Los Angeles County
Metropolitan Transportation
Authority
One Gateway Plaza
3rd Floor Board Room
Los Angeles, CA

File #: 2016-0778, **File Type:** Informational Report **Agenda Number:** 42.

SYSTEM SAFETY, SECURITY AND OPERATIONS COMMITTEE
EXECUTIVE MANAGEMENT COMMITTEE
OCTOBER 20, 2016

SUBJECT: ZERO EMISSION BUS PLANS

ACTION: RECEIVE AND FILE

RECOMMENDATION

RECEIVE AND FILE status report on Metro's Zero Emission Bus Plans.

ISSUE

At the April 2016 Metro Board of Directors Meeting, Metro's CEO was asked to provide a status report on Metro's initial plans for Zero Emission Buses and to provide a comprehensive plan to further reduce greenhouse gas emissions by gradually transitioning to a zero emission bus fleet.

DISCUSSION

Metro's current plan for Zero Emission Buses (ZEB's) and reducing Greenhouse Gas Emissions (GHG) include new engine and fuel deployment and ZEB (electric bus) operational testing. Our approach consists of the following projects and activities:

1. Purchase five (5) New Flyer all-electric articulated buses with depot and en-route chargers for deployment on Metro's Orange Line with expected delivery in late 2017.

2. Purchase five (5) BYD all-electric articulated buses with depot chargers, also for use on Metro's Orange Line, with expected delivery in late 2017.

3. Purchase additional zero emission buses under RFP OP28167 for delivery between FY18 and FY22.

4. Expand use of Low NOx "Near Zero" CNG engines and Renewable Natural Gas (RCNG) for all new bus purchases and for mid-life engine repowers starting in FY18.

Given the rapid growth in ZEB technology and the strong possibility that today's technology may be dated in a couple of years, the first two ZEB projects will be used to gain first-hand experience with two prominent ZEB approaches, i.e. en-route charging and depot charging; and with operational testing of the newest ZEB long range battery technology.

For additional ZEB's that may be purchased between FY18 and FY22, Metro will need to consider that costs and operational capabilities of ZEB technologies are maturing rapidly. ZEB's that are available today (in 2016) are more expensive to buy and to operate. ZEB's currently impose operational compromises such as limited operating range and battery charging requirements that need to be tested in a larger scale than previously. While Metro does plan to gradually build up Metro's ZEB fleet over the next 3-5 years, this assumes successful operational testing and experience; and that ZEB technologies continue to evolve. Assuming that occurs, Metro would expect to accelerate the rate that ZEB's are brought into Metro's bus fleet in the future.

The more immediate term strategy for air quality improvement is to consider purchasing "Near Zero" Cummins-Westport Low NOx ISL-G engines and renewable natural gas (RCNG) fuel for both new and repowered CNG buses. According to the fleet emission modeling done by Metro's technical consultant, this approach will have significant regional air quality benefits, including reducing NOx emissions for Metro's bus fleet by an additional 90%, and greenhouse gas emissions by an additional 80% below current fleet emission levels. This is the most cost effective approach that provides immediate emission and regional air quality benefits.

Low NOx engines were certified by CARB and EPA in 2015. The Low NOx engines may be run using existing operations infrastructure, and are commercially available today. It is anticipated that the majority of Metro's CNG powered bus fleet will be retrofit with Low NOx engines by 2026.

The attached report from Ramboll/Environ outlines different technology options for Metro to comply with pending CARB ZEB rules. The report provides a high-level cost assessments and emission impacts for several technology options, including battery electric buses, fuel cell buses, and Low NOx "Near Zero" CNG engines. Since the draft report was first released in February 2016, it has been updated and revised based on input from CARB staff and ZEB industry suppliers. As shown in Table 1, the expanded use of Low NOx CNG engines and renewable natural gas appear to be the most impactful strategies. This approach will have the greatest potential for emission reductions for our region at the lowest cost.

As compared to Electric Buses with Depot & En-route charging, Low NOx & RCNG offers:

- Approximately the same reduction in NOx (2.72 vs. 2.83 million tons)
- Approximately 39% greater reductions in GHG (11.4 vs. 8.2 million tons)
- At approximately half the increased costs from the baseline ($173M vs. $376.1M)

TABLE 1
ESTIMATED COSTS FOR EMISSION REDUCTION OPTIONS 2015 - 2055

	LNOx & RCNG	**Electric Buses**		**Fuel Cell Buses**	
Comparison to Baseline CNG		**Depot Charging**	**Depot & En-Route Charging**	**H2 from Methane**	**H2 from Electrolysis**
Increased Cost (NPV $ Million)	**$173.0**	$767.8	$376.1	$1,379.3	$1,680.2
GHG Reductions (million tons)	**11.4**	8.2	8.2	3.3	6.7
In-Basin NOx Reduction (million tons)	**2.72**	2.83	2.84	0.07	2.50
Cost Effectiveness					
$/Ton Reduction of GHG	**$15.19**	$93.71	$45.69	$419.43	$249.84
$/Ton Reduction of NOx	**$63,530**	$271,638	$132,667	$20,247,155	$670,849
Source: Ramboll/Environ, October 2016					

FINANCIAL IMPACT

Staff and consultants will continue to refine our comprehensive cost analysis that encompasses the total life-cycle cost for ZEB implementation. Details of the cost elements include, but are not limited to the necessary infrastructure changes, operation and maintenance costs (including staff training), engine repower mileage impacts, and short term capital cost impacts. Metro expects to pursue a number of competitive federal, state and local grant funding opportunities. Specific funding sources may include FTA "Lo-No" grants, Measure R and a "Buy Back" credit from BYD for the trade-in of Metro's original BYD 40' buses.

