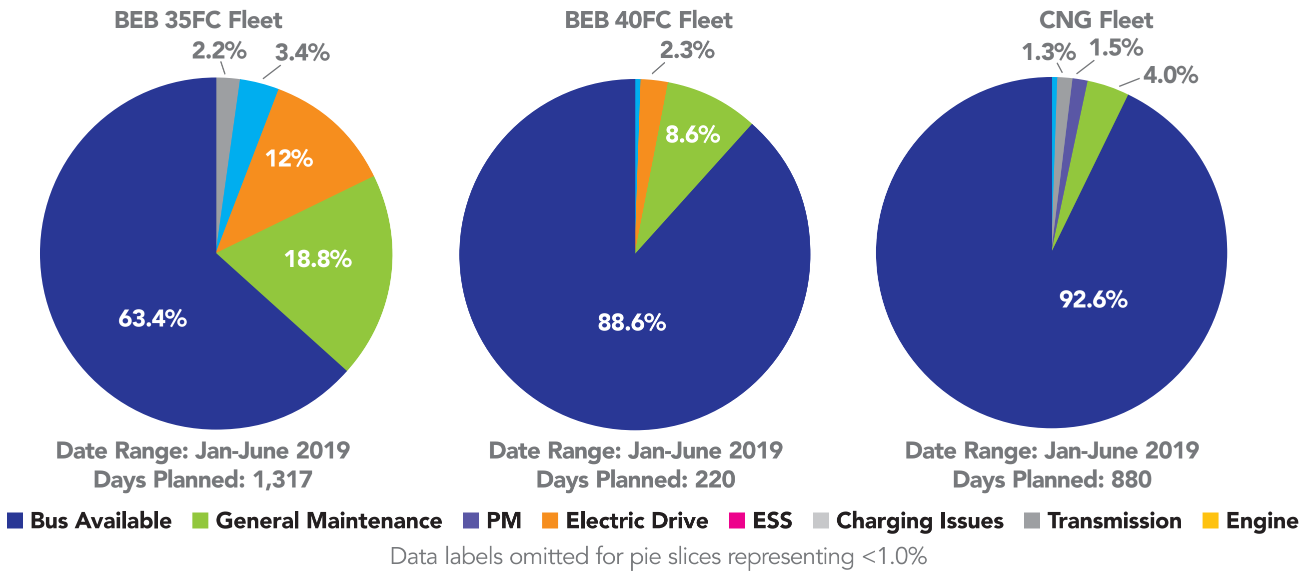
Studies show natural gas buses spend fewer days out of service than electric counterparts. A key factor of reliability is availability for roll out; natural gas buses more than exceed the expected rate of 85 percent while BEBs struggle to meet the minimum requirement.

The chart above details the extent of out-of-service days for buses in the Foothill Transit study. In the studied period, the 35-foot BEBs (which account for 12 of the 14 BEBs in operation) had an average availability rate of 63 percent. Daily per-bus availability for electric buses was as low as 46 percent during the first half of 2019. In contrast, CNG buses had an availability rate of 93 percent for the same period and an overall availability rate of 96 percent.[52] **See Table 19**

The BEBs were mostly unavailable due to general "bus-related" problems, though issues with the BEBs' low-voltage batteries impacted availability. Additional BEB downtime was impacted by issues with transmissions, air compressor, DC-DC converter, and traction motor components.[53]

[52]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 21, October 2019.
[53]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 4, October 2019.

Table 20



Daily per-bus availability for electric buses was as low as 46 percent with an average availability rate of 63 percent during the first half of 2019. In contrast, CNG buses had an availability rate of 93 percent for the same period and an overall availability rate of 96 percent. – NREL Foothill Transit Study[54]

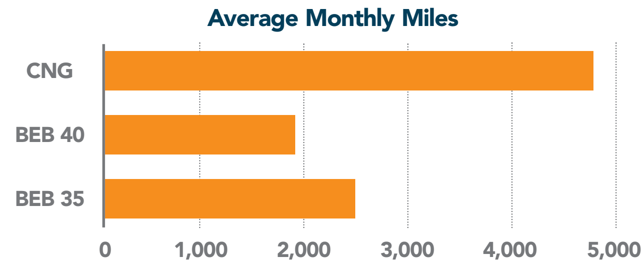
The graphs above detail these Foothill results.[55] **See Table 20**

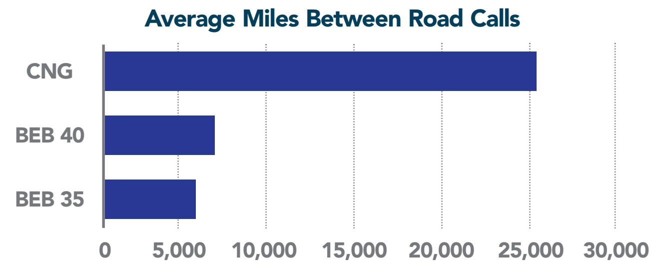
CNG Buses Perform More Miles Between Road Calls

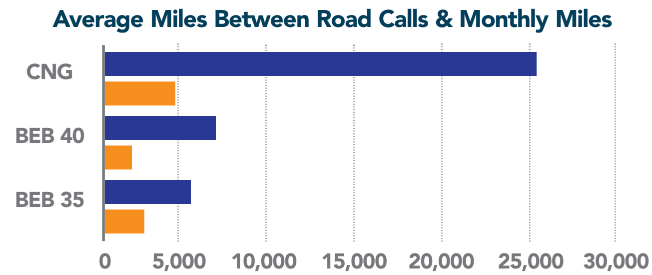
Once out on route, CNG buses had far fewer road calls, or revenue vehicle system failures, than their electric counterparts in the Foothill study. Such incidents require a bus to be replaced on route and/or cause a significant schedule delay affecting system operations.

Such reliability in the transit industry is measured in mean distance (miles) between failures (road calls), or MBRC. At Foothill, the average miles between road calls for natural gas buses exceeds that of the BEBs by between 18,000 to almost 20,000 miles.[56] And the natural gas buses operated by Foothill transit more than pull their weight in terms of delivering service miles. The charts at right provide data on the average monthly miles of operation for the Foothill buses as well as the MBRC rates. **See Table 21**

Table 21







[54]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 21, October 2019.
[55]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 26, October 2019.
[56]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 35, October 2019.

CNG Buses Less Expensive to Maintain and Repair

On average, natural gas buses have less expensive repair and maintenance costs over their full life cycle. In the Foothill study, the cost to maintain buses in the first half of 2019 was $0.68/mile for the BEB 35FC buses, $0.62/mile for the BEB 40FC buses, and $0.41/mile for the CNG buses.[57]

These increased costs for the Foothill electric buses are partially reflective of the fact that the BEB 35FC buses are past the warranty period for most components, resulting in higher parts and labor costs. While scheduled work order (regular maintenance and service) costs remain steady as the electric bus fleet ages (and admittedly report out less expensive at $0.06/mile and $0.04/mile versus $0.10/mile for the CNG bus fleet), the unscheduled labor costs increased over time for both electric models – $0.63/mile and $0.58/mile versus a stable $0.31/mile for CNG.[58] It is important to note here too that if the battery electric buses were routed on longer, more rigorous routes, thus accumulating more daily miles and servicing more passengers, both their scheduled and unscheduled service and labor costs would likely rise accordingly.

NREL reports that Foothill Transit has "issues" with the low-voltage batteries that power accessories such as the farebox, cameras, and GPS systems. The BEBs averaged 8.9 changeouts per bus at approximately 12,000 miles between changeout. The CNG buses averaged 1.6 changeouts per bus at more than 165,000 miles between changeout. The BEB manufacturer is reportedly working on a fix for the electric fleet; the CNG fleet has an automatic shutoff for these accessories.[59]

Overall cost per mile (low-voltage battery costs not included) for electric buses was 1.5 and 1.4 times higher than CNG buses. – NREL Foothill Transit Study[60]

Finally, most public transit authorities with electric buses in operation have yet to approach the time when the full battery system needs replacement. Estimates indicate that since batteries degrade over time, the typical BEB in service will require battery pack replacements through its required 12-year in-use life in order to retain battery capacity and required range. This timeframe is greatly impacted by miscellaneous climate, route, duty-cycle considerations.

BEB manufacturers have responded to this issue. Most electric bus manufacturers now offer battery pack warranties of 6 to 12 years; their cost varies greatly by purchase contract. In addition, some manufacturers have begun to offer battery pack leasing options to eliminate costly and unbudgeted mid-life battery pack replacement events.[61]

Natural gas buses require no needed fuel system overhaul or sizable powertrain investment after being placed in service.

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[57] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 7, October 2019.

[58] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 7, October 2019.

[59] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 53, October 2019.

[60] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 44, October 2019.

[61] "Financial Analysis of Battery Electric Transit Buses," NREL/TP-5400-74832, National Renewable Energy Laboratory, Page 8, June 2020.

Natural Gas Buses are the Alternative Fuel Workhorse

No Compromise on Duty or Performance with CNG Buses

Aside from cost issues, range limitations and deployment constraints also make it unrealistic that battery electric technology will be able to supplant natural gas and diesel buses in all cases. Many transit agencies deploy natural gas on bus rapid transit routes and other longer routes that require extended range capabilities.

Natural gas buses are essentially an interchangeable one-to-one replacement for diesel in terms of capability, size and seating with a typical 400-mile range, though range can be extended beyond that with the installation of additional fuel tanks. And natural gas bus performance and range are not adversely affected by terrain. In order to maximize electric bus performance, deployment is restricted to certain routes and duty cycles.

The Omnitrans all-electric fleet transition study details this challenge with BEB technology. Omnitrans currently operates 334 blocks during weekdays, 296 of which are longer than 100 miles; its largest block is 410 miles. According to Omnitrans:

"Depending on operational parameters, including operator behavior, ambient temperature, traffic, and ridership, these ranges may be unattainable or difficult to achieve on certain days. Based on existing routes, Omnitrans will only be able to support BEB on a 1:1 ratio until 2028 (pending advancements in the technology). If vehicle manufacturers cannot meet these range requirements after 2028, Omnitrans will consider a number of strategies to supplement onboard battery storage, including additional buses, midday charging, battery/charging management systems, and solar and battery storage."[62]

"BEBs are not really ready yet. The battery isn't good enough if there's any problem along the way, such as a climb or cold weather, and the extra infrastructure for midday charging is expensive." – City Lab by Bloomberg LP[63]

CNG Provides More Work, More Reliability

In the Foothill study, natural gas buses performed more work and were more reliable than the BEBs, two critical metrics for transit agencies. The average miles traveled by the natural gas buses exceeded that of the BEBs each month by between 2,200 and 2,800 miles.[64] While most cost comparison studies assume equivalent mileage for electric and natural gas buses, the reality is that fewer lifetime miles means that these studies greatly underestimate the true cost of operating electric buses.

If transit agencies are forced to replace their current diesel, hybrid, or natural gas fleets with mandated battery electric buses, more new buses will be required to replace the number currently in service in order to meet transit mileage needs.

A report by electric transit bus consultants MJ Bradley & Associates found that the average miles traveled per bus per day in the U.S. is less than 120 miles, but 50 percent of all transit buses in operation do more miles than the average. Some buses even travel over 250 miles per day.[65] Further, "with currently available bus models, many transit agencies will need 5 to 20 percent more electric buses than current diesel/CNG buses, and will need to shorten long daily bus assignments, if overnight depot charging is used."[66]

The Burns & McDonnell report details just how Foothill Transit will need to readjust its schedule of blocks to accommodate the transition to an all-BEB fleet. In order to maintain a minimum reserve ratio of 15 percent, additional BEBs will need to be purchased:

"The March 2019 plan assumes that all CNG buses would be replaced by electric buses by 2032 with a total of 353 electric buses in service to serve a peak vehicle requirement (PVR) of 287 buses. The existing fleet today operates with a reserve ratio of 15 to 20 percent with a minimum contract reserve ratio of 15 percent. Based on the analysis described in Section 4 of this report, Foothill will have a PVR of 320 and thus would need to purchase an additional 15 electric buses in order to maintain the 15 percent reserve ratio requirement in 2032 for a total adjusted fleet size of 368 buses."[67]

That obviously has huge implications for overall cost as the reported cost per mile to operate BEBs in the NREL study currently do not account for having to purchase and deploy extra buses. If BEBs are going to be put mostly in shorter route applications that means the amount of pollution they can offset also is more limited since fewer miles traveled means less pollution offset.

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[62] "Omnitrans Zero Emission Bus Rollout Plan," Prepared by WSP USA, Inc. for Omnitrans, Page 16, April 8, 2020.
[63] "The Verdict's Still Out on Battery-Electric Buses," City Lab by Bloomberg LP, Alon Levy, January 17, 2019.
[64] Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 14, October 2019.
[65] "Electric Bus 101: Economics, Politics, Myths & Facts," MJ Bradley & Associates, Dana Lowell, Slide 15, May 2019.
[66] "Electric Bus 101: Economics, Politics, Myths & Facts," MJ Bradley & Associates, Dana Lowell, Slide 16, May 2019.
[67] "In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Page 13-2, September 9, 2019.

Any Route, Any Weather with CNG Buses

Foothill's BEBs are operated on a single 16-mile route (Line 291) that circles through the Pomona Transit Center for charging at an average speed of 10.6 mph while the CNG buses are "randomly dispatched on all routes out of the operations facility, including higher speed routes."[68]

Natural gas bus performance and range are not impacted by weather or temperature, unlike electric. Multiple studies report that BEB range and efficiency can be impacted by extreme temperatures.

In his longtime research, public transit and urbanism author Alan Levy found several instances where electric bus range and performance promises were severely compromised by colder weather. In the Twin Cities region, the Minnesota Valley Transportation Authority's (MVTA) no-cost leased electric bus suffered greatly in cold temperatures. At freezing, the range was below target. In even colder temperatures, the bus could not complete its full day responsibilities. And on one 5-degree F day, the battery lasted all of 40 minutes for a total 16-mile range.[69]

BEB range in extreme temperatures is further impacted by passenger compartment heating and cooling (HVAC) usage.

Some reviews estimate that 30 percent of a BEB's battery power can be utilized for passenger heating and cooling purposes, significantly reducing the vehicle's mileage range. And Europe-based Electrification of Public Transport in Cities (ELIPTIC) reports that, "using the battery energy for electric heating significantly reduces the driving range (up to 50 percent in harsh winter conditions)."[70]

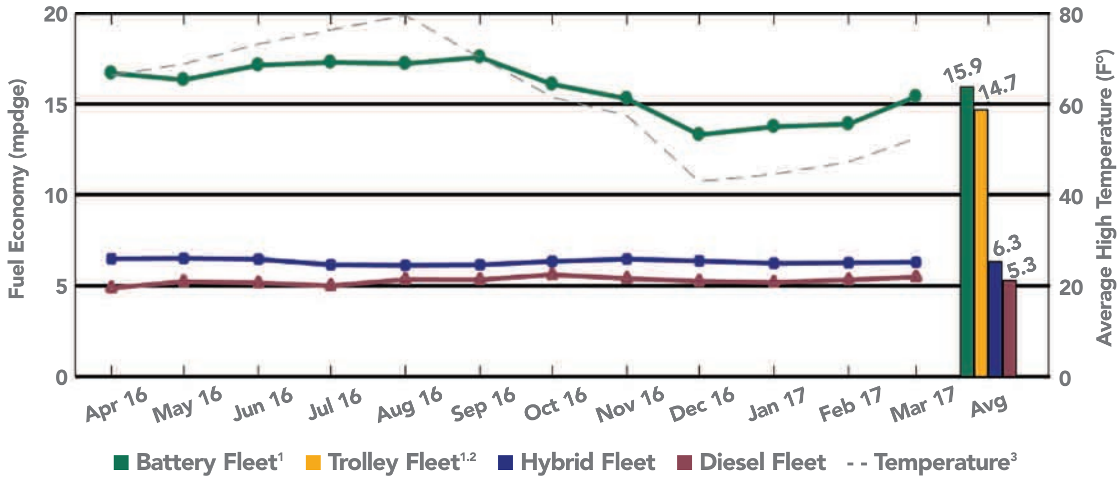
As a result, electric bus manufacturers have resorted to installing diesel or gasoline fuel-fired heating and cooling systems to maintain passenger compartment comfort. Real world emissions from these fuel-fired HVAC systems thus contradict BEBs' zero emission vehicle status since their real environmental impact is not reflected in their purity labeling. High-tech consultant Francesco Impari writes of his work, "According to our research based on 65 e-bus models, more than 40 percent of e-bus manufacturers are adopting gas powered HVAC solutions: an absolute oxymoron for the electric vehicle industry."[71]

Natural gas performance and range are not negatively impacted by passenger compartment HVAC use.

"More than 40 percent of electric buses adopt a fuel powered heating solution." – Medium.com[72]

[68]Foothill Transit Agency Battery Electric Bus Progress Report: Data Period Focus: Jan. 2019 through Jun. 2019, NREL/PR-5400-73516, National Renewable Energy Laboratory, slide 4, October 2019.
[69]"The Verdict's Still Out on Battery-Electric Buses," City Lab by Bloomberg LP, Alon Levy, January 17, 2019.
[70]"Policy Recommendations," Electrification of Public Transport in Cities (ELIPTIC), Page 11, July 17, 2018.
[71]"Challenges for Air Conditioning and Heating (HVAC) Solutions in Electric Buses," Medium.com, Francesco Impari, July 2, 2019.
[72]"Challenges for Air Conditioning and Heating (HVAC) Solutions in Electric Buses," Medium.com, Francesco Impari, July 2, 2019.

Table 22



1. Battery and Trolley fleet electrical energy converted to diesel gallon equivalent (dge); conversion factor = 37.64kWh/diesel gallon, based on the energy content of electricty (3,414 Btu/kWh) and diesel fuel LHV (128,488 Btu/gal).
2. Trolley fleet monthly fuel use and mileage data were not available; an estimated avg. mpdge is included for comparison.
3. Renton Municipal Airport average daily high temperatures; data acquired from: https://www.ncdc.noaa.gov/