The recommended bus procurement program, including zero emission buses is expected to be made under RFP OP28167, Forty and Sixty Foot Low Floor CNG or Zero Emission Buses. Funding for these projects will be identified when this contract is awarded. Currently the RFP is an active procurement and in a blackout period. Specific quantities and types of ZE buses to be purchased under RFP OP28167 are to be determined based on Metro's operational needs, and these ZE buses may be a combination of 40' and 60' buses. Each of these ZEB projects will be subject to Metro Board approval and funding availability.

NEXT STEPS

Staff will return to the Board with award recommendations for purchasing new CNG and zero emission buses in early 2017. This will include recommendations for quantities and types of zero emission buses that are best suited for Metro's operational needs, reflect best performance in field tests, and that fit within Metro's available funding.

ATTACHMENTS

Attachment A - Board Motion April 28, 2016
Attachment B - Staff Responses to Board Requests for ZEB Plans
Attachment C - Updated Ramboll/Environ Report September 29, 2016
Attachment D - List of Transit Properties Running ZEB's
Attachment E - Identified ZEB Suppliers
Attachment F - Noise Level Comparison of Conventional Buses and ZEB's
Attachment G - Metro Routes Most Suitable for ZEB Operation
Attachment H - Summary of ZEB Funding Opportunities

Prepared by: John Drayton, Director, Equipment/Vehicle Acquisition (213) 617-6285

Reviewed by: James T. Gallagher, Chief Operations Officer, (213) 922-4424

Phillip A. Washington
Chief Executive Officer

ATTACHMENT A

Metro

Los Angeles County
Metropolitan Transportation
Authority
One Gateway Plaza
3rd Floor Board Room
Los Angeles, CA

Board Report

File #:2016-0388, **File Type:**Informational Report

Agenda Number:

REGULAR BOARD MEETING
APRIL 28, 2016

Motion by:

DIRECTORS GARCETTI, SOLIS, FASANA AND DUPONT-WALKER

Related to Item 29

ZERO-EMISSION BUS TECHNOLOGY

As one of the largest transit agencies in the U.S., Metro needs to continue leading the nation in the application of best environmental and sustainable practices. After purchasing its first natural gas bus in 1995, Metro became the largest clean compressed natural gas (CNG) bus fleet in the nation with its last diesel bus retiring in 2011.

With the fast-paced evolution of new and clean technology, the transit industry is adopting and deploying new bus technologies that offer significant economic and environmental benefits. According to the American Public Transportation Association ("APTA"), 46.9 percent of U.S. public transportation buses are using alternative fuels or hybrid technology. Various transit agencies have embraced these advancements such as, but not limited to, the following: Philadelphia ("SEPTA"), Indianapolis ("IndyGo"), Seattle's King County Metro Transit, and Foothill Transit, which has the largest electric bus fleet in the country.

Although mile-range and mass production remains a challenge, continually improving technology and the steady decrease in cost is a clear indication that zero-emission bus vehicles are in high demand.

A strong commitment toward transitioning to a zero-emission bus fleet will position Metro to capitalize on Federal grant programs along with the State of California's cap-and trade programs.
WE THEREFORE MOVE that the Board direct the CEO to:

A. Develop an initial outline for a comprehensive plan to further reduce greenhouse gas emissions by gradually transitioning to a zero-emission bus fleet;

B. Report which public transit agencies have deployed zero emission vehicle buses in the U.S.

C. Identify manufacturers that provide zero emission bus technology for large U.S. transit agencies.

D. Report that provides the following information for zero emission buses:

1. Greenhouse gases and air pollutant levels;

2. Noise levels (i.e. decibels) comparison between conventional Clean Natural Gas ("CNG") and zero emission buses;

3. Production challenges and opportunities to partner with other agencies in large procurements to achieve economies scale discounts; comparison of long-term maintenance costs.

4. Chronological timeline of the advancements and forecasts in zero emission bus technologies;

E. Provide a report on all mile-range and run times for all current MTA bus routes.

F. Identify possible Federal, State and local funding sources that are eligible for the purchase of zero-emission bus vehicles.

G. For this new bus procurement of advanced transit buses, include the following:

1. Zero emission bus technology cost options for the base order and all other bus purchase options.

2. Increasing and maximizing seating capacity.

H. Report back on the above at the October 2016 MTA Board meeting and provide a semi-annual report thereafter on zero emission bus technology.

ATTACHMENT B

RESPONSES TO BOARD REQUEST FOR ZEB PLANS 4/28/16

During the April 28, 2016 Board meeting, staff was directed to report back and provide detailed updates on several items at the October 2016 Board of Directors meeting. Attached are technical responses to these questions, and supporting data is also attached to this report.

A. **Greenhouse Gas Emission Reduction Options:** Metro's technical consultant, Ramboll/Environ, has provided a detailed assessment of options for reducing greenhouse gas emissions and for transitioning to ZEB's. Key recommendations from this analysis include focusing on using longer range ZE buses and immediately adopting the use of Low NOx "Near Zero" CNG engines and using RCNG for fueling. For certain corridors, such as Metro's Orange Line, there will be opportunities to use specialty ZEB's with en-route opportunity charging. Based on this technology assessment and state of ZE technologies in 2016, Ramboll/Environ does not recommend pursuing fuel cell buses at this time.

B. **USA ZEB Transit Deployments**: As of April 2016, staff identified 57 transit agencies that are operating a total of 280 zero emission buses in the US.

C. **Current ZEB Manufacturers**: Staff has identified five (5) major domestic US manufacturers that have produced heavy duty 40' or 60' zero emission buses for large transit agencies in the US: BYD; Proterra; Gillig; New Flyer: and Nova Bus (a subsidiary of Volvo). Of these manufacturers, BYD and Proterra solely produce electric buses; Gillig, New Flyer and Nova offer both electric buses as well as conventionally powered transit buses. In addition to these five manufacturers, there are several other smaller manufacturers that produce light and medium duty transit vehicles in a variety of configurations.