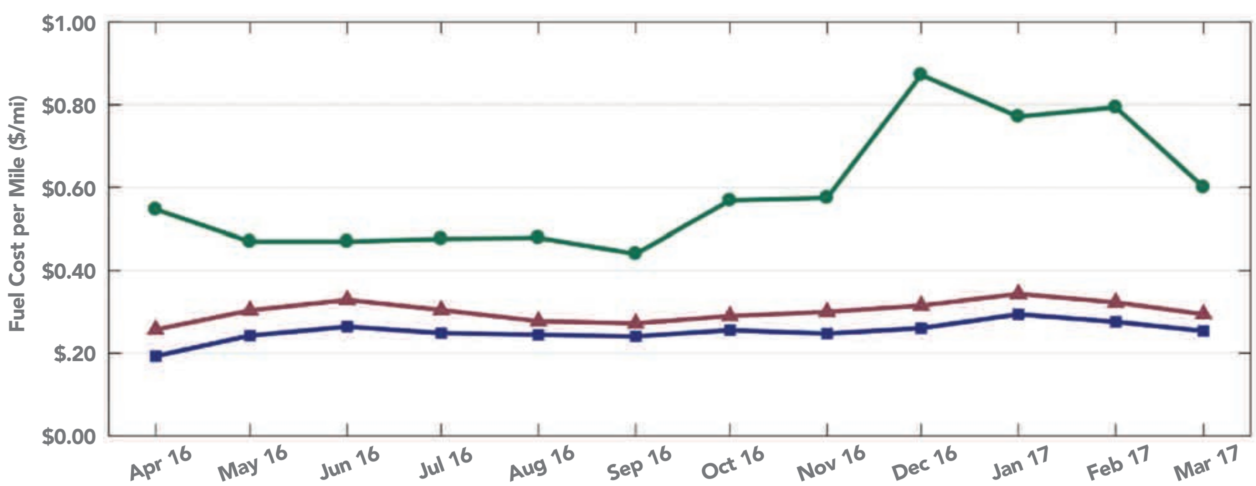
Changes in temperature can impact BEB fuel efficiency. In their study of electric bus efficiency in King County Metro Transit in Seattle, Washington, NREL researchers found, "Battery fleet fuel economy varied from a high of 17.6 miles per diesel gallon equivalent (mpdge) in September 2016 to a low of 13.3 mpdge in December 2016."[73] This is a 24 percent reduction in fuel economy/efficiency during periods of colder weather. It's important to note that the coldest temperature recorded in Seattle that December was above 40 degrees F:[74] The published efficiency ratings of new buses do not take into energy demand associated with operating heating systems in cold weather because that is not part of the efficiency performance test. **See Table 22**

As colder temperatures impact electric bus efficiency, fuel costs per mile increase. In King County, "The battery fleet experienced higher per-mile fuel costs ($0.57/mi) than the baseline fleets, especially during the winter months. This trend is a result of the battery fleet's lower fuel economy during the winter and higher electricity rates during the winter. The higher electricity rates were compounded by the fact that the battery fleet traveled fewer miles in December, January, and February, which resulted in higher costs from demand charges on a per-mile basis."[75]

These fluctuations are detailed in the chart below:[76] **See Table 23**

"There are some examples of technological or operational challenges, with electric buses unable to meet advertised range in certain climates and weather conditions or utilized on a route for which they are poorly suited." – Rocky Mountain Institute[77]

Table 23



	Battery Fleet	Hybrid Fleet	Diesel Fleet
Fleet average fuel cost/mi	$0.57/mi	$0.25/mi	$0.30/mi
Average fuel price	$0.20/kWh	$1.60/gal	$1.60/gal

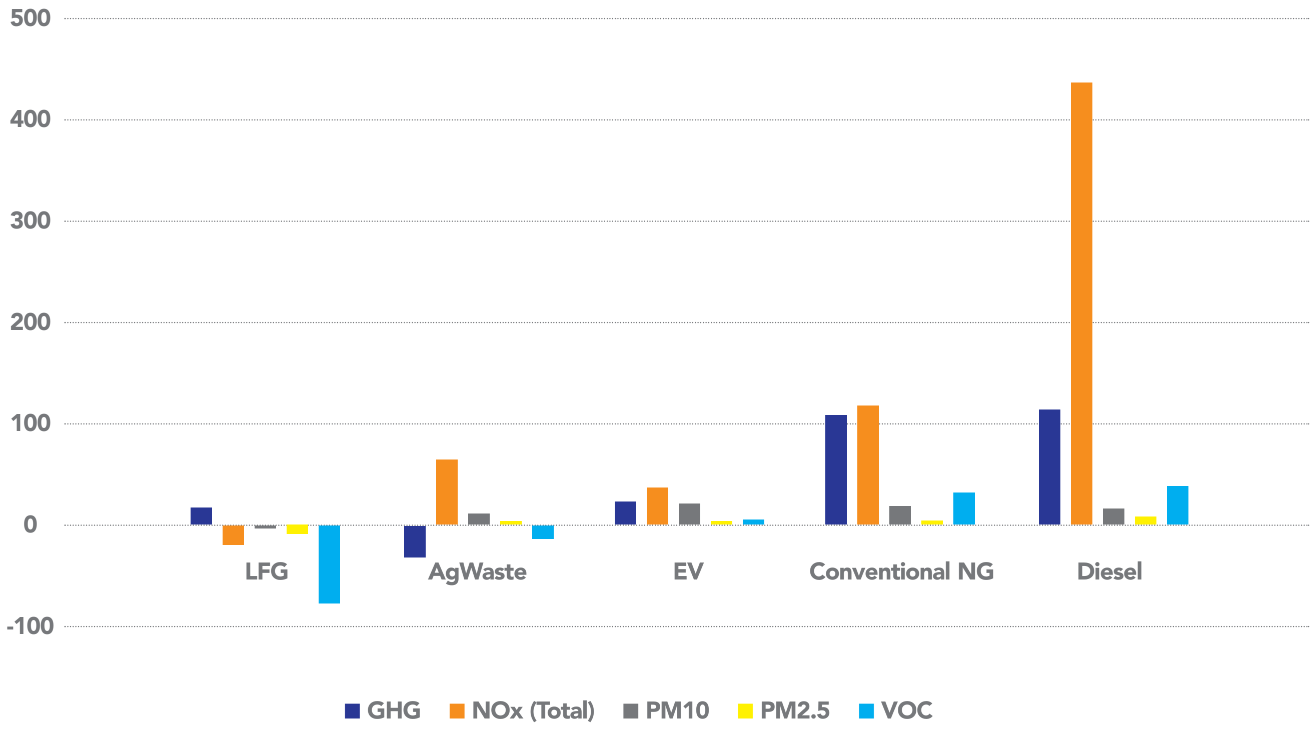
Natural Gas Buses are Zero Emissions Equivalent

Clean natural gas buses today reduce harmful emissions of nitrogen oxides (NOx) by 99 percent and particulate matter (PM) emissions by 96 percent compared to transit buses built prior to 2010. Thus, the emission difference is miniscule between new natural gas buses and electric buses which have no tailpipe emissions but do have particulate matter emissions associated with tire wear and braking. Importantly, natural gas buses produce these emission reductions without relying upon costly and cumbersome emission control equipment required of like diesel technology to meet minimum federal clean air standards.

Further, when considering full well-to-wheel emissions, in most cases natural gas buses fueled by RNG provide lower NOx emissions than battery electric buses. In California – which has the nation's highest volume of renewable energy used in its electricity production – the combination of locally-produced RNG to fuel ultra-low NOx natural gas buses is expected to produce lower emissions than a comparably-sized BEB fueled by electricity from the electric power grid generated by fossil-based natural gas.[78]

Modeling conducted by NGVAmerica using the AFLEET Tool (https://afleet-web.es.anl.gov/afleet) confirms the significant advantages to both greenhouse gas emissions and criteria pollutants when using renewable natural gas and low-NOx engines. The comparison below includes inputs from the California energy mix for electricity and thus include lower emissions for battery electric buses than would be the case in many states. **See Table 24**

Table 24: RNG Delivers Near-Zero or Better WTW Emissions (Annual GHG ton, Criteria Pollutant lb.)



Note: LFG = landfill gas RNG. AgWaste is RNG derived from agriculture waste.

[73]"Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses," Federal Transit Administration, FTA Report No. 0118; Page 29; February 2018.
[74]"Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses," Federal Transit Administration, FTA Report No. 0118; Figure 3-14 Monthly Fuel Economy for Battery, Hybrid, and Diesel Bus Fleets; Page 29; February 2018.
[75]"Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses," Federal Transit Administration, FTA Report No. 0118; Page 30; February 2018.
[76]"Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses," Federal Transit Administration, FTA Report No. 0118; Figure 3-15 Monthly Fuel Cost per Mile for Battery, Hybrid, and Diesel Bus Fleets; Page 31; February 2018.
[77]"Seattle City Light Transportation Electrification Strategy," Rocky Mountain Institute; Page 22; July 2019.
[78]"Presentation at Rethink Methane 2017," Wayne Nastri, Executive Officer, South Coast Air Quality Management District, February 21, 2017.

Natural Gas Buses Decarbonize Transportation

Get Carbon-Negative Transit Now with RNG

Fueling with conventional natural gas reduces greenhouse gas emissions (GHG) by about 12 percent compared to diesel. But according to the California Air Resources Board, fueling buses with renewable natural gas (biomethane) collected at local landfills, wastewater treatment plants, commercial food waste facilities, and agricultural digesters can yield a carbon-negative lifecycle emissions result. According to CARB data, renewable natural gas (RNG) holds the lowest carbon intensity of any on-road vehicle fuel, including fully renewable electric.[79]

The table at right includes the carbon intensity ratings of transportation fuels in CARB's Low Carbon Fuel Standard (LCFS) program.[80] **See Table 25**

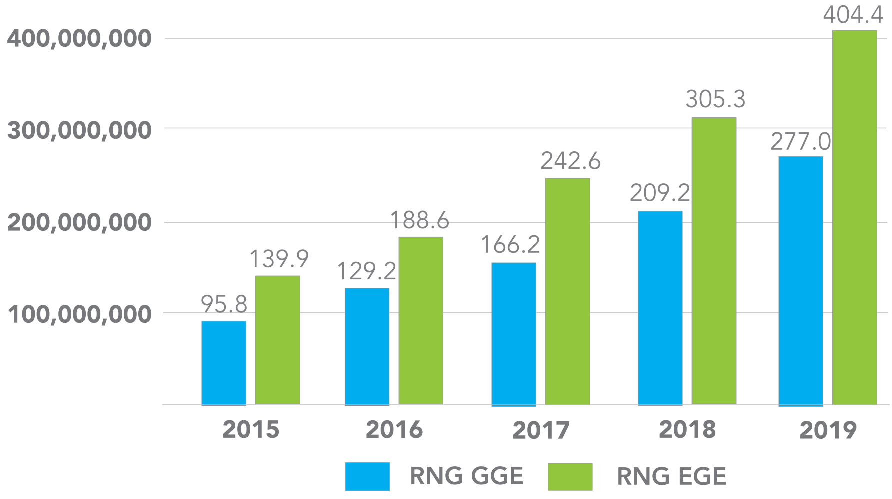
According to this CARB data, renewable natural gas (RNG) holds the lowest carbon intensity of any on-road vehicle fuel, including fully renewable electric.

On-road natural gas fueling trends show increasing adoption of RNG. According to data from the U.S. Energy Information Administration (EIA) and U.S. Environmental Protection Agency (EPA) Renewable Fuel Standard reporting, 39 percent of all on-road natural gas fuel in 2019 was RNG. And over the last five years, RNG use as a transportation fuel has increased 291 percent, displacing close to 7.5 million tons of carbon dioxide equivalent (CO2e).[81] **See Table 26**

Table 25

Fuel	CI	EER-(On-road HDVs)	EER-Adjusted CI	CI Value Relative to Baseline Diesel
Baseline Diesel	100.45	1.0	100.45	0%
CNG	79.21	0.9	88.01	-12%
Electricity, CA-Grid Average (CY2019 Proposed)	81.49	5.0	16.30	-84%
Electricity, National-Grid Average (EPA/NGVA)	196.39	5.0	39.28	-61%
Hydrogen (from LFG)	99.48	1.9	52.36	-48%
Hydrogen (from fossil NG)	117.67	1.9	61.93	-38%
RD from Tallow (average of approved pathways)	37.6	1.0	37.60	-63%
R-LNG (from LNG, average of approved pathways)	49.28	0.9	54.76	-45%
R-CNG (from LFG)	47.28	0.9	52.53	-48%
R-CNG (from AD of Wastewater)	43.02	0.9	47.80	-52%
R-CNG (from HSAD of Food/Green Waste)	0.34	0.9	0.38	-100%
R-CNG (from AD of Dairy Waste)	-254.94	0.9	-231.76	-331%

Table 26: RNG Growth (2015-2019)



RNG use as a transportation fuel has increased 291% over the last five years, displacing close to 7.5 million tons of carbon dioxide equivalent (CO2e).

Note: GGE = gasoline gallon equivalent. EGE = ethanol gallon equivalent. EGE units are converted to GGE using a 0.69 multiplier (77,000 Btu/112,400 Btu). Total Natural Gas in Transportation Figure derived from U.S. EIA's Annual Energy Outlook (2020). RNG numbers derived from U.S. EPA RFS Reporting. Total greenhouse gas emissions and associated carbon dioxide equivalent (CO2e) metric tons identified using average carbon intensity of landfill gas as reported by producers under CARB's Low Carbon Fuel Standard program.

[79] California Air Resources Board, Low Carbon Fuel Standard Program, Certified Fuel Pathways, updated April 27, 2020. Available at: https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities.
[80] California Air Resources Board, Low Carbon Fuel Standard Program, Certified Fuel Pathways, updated April 27, 2020. Available at: https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities.
[81] 2019 On-Road Natural Gas Fuel Volume Report, NGVAmerica and Coalition for Renewable Natural Gas, April 2020.

States with Low Carbon Fuel Standard (LCFS) programs – designed to promote the further decarbonization of transportation fuels – show greater use of RNG. In California, 77 percent of all on-road natural gas fuel in 2019 was RNG. Since 2016, RNG has greatly surpassed conventional natural gas in refueling NGVs.[82] **See Table 27**

Many fleets across the country – including transit properties – are requiring the use of RNG in their contracts with CNG fuel providers. For example, San Diego's Metropolitan Transit System reports that 100 percent of its natural gas motor fuel purchased is renewable biogas (RNG) to fuel its CNG buses, which account for 89 percent of its total fixed-route bus fleet.[83]

And with this increased usage and demand comes increased supply. The Coalition for Renewable Natural Gas reports 129 RNG production facilities are online today in the U.S. and Canada alone, with another 35 under construction and 75 in some phase of substantial development.[84]

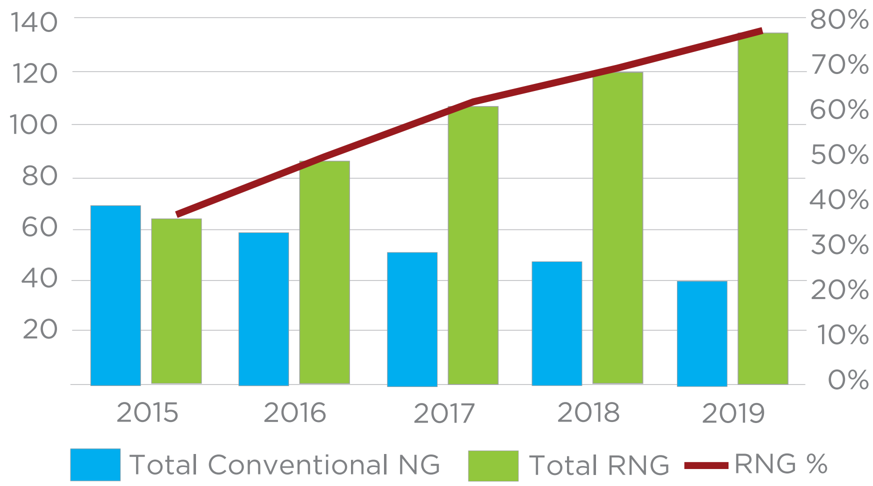
A December 2019 report by ICF for the American Gas Foundation found that by 2040, enough RNG could be in production annually to meet 75 percent of current overall diesel motor fuel needs.[85]

A conservative July 2020 GNA assessment of California's in-state transportation RNG supply concludes that there will be at least 160 RNG facilities dedicated to transportation end use on-line in the state by January 1, 2024. Furthermore, the state's capability to produce RNG for motor vehicle use from those facilities will grow over 3000 percent from January 2020 to January 2024, from 3.8 million DGE today to 119 million DGE (15.8 million MMBTU) in 2024.[86]

Supply of California-produced RNG dedicated to motor vehicle use is projected to expand at least 3000 percent from January 2020 to January 2024. – Gladstein Neandross & Associates[87]

And a March 2020 analysis by the International Energy Agency found that biogas and biomethane production in 2018 was only a fraction of the estimated overall global potential, reporting, "full utilization of the sustainable potential could cover some 20 percent of today's worldwide gas demand."[88]

Table 27: RNG Growth in California in DGEs



RNG use as a transportation fuel in California has increased 210% over the last five years, displacing over 4.2 million tons of carbon dioxide equivalent (CO2e).

Note: GGE = gasoline gallon equivalent. Natural gas figures from CARB's Low Carbon Fuel Standard Reporting Tool Quarterly Summary at https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm. Greenhouse gas emissions and associated carbon dioxide equivalent (CO2e) metric tons calculated from data reported under CARB's LCFS program using an RNG carbon intensity value of 33.895 g/mj.

[82] 2019 California On-Road Natural Gas Fuel Volume Report, NGVAmerica and Coalition for Renewable Natural Gas, June 2020.
[83] "Community Impact and Performance Report 2018," Metropolitan Transit System (MTS), San Diego, CA, page 4, available at: https://www.sdmts.com/sites/default/files/attachments/communityimpact2018v2.pdf.
[84] Coalition for Renewable Natural Gas, accessed July 24, 2020 at: http://www.rngcoalition.com/.
[85] "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment," Prepared by ICF for the American Gas Foundation, December 2019. Figure calculated using ICF's high resource potential scenario where 4,513 tBtu – equivalent to 32.5 DGEs – of RNG could be produced annually by 2040.
[86] "An Assessment: California's In-State RNG Supply for Transportation 2020-2024," Gladstein Neandross & Associates, July 2020.
[87] "An Assessment: California's In-State RNG Supply for Transportation 2020-2024," Gladstein Neandross & Associates, July 2020.
[88] "The Outlook for Biogas and Biomethane," International Energy Agency, March 2020.

This expanding interest in RNG as a motor fuel is not restricted to North America. European Biogas Association and Gas Infrastructure Europe report a 51 percent increase in biomethane plants in Europe over the past two years, from 483 in 2018 to 729 in 2020. Eighteen European countries produce biomethane, with Germany having the highest share of plants at 232 followed by France at 131 and the UK with 80.[89]

As long as humans, animals, and organic matter inhabit the Earth, there will be continuous sources of RNG to capture for use as affordable motor fuel.

CNG Buses Offer the Most Cost-Effective Emission Reduction Investment

NREL's report does not evaluate the cost-effectiveness of deploying natural gas or electric buses from the perspective of cost to reduce emissions. However, it is easy enough to calculate the cost of the emission reductions of the Foothill fleet based on the cost per mile to operate these buses and using the Argonne National Laboratory's AFLEET Calculator, a tool that presents tailpipe and well-to-wheel emissions comparisons. AFLEET enables the user to model the emission benefits of different fuels including renewable natural gas.

Analysis concludes that today's natural gas buses lower emissions more cost-effectively than battery electric buses. The Burns & McDonald study concluded that, without incentives, transitioning its all-CNG fleet to an all-BEB fleet would cost Foothill Transit an additional $409.7 million total cumulative additional costs over 25 years. If ambitious electric vehicle publicly funded incentives continue to remain available, Foothill should be prepared to spend $141 million in cumulative additional costs over the next 25 years.[90]

Comparing the acquisition costs of new buses and the lifetime emissions reductions provided by these buses compared to purchasing new diesel buses, natural gas buses operating on renewable natural gas outperform battery electric buses both in terms of the total amount of emissions reduced and also in terms of the number of new buses deployed, providing a win-win for transit operators and the environment.