D. **Additional Updates on Zero Emission Buses**:

1. Greenhouse gases and air pollutant levels. All the programs identified for Zero and Near Zero Emission propulsion systems have impacts on criteria pollutants and GHG emissions. The most cost effective option for emission reductions today is Near Zero CNG engines. Refer to Ramboll/Environ report.

2. Noise levels (i.e. decibels): Attached is a comparison between conventional CNG and zero emission buses. Based on Altoona noise testing data, the average interior and exterior noise levels for Zero Emission buses are 4-8 dB lower than CNG buses.

3. Partnering and Scalability: Production challenges and opportunities to partner with other agencies in large procurements to achieve economies of scale discounts; comparison of long-term maintenance costs.

Metro has identified over 50 transit operators who have initiated ZEB programs. No single US transit operator, even the largest operators like LA Metro, have the resources and means to single-handedly support ZEB commercialization. We have also surveyed the five major US bus manufacturers who have produced heavy duty 40’ and 60’ buses and will pursue any opportunities to leverage Metro’s ZEB investments. We will also continue to reach out to regional municipal transit operators and provide opportunities to partner with Metro on our upcoming bus procurements.

4**.** Chronological timeline of the advancements and forecasts in zero emission bus technologies; refer to Ramboll/Environ report.

E. **Metro Routes Suitable for ZEB’s –** Metro reviewed all lines and run assignments by operating division, and also looked at potential layover facilities to rank the best corridors for ZEB operation. Out of Metro’s 1,900 weekly run assignments, 71% are under 150 miles, and 99% are under 250 miles; many of these lines may be suitable to battery electric buses. However, many of these runs also have extended run times; almost every operating division has run assignments where buses don’t return to the home division for 20 hours or more.

The top rated corridor for ZEB’s is the Metro Orange Line (MOL) BRT which currently operates 43 articulated buses. The MOL corridor has several advantages for operating ZEB’s, including a dedicated right-of-way with no traffic and Metro-owned terminals at each end that can be used for en-route opportunity charging. Metro is also looking at other BRT services like the Silver Line that have similar operational characteristics and advantages for deploying ZEB’s.

Attached is a line-by-line assessment of all Metro bus routes and operating divisions to help determine suitability for ZEB operation.

F. **ZEB Funding Sources –** Attached is a listing of potential Federal, State and local funding sources that are eligible for the purchase of zero-emission bus vehicles.

G. **ZEB Bus Procurements –** Recommendations from Metro’s Board for costing ZE options and considering seating capacity have been included in the new bus solicitation that is currently underway. The full RFP can be found on-line on Metro’s Vendor Portal (here). Staff will report back periodically on the status of these items when they return to the Board with recommendations for contract award(s) based on this solicitation.

UPDATED DRAFT

Intended for

Advanced Transit Vehicle Consortium
Los Angeles, California

Prepared by

Ramboll Environ US Corporation
Los Angeles, California

M.J. Bradley & Associates, LLC
Concord, Massachusetts

Date

September 29, 2016

ZERO EMISSION BUS OPTIONS: ANALYSIS OF 2015-2055 FLEET COSTS AND EMISSIONS

NEW TRANSIT VEHICLE TECHNOLOGIES AND ADVANCED TECHNOLOGY IMPLEMENTATION (OP33203093)

Metro

Date 09/29/2016

Authors **Dana Lowell and David Seamonds**
M.J. Bradley & Associates

Varalakshmi Jayaram, Julia Lester, and Lit Chan
Ramboll Environ

Acknowledgements: This report was developed with significant assistance from staff of the Los Angeles County Metropolitan Transportation Authority, without whose help it could not have been completed. The authors would like to acknowledge and thank John Drayton, Kwesi Annan, Philip Rabottini, Steven Schupak, Evan Rosenberg, and Scott Page. We would also like to thank the California Air Resources Board, American Public Transportation Association, and transit bus manufacturers for their valuable data and comments.

Ref 06-35843D

Metro

CONTENTS

TABLES

CONTENTS (CONTINUED)

FIGURES

q:\m\metro_atvc\06-35843c-g\revised zeb analysis\zeb lcc analysis updated draft report_092916.docx
New Transit Vehicle Technologies and Advanced Technology Implementation (OP33203093)

EXECUTIVE SUMMARY

The Los Angeles County Metropolitan Transportation Authority (LACMTA) currently operates an active fleet of 2,194 urban transit buses in fixed-route service throughout the Los Angeles metropolitan area. All of LACMTA's buses are compressed natural gas (CNG) buses which operate on standard natural gas procured from the local natural gas utility. LACMTA fuels these buses at eleven CNG fuel stations located on LACMTA property at various locations throughout the city.

LACMTA continually renews their bus fleet by purchasing new buses and retiring their oldest buses. Their general policy is to keep buses in service for 14 years; as such approximately 7% of the fleet is replaced each year with new buses.

This report summarizes the results of modeling to estimate capital and operating costs, as well as exhaust emissions, for the LACMTA bus fleet over the period 2015 – 2055 under five different future bus technology/fuel purchase scenarios:

1) **BASELINE:** Continue to purchase standard CNG buses to replace retiring buses, and continue to purchase conventional natural gas.
2) **RENEWABLE NATURAL GAS**: Beginning in 2016 start to phase in the purchase of renewable natural gas (RNG), with 100% of natural gas use by the bus fleet renewable gas after 2017. Continue to purchase standard CNG buses to replace retiring buses.
3) **RENEWABLE NATURAL GAS PLUS LOW NOx BUSES:** In addition to phasing in the use of renewable natural gas, in 2019 begin to purchase new CNG buses with "Low NOx" engines (LNOx), certified to have NOx, CH_4, and PM emissions 92%, 72% and 50% lower, respectively, than emissions from "standard" natural gas engines that meet California Air Recourses Board new engine standards. In addition, beginning in 2018 begin to repower old buses with new Low NOx engines during their mid-life overhaul. Under this scenario the entire fleet will turn over to Low NOx natural gas engines by 2028.
4) **ELECTRIC BUSES:** Starting in 2025 replace all retiring buses with battery-electric buses. Under this scenario the entire bus fleet will turn over to electric buses by 2039. There are two options for battery charging under this scenario: 1) charging at the bus depot only, and 2) charging at the bus depot and in-route throughout the day.
5) **FUEL CELL BUSES:** Starting in 2025 replace all retiring buses with hydrogen fuel cell buses. Under this scenario the entire bus fleet will turn over to fuel cell buses by 2039. There are two options for producing the necessary hydrogen fuel under this scenario: 1) produce hydrogen on-site at LACMTA depots using steam reformation of natural gas (SMR), and 2) produce hydrogen on-site at LACMTA depots using electrolysis of water.

Scenarios four and five represent current options available to transit agencies under the California Air Resources Board's (CARB) proposed Zero Emission Bus (ZEB) rule. Scenario three is an alternative approach to reducing both GHG and NOx emissions that could be considered as an alternative method to meet the intent of CARB's ZEB rule.

This September 2016 updated draft report is a revision to a Draft report released by LACMTA/ATVC in February 2016 ("draft analysis"). It incorporates updated assumptions based on newly available information. The major differences between this revised analysis and the draft analysis include:

- Fuel costs for electricity used to power battery buses, and hydrogen used to power fuel cell buses, presented in this revised analysis, are net of credits that LACMTA could generate under California's Low Carbon Fuel Standard (LCFS). LCFS credits for electricity and hydrogen were not included in the draft analysis. Commercial providers of Renewable Natural Gas can also generate credits under LCFS, and these credits were implicitly included in LACMTA's projected cost of RNG in the draft analysis, as well as in this revised analysis.

- Projected purchase and overhaul costs for battery-electric and fuel cell buses were revised downward based on feedback from bus manufacturers. The revised prices reflect recent, significant reductions in near-term battery prices (2017 – 2020) as well as recent projections of continued, significant battery cost reductions through 2030.
- Revised assumptions for projected average energy use (kWh/mi) for electric buses in LACMTA service. The revised assumptions are based on the average energy use from a fleet of five 40-ft electric buses recently put into service by LACMTA, which has accumulated approximately 30,000 in-service miles to date. In this revised analysis, electric buses are projected to use approximately 20% more energy per mile than was assumed in the draft analysis.
- Revised assumptions for projected average range per charge for electric buses, based on the revised assumptions for average energy use, as well as revised assumptions about the battery capacity of commercially available electric buses after 2025. Based on feedback from bus manufacturers, and recent developments, this analysis assumes that future electric buses will have approximately 20% larger battery packs than was assumed in the draft analysis, thus increasing their expected range per charge. The effect of the larger projected battery packs on range is, however, offset by projected greater energy use per mile.
- Revised assumptions about the practical replacement ratio of in-service CNG buses with battery-electric buses. The revised assumptions are based on an analysis of all of LACMTA's week-day scheduled bus assignments (time and mileage in-service), compared to the revised assumptions for practical battery bus range per charge. This analysis is summarized in Section 2.1 and 2.2. This analysis determined that lower replacement ratios would be required in the 2025 – 2035 time frame than was assumed in the draft analysis (i.e. fewer electric buses would be required to replace CNG buses).

Note that on 9/12/16 one electric bus manufacturer (Proterra) released preliminary information about an extended range version of their 40-ft transit bus, which can carry up to 660 kWh of batteries, potentially extending practical electric bus range beyond that estimated in this analysis. Significant questions remain unanswered about this bus, including its purchase cost, its in-use energy use in LACMTA service, its passenger capacity, and the manufacturer's production capability and timing. As such, this updated draft report does not incorporate the potential effect of this bus on future electric bus costs.

LACMTA currently has an active solicitation for purchase of 40-ft and 60-ft buses, including electric buses, with bids due in January 2017. It is expected that this solicitation will yield better information about the near-term purchase costs and technical capabilities of electric buses from several manufacturers, including the Proterra extended range bus.

When this information is available, this analysis will be updated again, with revised assumptions that reflect the new information. It is expected that this next update will be available in late January 2017.

SUMMARY OF RESULTS

Table 1 summarizes the net present value of total estimated fleet costs from 2015 – 2055 under each scenario in 2015 dollars. As shown, the use of RNG by itself is not projected to increase total fleet costs. The use of RNG and the transition to LNOx buses is projected to increase total fleets costs by $173 million over the next 40 years, an increase of $0.001 per revenue seat-mile, which is 1.1% greater than projected baseline costs.

The transition to electric buses is projected to increase total fleets costs by $376 - $768 million over the next 40 years, an increase of $0.003 - $0.006 per revenue seat-mile, which is 2.3% - 4.7% greater than projected baseline costs. Exclusive depot charging is projected to be more expensive than depot and in-route charging.

The transition to fuel cell buses is projected to increase total fleets costs by $1.4 - $1.7 billion over the next 40 years, an increase of $0.012 - $0.014 per revenue seat-mile, which is 8.5% - 10.3% greater than projected baseline costs. Production of hydrogen fuel for fuel cell buses using electrolysis is projected to be more expensive than hydrogen production using SMR.

Table 1. LACMTA Zero Emission Bus NPV Estimated Total Fleet Costs 2015 - 2055 (2015 $ million)

Cost Element		BASELINE	RENEW NG	LOW NOx CNG BUS & REPOWER		ELECTRIC BUS		FUEL CELL BUS	
		Std CNG Bus Conv NG	Std CNG Bus RNG	LNOx Bus Conv NG	LNOx Bus RNG	Depot Charging	Depot & In-Route Charging	H_2 by SMR	H_2 by Electrolysis
Capital	Bus Purchase	$2,299.1	$2,299.1	$2,332.0	$2,332.0	$3,031.6	$2,931.4	$3,133.2	$3,133.2
	Bus Repower			$100.3	$100.3				
	Bus mid-life OH	$164.2	$164.2	$173.2	$173.2	$307.3	$280.8	$609.1	$609.1
	Depot Mods					$61.1	$36.0	$49.8	$49.8
	Fuel Infra	$0.0	$0.0	$0.0	$0.0	$49.3	$63.6	$165.2	$165.2
	sub-total	*$2,463.3*	*$2,463.3*	*$2,605.5*	*$2,605.5*	*$3,449.3*	*$3,311.7*	*$3,957.4*	*$3,957.4*
Operating	BO Labor	$10,441.4	$10,441.4	$10,441.4	$10,441.4	$10,663.5	$10,441.4	$10,441.4	$10,441.4
	Fuel	$1,244.4	$1,244.4	$1,248.3	$1,248.3	$862.5	$844.9	$1,071.4	$1,372.3
	Maintenance	$2,128.6	$2,128.6	$2,155.6	$2,155.6	$2,070.3	$2,055.9	$2,186.9	$2,186.9
	sub-total	*$13,814.4*	*$13,814.4*	*$13,845.3*	*$13,845.3*	*$13,596.3*	*$13,342.2*	*$13,699.7*	*$14,000.5*
TOTAL		**$16,277.7**	**$16,277.7**	**$16,450.8**	**$16,450.8**	**$17,045.6**	**$16,653.9**	**$17,657.1**	**$17,957.9**
INCREASE		**NA**	**$0.00**	**$173.03**	**$173.03**	**$767.85**	**$376.14**	**$1,379.33**	**$1,680.15**
AVG $/mile		$4.18	$4.18	$4.22	$4.22	$4.27	$4.28	$4.53	$4.61
AVG $/revenue seat-mile	**Value**	$0.138	$0.138	$0.139	$0.139	$0.144	$0.141	$0.150	$0.152
	% diff to baseline	*NA*	*100.0%*	*101.1%*	*101.1%*	*104.7%*	*102.3%*	*108.5%*	*110.3%*

Table 2 summarizes total estimated fleet emissions from 2015 – 2055 under each scenario. This data is also shown in Figure 1.

As shown, compared to the baseline the use of RNG is estimated to increase NOx emitted within the South Coast Air Basin[1] over the next 40 years by 1% and reduce PM emitted within the basin by 128%. The use of RNG will also reduce NOx and PM emitted outside of the South Coast Air Basin over

[1] The South Coast Air basin encompasses Orange County and parts of Los Angeles, San Bernardino, and Riverside counties in southern California, including the entire city of Los Angeles.

the next 40 years by 82% and 600% respectively. PM emissions decrease by more than 100% because both in-basin and out-of-basin upstream PM emissions from production of RNG are negative due to credits, more than offsetting all tailpipe PM emissions from CNG buses.

The use of RNG will reduce CH_4 emissions by 2%, reduce CO_2 emissions by 81% and reduce total CO_2-equivalent GHG emissions by 70%.

Table 2. LACMTA Zero Emission Bus Estimated Total Fleet Emissions (tons) 2015 - 2055

Pollutant	BASELINE	RENEW NG	LOW NOx CNG BUS & REPOWER		ELECTRIC BUS		FUEL CELL BUS	
	Std CNG Bus Conv NG	Std CNG Bus Renew NG	LNOx Bus Conv NG	LNOx Bus Renew NG	Depot Charging	Depot & In-Route Charging	H_2 by SMR	H_2 by Electrolysis
NOx (in-basin)	6,296	6,385	3,483	3,573	3,444	3,431	6,228	3,792
PM (in-basin)	81.1	-22.8	79.0	-25.4	40.0	39.7	723.5	49.1
CH_4	89,590	87,421	76,590	74,414	41,124	40,965	59,292	45,651
CO_2	13,637,506	2,618,086	13,681,149	2,624,750	6,537,416	6,486,030	11,106,350	8,011,017
GHG (CO_2-e)	15,877,260	4,803,609	15,595,906	4,485,096	7,565,519	7,510,164	12,588,639	9,152,286
NOx (Out-of-basin)	10,157	1,785	10,190	1,789	4,954	4,910	6,410	6,228
PM (out-of-basin)	110.4	-551.7	110.7	-553.5	70.1	68.3	73.0	117.5

Compared to the baseline the use of RNG and the transition to LNOx buses is projected to reduce NOx and PM emitted within the South Coast Air Basin over the next 40 years by 43% and 131%, respectively, and to reduce NOx and PM emitted outside of the South Coast Air Basin over the next 40 years by 82% and 602%, respectively. PM emissions decrease by more than 100% because upstream PM emissions from production of RNG are negative due to credits, more than offsetting all tailpipe PM emissions from LNOx CNG buses. The use of RNG and LNOx CNG buses will reduce CH_4 emissions by 17%, will reduce CO_2 emissions by 81% and will reduce total CO_2-equivalent GHG emissions by 72%.