The emission figures below are based on comparisons made using the AFLEET Tool and Foothill specific inputs such as bus cost and fuel economy. The comparisons used a 15-year life and the AFLEET default value of 35,000 miles per year (using the lower mileage of the Foothill electric buses would significantly lower their overall benefit – the intent here is to show the relative benefits if operated on similar routes and accumulating similar annual miles). Using the acquisition costs from the Foothill report and the emission factors in the AFLEET tool, the example below illustrates the number of buses acquired and the emission benefit provided by using $10 million to purchase natural gas buses or battery electric buses. As most California transit agencies use renewable natural gas and an increasing amount of natural gas used for transportation is renewable, the emissions calculations shown here are based on modeling benefits of landfill gas.

Analyzing the cost to reduce emissions in this way ignores other factors such as the infrastructure expenditures, and operation and maintenance costs. Examples including these other costs are provided in a later section. **See Table 28**

Table 28

	Cost	Vehicle	NOx/lb. Reductions	NOx Cost $/lb.	GHG/tons Reductions	GHG Cost/ton
NG	$575,000	17.39	94,800	$105.49	26,045	$383.96
BEB	$879,845	11.37	62,738	$159.39	14,600	$684.94
Diesel	$476,000	21.01	NA			

[89]"European Biomethane Plants Up by 51% in Two Years," *Bioenergy Insight*, June 18,2020. Accessible at: https://www.bioenergy-news.com/news/european-biomethane-plants-up-by-51-in-two-years/.

[90]"In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Pages 13-4 & 13-7, September 9, 2019

The cost effectiveness is compared to the lifetime emissions that would have occurred if a transit agency had continued to purchase new diesel fueled buses. The data and results show that natural gas buses are more cost-effective in delivering NOx reductions ($105 per lb. reduced versus $159) and greenhouse gas reductions ($384 per ton reduced versus $685) and result in the deployment of a greater number of new buses. For the same amount of money, a transit agency could purchase 50 percent more natural gas buses than battery electric buses, providing 51 percent more NOx emission reductions, and 78 percent more greenhouse gas emission reductions when using renewable natural gas.[91] **See Table 29**

Spend A Lot, Get Very Little More with Electric

Looking at the cost effectiveness in a slightly different way, the cost-effectiveness of acquiring battery electric buses to replace natural gas buses – something that environmentalists are advocating for in some areas – also was evaluated.

The table/chart at right shows that it is extremely expensive to replace natural gas buses with battery electric buses to achieve additional NOx emission reductions. Replacing a new natural gas bus powered by an ultra-low-NOx natural gas engine with a battery electric bus would cost $12,751 per lb. of NOx reduced (or 29 times more per lb. than the cost of replacing diesel buses with new, lower-NOx natural gas buses). **See Tables 30 & 31**

Simply stated, the required added financial investment needed to purchase and operate battery electric buses to achieve a 100 percent vehicle NOx-free lifetime result doesn't pencil out compared to the ultra-low-NOx lifetime result of new zero emission equivalent natural gas buses.

Natural gas buses fueled by renewable natural gas offer the most cost-effective solution to immediately lower smog pre-cursor emissions like NOx and decarbonize transit. NGVs have the most affordable total cost per mile of any alternative fuel choice.

Table 29: Emission Reductions Achieved with $10 Million Investment

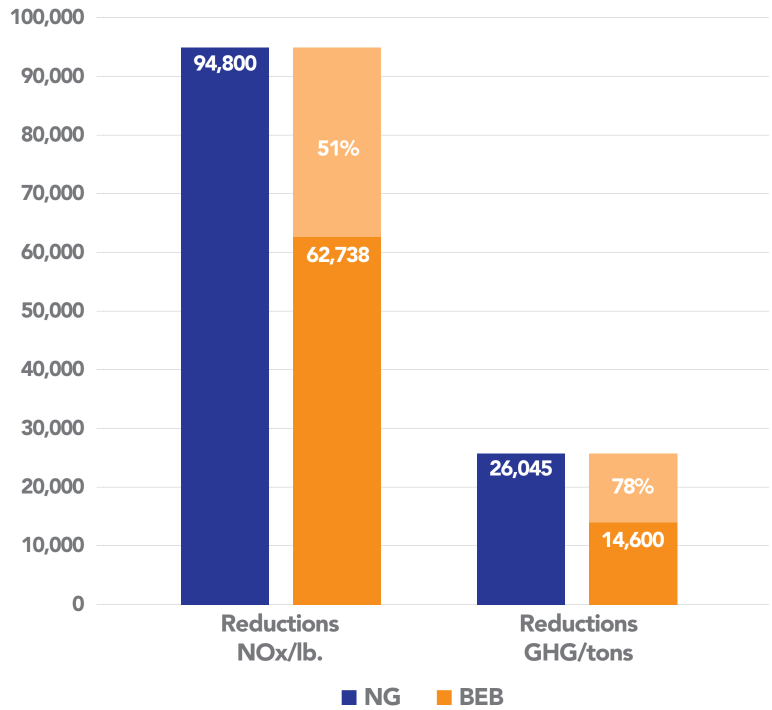
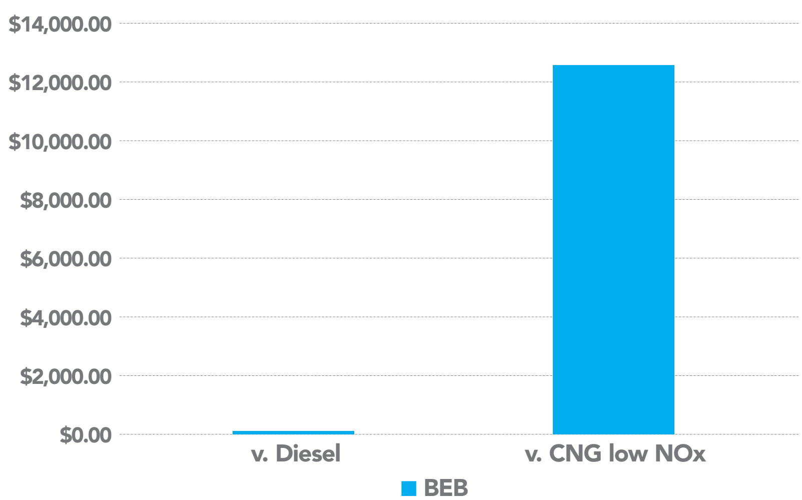


Table 30

	Lifetime NOx (lb.)	Reductions v. Diesel	$/lb. v. Diesel	$/lb. EV v. CNG Low NOx
BEB	0.00	5,520.00	$159.39	$12,751
CNG Low-NOx	69.00	5451.00	$105.49	
Diesel High IU	5,520.00	0.00	N/A	

Table 31: $/lb. NOx Reductions



[91] The NOx emission reductions shown are based on tailpipe and treat BEB as having zero emissions without consideration of upstream emissions, while the GHG emissions consider well-to-wheel inputs. The figures here were generated using the Argonne National Laboratory AFLEET Tool available at: https://afleet-web.es.anl.gov/afleet/.

Natural Gas Buses Have the Lower Total Cost of Operation

Foothill Study

Based on the data presented in the NREL Foothill study, natural gas buses are less expensive to own and operate than battery electric buses. This is true both in terms of the actual costs per mile and the costs per mile adjusted for duty cycles. Foothill does not provide a true apples-to-apples comparison since the buses have different operational range capabilities and are used on different routes, with the BEBs operating on shorter, slower routes and the natural gas buses on longer, higher speed routes. These operating conditions have an impact on fuel economy and likely on maintenance.

NREL's report includes the cost of fuel per mile, the cost of maintenance per mile and total operating cost per mile which combines the two previous costs. NREL does not factor the capital costs of the buses or fueling infrastructure into the cost per mile figures. NREL previously evaluated the fuel economy of the natural gas buses operating on the slower speed Foothill route and recorded an average fuel economy of 2.09 miles per diesel gallon equivalent (mpdge). It is important to recognize that this average fuel economy figure – when compared to the BEB result – does not account for the added weight and range capability required of the CNG buses due to their more rigorous and longer assigned duty cycle. This average fuel economy result would be greater for CNG buses if they were deployed on shorter, less strenuous routes with fewer passengers and built with smaller, lighter, lower range fuel systems as the BEBs were.

Previous NREL reports used this adjusted-to-fuel economy to show what the cost per mile of the natural gas buses would be if they were operated under similar conditions as the BEBs (e.g., slower speed, more stop-and-go service). NREL however did not provide such a comparison in its most recent report (Oct. 2019). As we believe it is valuable to do so, we have included cost per mile comparisons using adjusted fuel economy for natural gas buses operating in slower speeds, and similarly evaluated the impact of electric buses operating on longer routes with higher speeds.

To account for higher speed operation, we assumed that BEBs would require additional batteries if operated on longer, higher speed routes and that they would be 20 percent less efficient to operate or consume about 20 percent more electricity and that 15 percent of the energy purchased by transit agencies would be lost during charging. NREL has reported that between 7 – 15 percent of electricity is lost during inductive and conductive charging. The results including NREL's data and the revised data are shown in Table 32. The current natural gas fuel economy figures were adjusted downward based on the fuel economy difference that previously was recorded by NREL when the natural gas buses went from operating in higher speeds to lower speeds.

The table below includes key data compiled and reported by NREL with adjustments made highlighted in blue. Further down are the comparisons of the cost per mile based on actual fuel economy as well as fuel economy adjusted for different operating conditions. **See Table 32**

The key takeaways are as follows:

• The total cost per mile of the natural gas buses in nearly all cases is less than the cost per mile of operating the BEBs.

• Looking at the cost over the entire period covered to date by NREL, natural gas buses on average cost between $0.32 - $0.37 less per mile to operate and maintain based on the actual duty cycles encountered by the buses.

• When adjusted for slower speed operation, the average cost per mile for the natural gas buses is between $0.04 - $0.09 less than the BEBs.

• The only scenario when the natural gas buses were more costly to operate was during the last six-month period in which there was a significant increase in cost of the CNG purchased due to regional supply issues – resulting in average increase in CNG cost of $0.20 per diesel gallon equivalent. With this increase in fuel cost, the CNG buses operating in slower speeds and reduced fuel economy are estimated to cost $0.02 - $0.08 more to operate than the BEB buses.

• Comparing the costs if all buses were operated on the higher speed CNG routes, it is estimated that the BEB buses would have cost $0.40 to $0.45 more per mile than the CNG buses.

It is worth noting that there is some uncertainty associated with the adjustments made here both in terms of revising the fuel economy and costs for the natural gas and the BEBs. Additional studies evaluating natural gas buses and electric buses of the same size operating on the same routes with similar ranges would be beneficial since natural gas buses operated on shorter routes could benefit from reduced numbers of cylinders and reduced weight and BEBs on longer routes would either have to recharge more frequently or carry more batteries, factors that would impact efficiency as well as acquisition costs.

Table 32

Foothills NREL Report Oct 2019	BEB 35FC All Data	BEB 35FC Most Recent Period	BEB 40FC All Data	BEB 40FC Most Recent Period	CNG All Data	CNG Most Recent Period
Number of vehicles	12	12	2	2	8	8
Bus Manufacturer	Proterra	Proterra	Proterra	Proterra	NABI	NABI
Bus Cost	$904,490	$904,490	$879,845	$879,845	$575,000	$575,000
Fuel cost per mile	0.45	0.39	0.45	0.39	0.26	0.33
Total maintenance cost per mile	0.42	0.68	0.47	0.62	0.28	0.41
Total operating cost per mile unadjusted	0.86	1.07	0.91	1.01	0.54	0.74
Revised NG fuel $/mile Lower Speed Operation					0.54	0.68
Revised BEB electricity $/mile w/higher speed	0.52	0.47	0.52	0.47		
Revised NG TOC Lower Speed Operation	0.86	1.07	0.91	1.01	0.82	1.09
Revised BEB TOC Higher Speed	0.94	1.15	0.99	1.09	0.54	0.74

Comparing TOC Results	All Data	Most Recent	All Data	Most Recent
Difference NG compared to BEB unadjusted	($0.32)	($0.33)	($0.37)	($0.27)
Difference NG compared to BEB lower speed	($0.04)	$0.02	($0.09)	$0.08
Difference NG compared to BEB higher speed	($0.40)	($0.41)	($0.45)	($0.35)

As noted, NREL's cost analysis only looks at fuel and maintenance costs and does not evaluate the capital cost impact on per mile cost. As part of any total ownership costs, capital costs of the buses are an important factor, particularly in the case of buses that are more expensive to operate during their life. The argument by BEB proponents that BEBs will eventually pay for themselves through lower operating costs is not supported by the data. BEBs actually cost more to operate per mile or, in limited cases, may only be a few cents less per mile to operate than their CNG or diesel counterparts, they cannot pay for themselves if they cost hundreds of thousands more to purchase upfront than other bus options.

The Burns & McDonnell Foothill operational study confirms this conclusion. Requiring an all-electric bus fleet over the next 25 years will cost Foothill an additional $15.4 million annually without incentives in terms of total cost of ownership, which includes bus purchase, infrastructure upgrades, and annual operations and maintenance. If generous public incentives continue, that cost is lower but still $6.3 million more per year than operating and maintaining a clean CNG fleet.[92]

Transit buses – regardless of fuel type – contribute to reducing climate change emissions by reducing vehicles miles traveled and reducing urban congestion. Increased use of mass transit including buses must play a part in addressing climate change, but it is largely ineffective to argue that all new transit buses must be electric in order to address climate change and reduce emissions. In total, transit buses in the U.S. consume less than 0.5 percent of motor fuel and result in less than 0.5 percent of the greenhouse emissions generated by the transportation sector. When considering the upside to operating transit buses, the actual emissions are likely already negative as result of reduced emissions from automobile trips and reduced congestion.

Table 33: ICF Report 2019 - $2019 Costs per Bus

	Diesel	CNG	Electric
Infrastructure	**$3,886**	**$35,076**	**$44,127**
Capital	$0	$18,000	$26,400
O&M	$3,886	$17,706	$17,727
O&M	**$506,459**	**$370,305**	**$244,815**
Fuel	$268,392	$114,157	$64,004
Vehicle O&M	$238,067	$256,148	$180,810
Combined Cost	**$510,345**	**$405,381**	**$288,942**
Capital Cost of Bus	**$476,000**	**$544,000**	**$753,000**
Total All	**$986,345**	**$949,381**	**$1,041,942**
Infrastructure Cost Per Mile	$0.01	$0.09	$0.11
O&M Cost Per Mile	$1.24	$0.91	$0.60
Capital Cost Bus Per Mile	$1.17	$1.33	$1.85
Total	**$2.42**	**$2.33**	**$2.55**
100 Bus Fleet Station Cost	**$388,600**	**$3,507,600**	**$4,412,700**

Net Savings for NG per Bus	**$92,561**
100 Bus Fleet	**$9,256,100**
What if it took 1.2 BEBs to do work on NGV?	
Net Savings for NG per Bus	**$300,949**
100 Bus Fleet	**$30,094,940**

Note: The data presented here demonstrates the relative cost effectiveness of adopting natural gas or electric for a fleet that currently only operates diesel buses or that would need to incorporate new natural gas and/or electric infrastructure. The cost assumptions have been revised to reflect the higher diesel and natural gas bus purchase costs presented in the ICF report. The electric bus cost of $753,000 is retained for this initial comparison. ICF also assumes much lower operational costs for electric buses than for natural gas buses with figures that are not supported by data presented in either of NREL's Foothill Transit or Long Beach Transit reports.

ICF Study

The ICF report was completed in December 2019 and presents some interesting results to consider. The table above was created using the data presented in that report.[93] **See Table 33**

[92]"In Depot Charging and Planning Study," Burns & McDonald Engineering Company, Inc. for Foothill Transit, Report Project Number 110549, Pages 13-4 & 13-7, September 9, 2019

[93]"Comparison of Medium- and Heavy-Duty Technologies in California," Prepared for California Electric Transportation Coalition and the Natural Resources Defense Council by ICF; Part 2, Table VI-11, Page 45; December 2019.

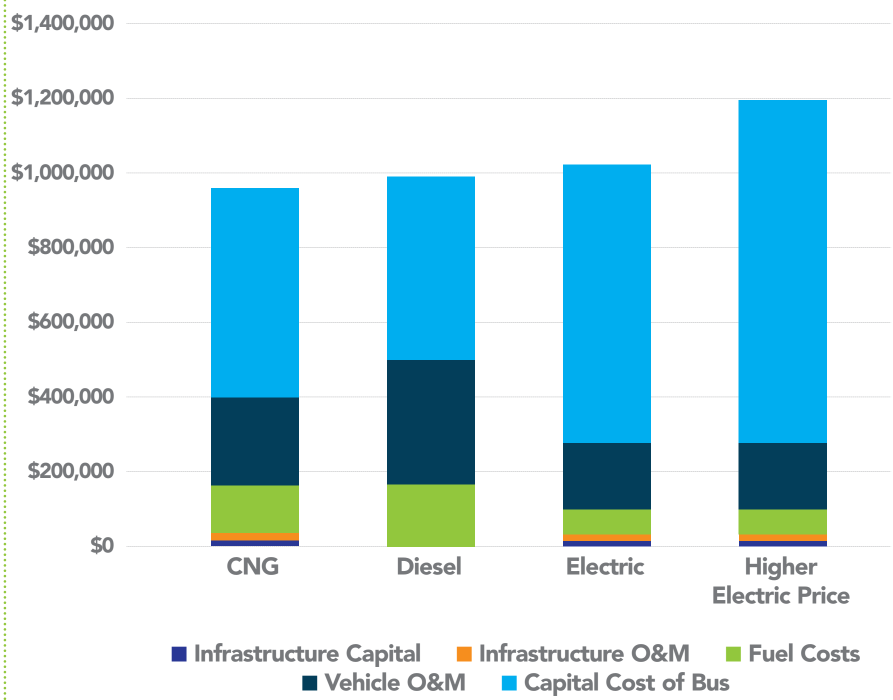
The conclusion reached using the ICF 2019 figures is that the lifetime savings of operating natural gas buses versus electric buses is roughly $92,500 per bus or $9.2 million for a fleet of 100 buses.

This is despite using an electric bus cost that appears to be at least $100,000 too low based on APTA's recent data on bus purchase costs and also assumes much lower fuel and operation and maintenance costs for BEBs that are 50 percent lower than real world results. The graph at right shows the impact of revising the ICF figures to reflect only the higher cost of 40-foot electric buses currently being purchased in California. The bar for electric initially shows the estimated total lifetime costs using the ICF data with lower cost for an electric bus (i.e., $753,000) while the higher electric price shown in the bar at far right is based on APTA's reported purchase price for 2019 40 foot electric bus (i.e., $903,679). **See Table 34**

Also, consider what would happen if a fleet had to deploy 20 percent more electric buses as noted in the MJ Bradley report in order to provide the same level of service as natural gas. As the numbers indicate above, a fleet would have to incur an additional $20 million in costs for a total of $30 million more to operate an equal fleet of 120 electric buses versus one comprised of 100 natural gas buses (this is assuming or using the lower bus ICF bus cost).

Using the capital costs of electric buses presented in the APTA 2019 report with specific numbers for California (i e. average cost of $903,679 for a 2019 40-foot BEB), the net savings per natural gas bus increase to $243,240 and $24.3 million for a fleet of 100 buses. If 20 percent more electric buses must be ordered, the total savings for the natural gas fleet of 100 buses would be $48 million.