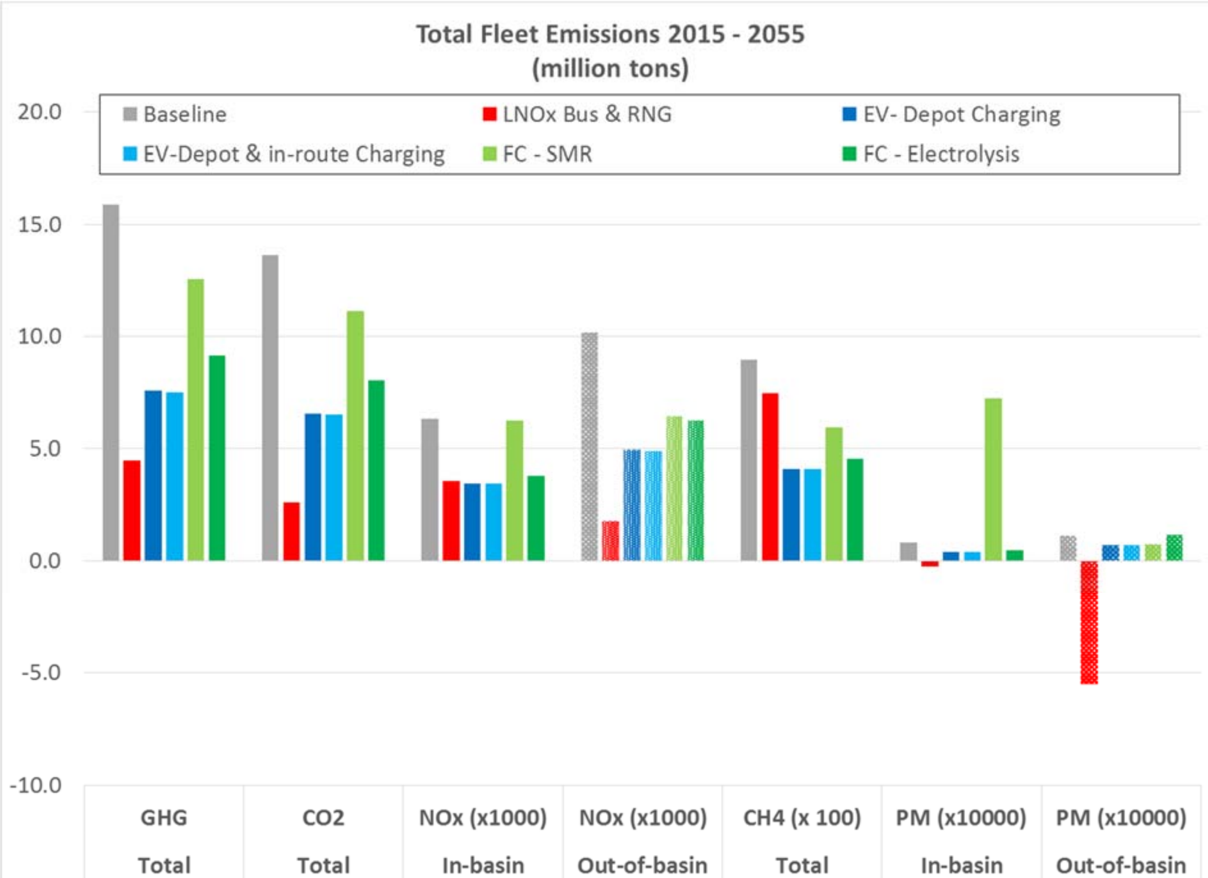
Compared to the baseline the transition to electric buses is projected to reduce NOx emitted within the South Coast Air Basin over the next 40 years by 45% -46%, and to reduce NOx emitted outside of the South Coast Air Basin over the next 40 years by 51% - 52%. It will also reduce PM emitted within the South Coast Air Basin over the next 40 years by 51%, and reduce PM emitted outside of the South Coast Air Basin over the next 40 years by 51% -52%. The transition to electric buses will reduce CH_4 emissions by 54%, reduce CO_2 emissions by 52%, and reduce total CO_2-equivalent GHG emissions by 52% - 53%. The use of depot and in-route charging will reduce emissions slightly more than the use of depot charging only, due to fewer in-service bus miles.

Compared to the baseline, the transition to fuel cell buses is projected to reduce NOx emitted within the South Coast Air Basin over the next 40 years by 1% - 40%, and to reduce NOx emitted outside of the South Coast Air Basin over the next 40 years by 37% - 39%. The transition to fuel cell buses will also reduce CH_4 emissions by 34% - 39%, reduce CO_2 emissions by 19% - 41%, and reduce total CO_2-equivalent GHG emissions by 21% - 42%.

Production of hydrogen using electrolysis will reduce NOx and GHG emissions significantly more than production of hydrogen using SMR. In addition, compared to the baseline, production of hydrogen using electrolysis will reduce PM emitted within the South Coast Air basin by 39%, but will increase PM emitted outside of the South Coast Air Basin by 6%. Production of hydrogen using SMR will increase

PM emitted within the South Coast Air Basin by 792% while reducing PM emitted outside of the South Coast Air Basin by 34%.

Figure 1. LACMTA Zero Emission Bus Estimated Total Fleet Emissions 2015 – 2055



The modeling summarized here indicates that Scenario 3, the use of RNG and transition to LNOx buses, will be more effective at reducing in-basin PM, total CO_2, total GHGs, and total NOx from the LACMTA fleet over the next 40 years than transition to either electric or fuel cell buses, but will be slightly less effective at reducing in-basin NOx.

This approach will also be less expensive than transition to either electric or fuel cell buses. Table 3 presents a summary of the cost-effectiveness of emission reductions under each scenario.

If all incremental costs (above baseline) are attributed to GHG reduction, the use of RNG and transition to LNOx buses will cost $15/ton of GHG reduced over the next 40 years. The transition to electric buses will cost $46 - $94/ton of GHG reduced, and the transition to fuel cell buses will cost $250 – $419/ton of GHG reduced.

If all incremental costs (above baseline) are attributed to NOx reduction, the use of RNG and transition to LNOx buses will cost $64 thousand/ton of in-basin NOx reduced over the next 40 years. The transition to electric buses will cost $133 - $272 thousand/ton of in-basin NOx reduced, and the transition to fuel cell buses will cost $0.67 – $20 million/ton of in-basin NOx reduced.