Table 34: Total Cost of Ownership Using ICF Costs and Higher APTA Bus Costs



Long Beach Study

While much of this report is based on the Foothill Transit study, it is worthwhile to also highlight the recent results reported by NREL for Long Beach Transit. NREL prepared the 2020 Long Beach report as part of a Federal Transit Administration initiative.[94] The report – like the Foothill Study – evaluates BEB and CNG powered buses operated by an urban transit agency. The BEBs in Long Beach also operate on shorter, slower speed routes and, overall, accumulate significantly fewer miles (specifically 41 percent fewer miles) each month than the CNG buses.

The key summary results highlighted below show the BEBs as being about $0.13 cent per mile less costly to operate than the CNG buses. A major reason for the difference is the fact that the CNG buses in this study cost about $0.10 more per mile in maintenance costs (numbers in chart do not add up) with fuel cost only accounting for a difference of only about $0.01 per mile. This is without adjusting for fuel economy as NREL does in some places in its report. Adjusting the fuel economy for the CNG buses which typically operate at an average speed of 10.3 miles per hour to the 8.1 miles per hour incurred by the BEBs results in a small reduction in energy efficiency for the CNG buses (dropping to 3.26 mpdge from 3.49 mpdge). Adjusting for the increased fuel consumption results in the higher per mile CNG fuel costs and results in a net savings per mile for BEBs over CNG buses of about $0.16 per mile.[95] **See Table 35**

Table 35: Long Beach Transit – Fleet Operations and Economics

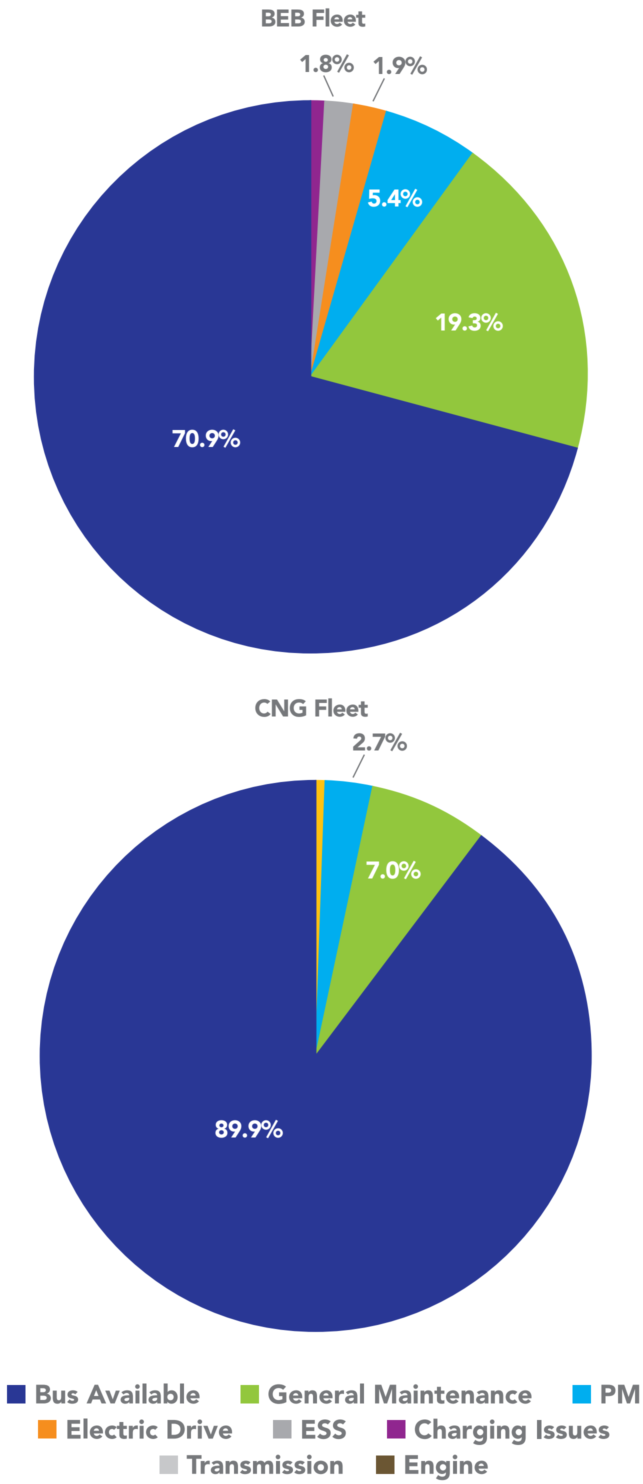
	BEB	CNG
Number of vehicles	10	8
Period used for fuel and oil analysis	1/2018-12/2018	1/2018-12/2018
Total number of months in period	12	12
Fuel and oil analysis base fleet mileage	144,127	282,997
Period used for maintenance analysis	1/2018-12/2018	1/2018-12/2018
Total number of months in period	12	12
Maintenance analysis base fleet mileage	161,275	315,382
Average monthly mileage per vehicle	1,344	3,285
Availability	71	80
Fleet energy usage in kWh (BEB) or gge (CNG)	261,927.8	92,813.38
Roadcalls	38	21
Total MBRC	4,244	15,018
Propulsion roadcalls	18	13
Propulsion MBRC	8,960	24,260
Fleet kWh/mile (BEB) or mpgge (CNG)	1.82	3.05
Representative fleet mpdge (energy equivalent)	20.71	3.49
Energy cost per kWh (BEB), cost per gge (CNG)	0.27	1.32
Energy/fuel cost per mile (based on purchased energy)	0.42	0.43
Total scheduled repair cost per mile	0.15	0.19
Total unscheduled repair cost per mile	0.29	0.36
Total maintenance cost per mile	0.44	0.54
Total operating cost per mile	**0.85**	**0.98**

[94] "Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses," Federal Transit Administration, FTA Report No. 0163; April 2020.
[95] "Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses," Federal Transit Administration, FTA Report No. 0163; Table A-1, Page 36; April 2020.

Here several points about this report are worth highlighting. As in other reports, the CNG buses have a higher reliability rate both in terms of availability (90 percent versus 71 percent) – note the NREL-produced table above lists CNG availability at 80 percent, but the pie chart below it[96] shows the correct 90 percent rate – and miles between road calls (nearly 2.5x better than BEBs), recording much higher miles driven each month than the BEBs. Given the higher utilization, it is not surprising that buses that incur 41 percent more miles driven than their BEB counterparts would incur higher maintenance costs. But in this case the increase in maintenance costs was only 19 percent. It is not known how the higher mileage would impact BEBs, but it is likely that maintenance costs also would go up if driven similarly. **See Table 36**

It is clear from this evaluation that BEBs fall far short of overcoming the much higher capital costs incurred for their purchase as the savings over the life of the buses based on current utilization and a possible 15-year life show that the buses would only save about $39,000 during their lifetime. This is far short of offsetting the $454,000 delta that Long Beach paid for acquired the BEB buses. It is also worth pointing out that based on the chart above the BEBs cost for energy per mile should be $0.49 per mile not $0.42 since the table shows electricity costing $0.27 per kWh and the fuel utilization for the BEBs at 1.8 kWh per mile. If that is truly the case, then the estimated savings for BEBs is almost 50 percent less or only about $0.09 per mile.

Table 36



1. Data period for availability analysis: Jan 2018-Dec 2018
2. Data labels omitted for pie slices representing <1.0%

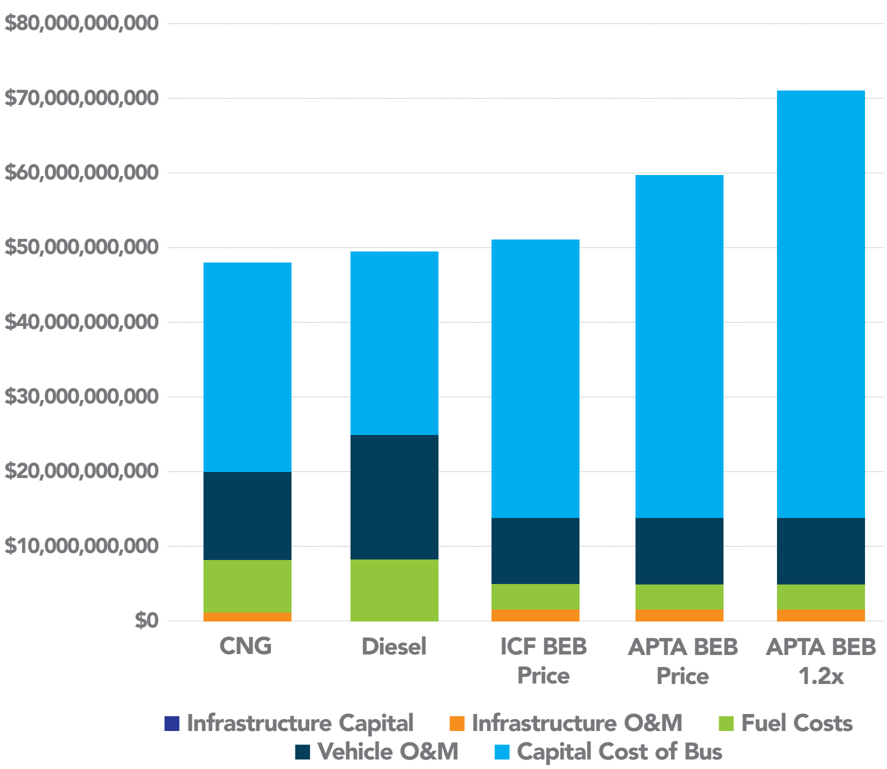
[96] "Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses," Federal Transit Administration, FTA Report No. 0163; Table 4-5, Page 15; April 2020.

Replacing America's Transit Bus Fleet

What would it cost to nearly replace the entire U.S. transit bus fleet, upgrading to new, cleaner, more efficient vehicles? Using the results and data presented in the variety of reports analyzed here, natural gas transit buses – fueled by renewable natural gas – are the most affordable, effective, and immediate way to reduce emissions and update aging technology. **See Table 37**

Using BEB bus pricing and incomplete fuel and vehicle operation and maintenance costs from the pro-EV ICF California report, the chart at right details the costs to replace 50,000 40-foot transit buses in the U.S. fleet. The comparisons are based on 40-foot buses because they account for the vast majority of the U.S. transit bus fleet. These figures include all costs associated with infrastructure capital, infrastructure operations and maintenance, fuel costs, vehicle operations and maintenance, and initial bus purchase.

Table 37: Cost 50,000 40-Foot Bus Nationwide Fleet

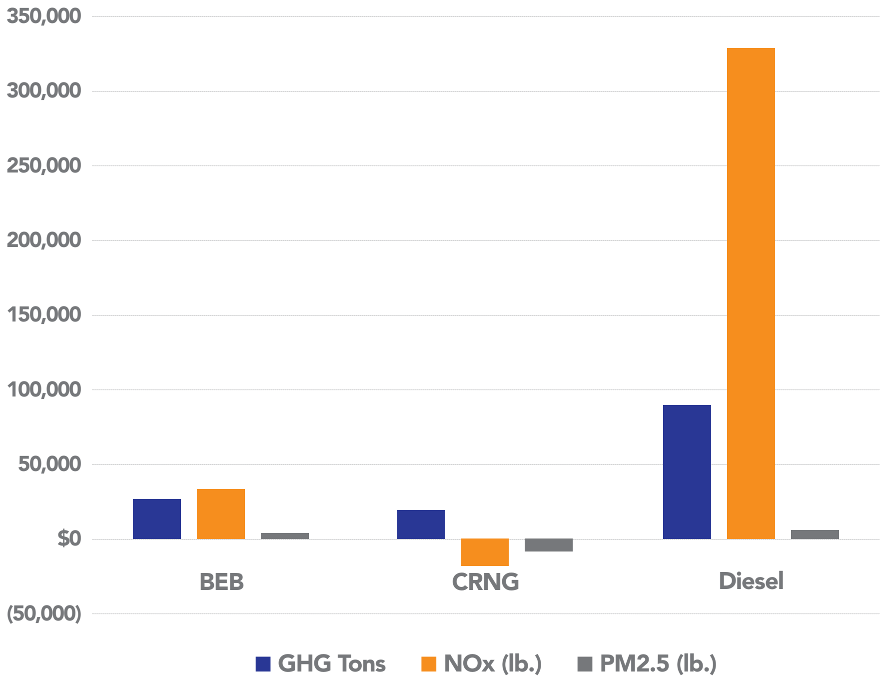


A complete CNG fleet replacement tallies in at $47.5 billion, with new diesel at $49.3 billion and BEBs at $52.1 billion. If factored using APTA's actual average BEB bus pricing, the electric fleet costs rise to $59.6 billion. And considering that replacing one diesel or natural gas bus with electric actually requires 1.2 BEBs to meet the same performance and routing requirements, complete BEB fleet replacement costs rocket to $71.6 billion, or $24 billion more than deploying the CNG bus fleet.

But many environmental advocates – supported by policymaking agencies like the California Air Resources Board – refuse to allow any replacement future transit option other than electric. How do their emissions results compare? **See Table 38**

Using the AFLEET Tool and evaluating the well-to-wheel emissions for criteria pollutants and greenhouse gas emissions reveals the tremendous benefit of opting to go with an all-CNG transit bus future over an all-electric bus future. For purposes of this calculation, the inputs included using the higher fuel economy figures presented in NREL's Foothill Transit for electric buses since AFLEET's default values provide more conservative fuel economy values for electric buses. For CNG emissions, the inputs included RNG from landfill gas; results could be even better for CNG if agriculture gas was factored. AFLEET also allows the user to model low-NOx natural gas engines, which are the only type of engine available today for CNG transit buses, and higher in-use emission factors for current diesel engines, which when operated in lower-speed operations have been shown to producer higher emissions. The emissions shown here include the use of both the low-NOx natural gas engines and higher in-use diesel emission factors.

Table 38: AFLEET CA Transit WTW Foothill BEB FE Convert 50,000 40-Foot Buses to One Fuel



The modeling shows that natural gas buses actually generate negative emissions for PM and NOx when fueled with landfill RNG. CNG buses result in annual emission reductions of more than 10,000 tons of GHG, 25 tons of NOx, and 6.26 tons of PM2.5.

Replacing America's transit fleet with RNG-fueled buses not only results in considerable cost savings but achieves far greater emissions benefits than any other commercially available technology today. Natural gas buses fueled by RNG offer a Net-Zero Now result immediately at a much lower cost than battery electric buses.

Recommendations for Policy Makers

ENSURE FLEXIBILITY AND SUSTAINABILITY

• Recognize that for most transit agencies there is not a one-size-fits-all solution due to varying climates and temperature ranges, route distances, terrain and duty cycles, and passenger capacity needs. Differing clean powertrains are needed for differing real-world applications.

• Due to those varied duty cycles and operational needs of transit agencies, establish technology-neutral directives for meeting stricter emissions targets and fleet sustainability targets. End results matter most – total cost and number of clean buses on the road and their overall emissions impact. What technology is used to get there should not be dictated.

• Promote a circular economy in your community by putting your "waste to wheels". Encourage projects that leverage local RNG production facilities (including government-owned landfills, wastewater treatment plants, and food waste digesters) with opportunities to fuel your public natural gas fleet vehicles, including transit buses, for a net-carbon-negative result.

DETERMINE TRUE COST OF OWNERSHIP

• Evaluate all costs in transitioning to new technologies including upfront vehicle acquisition costs, fueling infrastructure and power acquisition costs, and lifetime operating and maintenance costs. Consider investments in existing natural gas infrastructure already made in those evaluations.

• Recognize that overly optimistic promises regarding fuel efficiency and low vehicle operating costs from BEB manufacturers are based on certification results that do not reflect real-world operation, use of onboard passenger heating and cooling systems, or significant energy losses associated with charging.

• Calculate the cost of purchasing additional buses needed to ensure the same level of service routing, frequency, and reliability when replacing diesel or natural gas buses with electric fleets. Additional battery electric buses are needed to meet BEB's performance limitations and reliability struggles.

• Consider all costs associated with refueling, including base commodity cost of fuel plus any other associated demand or time charges, cost of refueling infrastructure development, operations, and maintenance, and access fees and infrastructure upgrades needed outside the bus lot.

IMPACT FRONTLINE COMMUNITIES SOONER

• Make informed investments based on cost effectiveness and access to affordable, commercially available, ready-right-now technology to get more clean buses on the road today.

• Invest in natural gas buses and get clean air now with more new buses deployed across the entire service territory regardless of duty cycle with no service reductions or significant fare increases.

ADDRESS REFUELABILITY

• Understand the electric load needs for mega-charging events associated with BEB refueling, both on route and at bus depots where overnight charging would occur and if electric grid can accommodate.

• Consider all costs involved in the transitioning of large public transit fleets to cleaner technology. With electric, prohibitively expensive grid expansion needs and improvements will be required for mega-charging events; those added costs will be shouldered collectively by ratepayers, transit bus riders, and taxpayers.

• Ensure the resiliency of refueling operations during times of major power outages, system unreliability, states of emergency, and forced mass public evacuations (e.g. storms and hurricanes). Major outage events – like multi-day fire prevention and rolling blackouts – will encumber operations and halt recharging operations, thereby stranding a BEB fleet. Natural gas refueling is much more resilient and reliable.

UNDERSTAND TOTAL FOOTPRINT

• Acknowledge that every technology option has an environmental footprint when comparing new technology options; while BEBs have no tailpipe, they still have sizable environmental and human rights impacts through vehicle manufacturing, battery component mining and sourcing, electricity generation and transmission, and emissions from fossil fueled onboard heating and cooling systems.

• If achieving lower criteria pollutants (NOx and PM) are a key reason for considering new, advanced technology buses, understand the significant emission reductions – 90+ percent in most cases – offered by natural gas buses powered by low-NOx engines.

• If achieving steep reductions in greenhouse gas (GHG) emissions is a key reason for moving to newer technology buses, understand that renewable natural gas provides a net-carbon zero, even negative, result depending on the RNG source. RNG-fueled natural gas buses provide the least impactful environmental footprint compared to battery electric buses charged on even the greenest electric grid.

ACHIEVE TIMELY TOTAL FLEET REPLACEMENT

• Understand that the cost and affordability of clean technology chosen has a direct impact on the timeliness of total bus fleet replacement. Significantly more costly buses mean fewer buses replaced, leaving older, dirtier ones in service longer.

• Invest in natural gas buses and get more clean buses and more cost-effective emissions and climate impact with no deterioration of service.

Glossary of Terms

APTA	American Public Transit Association
BEB	Battery Electric Bus
BTU	British Thermal Units
CARB	California Air Resources Board
CO2e	Carbon Dioxide equivalent
CNG	Compressed Natural Gas bus
CRNG	Compressed Renewable Natural Gas
DGE	Diesel Gallon Equivalent
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EV	Electric Vehicle
FTA	Federal Transit Administration
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gases
LCFS	Low Carbon Fuel Standard
LFG	Landfill Gas, Renewable Natural Gas generated from landfill waste
MBRC	Miles Between Road Calls
MMBTU	One Million British Thermal Units
MPDGC	Miles Per Diesel Gallon Equivalent
NOx	Nitrogen Oxides
NREL	National Renewable Energy Laboratory
PM	Particulate Matter
RNG	Renewable Natural Gas, or biomethane
TCO	Total Cost of Ownership
TOC	Total Operational Cost
XFC	Extreme Fast Charging

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