Table 3. Zero Emission Bus Options Cost Effectiveness of Emission Reductions ($/ton)

			Electric Bus		Fuel Cell Bus	
		LNOx Bus & RNG	Depot Charging	Depot & In-route Charging	SMR	Electrolysis
Compared to Baseline	Increased Cost (NPV $ million)	$173.0	$767.8	$376.1	$1,379.3	$1,680.2
	GHG Reduction (million ton)	11.4	8.2	8.2	3.3	6.7
	In-basin NOx Reduction (ton x000)	2.72	2.83	2.84	0.07	2.50
Cost effectiveness of Emission Reductions	$/ton GHG	$15.19	$93.71	$45.69	$419.43	$249.84
	$/ton IB NOx	$63,530	$271,638	$132,667	$20,247,155	$670,849

1. FLEET COST & EMISSIONS MODEL DESCRIPTION

Both the fleet cost model and the fleet emissions model are based on a fleet assignment of 2,500 40-ft buses, which provides equivalent total passenger capacity (seat-miles) to LACMTA's current mixed fleet of 1,212 40-ft, 626 45-ft, and 356 60-ft buses. This fleet assignment is held constant throughout the analysis period; the models assume no growth (or reduction) in LACMTA service during the 40-year analysis period.

The starting fleet in calendar year 2015 is assumed to be composed of 625 buses with engines built prior to model year 2007, and 1,875 buses with model year 2007 – 2014 engines, consistent with LACMTA's current fleet[2]. The model assumes that 178 older buses will be retired each year and replaced by new buses, to maintain 7% annual fleet turnover. For all scenarios other than electric buses charged exclusively at the depot, the model assumes that old buses will be replaced one-for one with new buses, so that total fleet size and total annual fleet miles will stay constant from year-to-year.

Due to daily range restrictions the model assumes that one retiring bus will need to be replaced with more than one electric bus, if the electric buses are charged only at the depot; the replacement ratio is based on assumed daily range between charging events relative to the minimum required daily range for current buses based on actual week-day bus assignments (see section 2.2). For this scenario this results in a slight increase in fleet size over time, as well as an increase in annual fleet miles, because dead-head mileage is also assumed to increase due to the need to make more daily bus-swaps in service.

For electric buses charged both at the depot and in-route using route-based chargers, the model assumes that the in-route charging will increase daily bus range above the minimum requirement, so that retiring buses can be replaced one-for one with new electric buses, and fleet size and annual fleet mileage will stay constant over time.

As the fleet composition changes over time, the model calculates for each scenario total mileage and fuel use each year by all buses of each type (CNG, Low NOx CNG, Electric, Fuel Cell) in each of the following model year bins: Pre-MY2007, MY2007 - MY2014, MY2015 - MY2024, MY2025 – MY2034, MY2035 – MY2044, MY2045 – MY2054. The model then applies cost and emission factors to calculate total costs and emissions associated with the buses of each type in each model year bin that year, and sums the costs and emissions across the bins to get the calendar year annual fleet totals.

The cost and emission factors used by the model are specific to each bus type and each model year bin. In that way, the model accounts for changes in technical capability and purchase and operating costs, as well as changes in emissions performance, for the different technologies as they mature over time. For example, range between charging events is assumed to be greater for MY2035 – MY2044 electric buses than for MY2025 – MY2034 buses, resulting in a smaller replacement ratio. Similarly, purchase and maintenance costs for electric and fuel cell buses (in 2015$) are assumed to be lower for MY2035 – MY2044 buses than they are for MY2025 – MY2034 buses.

---

[2] The current fleet has a larger number of older buses, but for the past few years LACMTA has been repowering older buses with new engines during mid-life overhauls. Engines built in model year 2007 and later have significantly lower nitrogen oxide (NOx) emissions than earlier model year engines.

1.1 Fleet Cost Model

The fleet cost model includes capital and operating costs associated with each bus and fuel purchasing scenario. The included capital cost elements are: bus purchase, bus repower (Low NOx CNG scenario only), bus mid-life overhaul, depot upgrades and expansion, and new fueling infrastructure.

Fueling infrastructure costs include purchase of battery chargers (electric bus scenarios), and purchase of hydrogen production and fueling stations (fuel cell bus scenarios). The model does not directly include any future costs associated with renewal or replacement of existing LACMTA CNG fueling stations. These stations are currently operated under contract by a third party, and the contract requires that the operator maintain these stations in full working order at all times. In effect, the future cost of upgrade and overhaul for these stations is included in the contract price of natural gas (dollars per therm[3]) and is therefore captured indirectly in the model for all scenarios as part of natural gas fuel costs.

Depot expansion is only required for the electric bus scenarios. For the depot-only charging scenario, in which fleet size increases, expansion of existing depots or construction of new depots is required to accommodate the larger fleet. Expansion of depot parking areas is also required for both electric bus scenarios to accommodate the installation of depot-based chargers in bus parking areas.

Other depot upgrades include investments related to high voltage safety and diagnostic equipment (electric bus and fuel cell scenarios) and investments in hydrogen sensors and improved ventilations systems (fuel cell scenario). Neither the baseline nor Low NOx CNG bus scenarios require any depot upgrades.

The included operating cost elements are: bus operator labor (including direct fringe benefits), bus maintenance (labor and material), and fuel purchase (including commodity costs and operating costs for fueling infrastructure). For all bus technologies, the fuel costs used in the model are net of projected financial credits that could be generated under California's Low Carbon Fuel Standard (LCFS). For natural gas (baseline) and renewable natural gas these LCFS credits would accrue to the fuel provider under LCFS rules; they are implicitly included in the model based on projected LACMTA costs to purchase natural gas or RNG. For electricity used to power battery-electric buses, and for hydrogen produced on-site at LACMTA depots to power fuel cell buses, LCFS credits would accrue directly to LACMTA. The model explicitly calculates these credits and deducts them from projected electricity purchase and hydrogen production costs.

The fleet cost model does not include original purchase costs associated with any existing LACMTA fueling, maintenance, or bus storage facilities; operating costs associated with maintenance and bus storage facilities; overhead costs for maintenance and transportation supervision or management; or overhead costs associated with operations planning, marketing, and revenue collection activities. All of these costs are assumed to be substantially similar regardless of which future bus technology and fuel purchase scenario is followed.

1.2 Fleet Emissions Model

The fleet emissions model estimates, for each future bus technology/fuel purchase scenario, total annual emissions of carbon dioxide (CO_2), nitrogen oxides (NOx), particulate matter (PM), and methane (CH_4). Using the global warming potential of methane over a 100-year period (GWP_{100}) the model also uses estimated CO_2 and CH_4 emissions to estimate total annual greenhouse gas (GHG) emissions in terms of CO_2-equivalent emissions (CO_2-e). For both NOx and PM emissions the model

[3] A therm is an amount of natural gas with 100,000 British thermal units (BTU) heat content

estimates separately the amount emitted under each scenario within the South Coast Air Basin, as well as the amount emitted outside of this air basin. The South Coast Air Basin encompasses Orange County and parts of Los Angeles, San Bernardino, and Riverside counties in southern California.

The fleet emissions model estimates total emissions associated with each bus technology/fuel purchase scenario on a "wells-to-wheels" life cycle basis. In addition to direct tail-pipe emissions from the engine of each in-service bus, the model estimates "upstream" emissions associated with the production and delivery of the fuel used by the buses each year.

For CNG buses upstream emissions include those associated with natural gas production, processing, pipeline transport, and compression. For electric buses upstream emissions include stack emissions from electricity generation, as well as emissions associated with production, processing, and transport of the hydrocarbon fuel(s) (i.e. coal and natural gas) used for electricity generation. For fuel cell buses upstream emissions include emissions generated directly during production, storage, transport, and compression of hydrogen; these emission come mostly from generating the electricity used for both water electrolysis and SMR. For the SMR production path upstream emissions also include emissions associated with production, processing, and transport of the natural gas used to produce the hydrogen.

All tailpipe NOx and PM emissions are assumed to be emitted within the South Coast Air Basin, as are upstream emissions from facilities and processes conducted within the basin (i.e. emissions from power plants located within the basin and from fuel production and transport activities that occur within the basin). Other upstream emissions (i.e. from natural gas extraction and processing, and from power plants located outside of the basin) are assumed to be out-of-basin emissions.

Emission factors used for upstream emissions vary by calendar year, to account for expected changes in the energy mix over time. For example, it is assumed that over the next 40 years average emission rates for electricity generation in California will fall significantly, reflecting greater use of zero-emission and renewable generating sources, in response to both government policy and market forces.

2. MAJOR ASSUMPTIONS AND DATA SOURCES

2.1 Electric Bus Range

To estimate the range per charge for current and future electric buses used in LACMTA service, the authors conducted a literature review, interviewed technical and sales staff from three transit bus manufacturers that currently offer 35-ft to 42-ft electric transit buses commercially[4], and evaluated the results of an on-going in-service test of battery buses at LACMTA.

For an electric bus, range per charge (miles) is a function of two primary variables: 1) the energy capacity of the installed battery pack (kWh), and 2) actual energy use in service (kWh/mi). For any given bus the size of the battery pack is fixed, but energy use can vary based on a number of variables, including driver behavior, bus loading, and route characteristics (i.e. average speed and topography).

In addition, batteries lose capacity over time, as they are charged and dis-charged on a daily basis. This loss of capacity must be factored in to establish a practical range that can be relied on over the expected service life of a bus. Capacity loss is not solely a function of charge/discharge cycles; however, it can also be affected by the “depth” of discharge. Most battery manufacturers do not recommend depleting the battery fully (to zero percent state of charge) on a daily basis, as this can increase the rate at which batteries lose capacity. Over the past 20 years the general rule of thumb has been to use 80% depth of discharge as a planning factor when calculating practical electric vehicle range, to maximize in-service battery life.

Each of these variables is discussed further below, along with the author’s projections of practical electric bus range based on these variables.

2.1.1 Electric Bus Battery Capacity

Virtually all commercially available 40-ft electric transit buses sold today (MY2016) have installed batteries with 300 – 330 kWh of energy storage capacity. In practical terms the size of the battery pack is constrained primarily by available packaging volume on the vehicle, but may also be constrained by axle weight limits. As such, increasing the energy storage capacity of electric buses will require further improvements in battery technology, to increase energy density (kWh/kg; kWh/ft^3).

All bus manufacturers interviewed indicated that their battery suppliers are promising significant improvements in energy density over the next 5 – 15 years, though estimates vary as to when these improvement will be available, and how large they will be. One bus manufacturer indicated that battery packs larger than 400 kWh would be available within two years; others were more cautious, indicating that battery packs with 33% greater capacity than current packs “might” be available by 2025, with further increases in later years.

For this analysis the authors used conservative estimates for the energy storage capacity of battery packs on future electric buses, as follows: Model Year 2025 – 2034, 420 kWh; model year 2035 – 2044, 450 kWh; model year 2045+ 482 kWh.

[4] BYD, Proterra, and New Flyer.

2.1.2 Electric Bus Energy Use

LACMTA operated a pilot fleet of 5 40-ft battery buses in regular Metro service between June 2015 and April 2016. These buses are used on a route with average speed of approximately 9 MPH. Since entering service they have accumulated more than 30,000 in-service miles. Weekly average energy use for all 5 buses has ranged from 2.3 kWh/mi to 3.5 kWh/mi; the over-all average since the beginning of the test is 3.2 kWh/mi. The route on which these buses operate has a slower average speed (9 MPH) than the LACMTA fleet average speed (12 MPH). Prior modeling conducted by the authors indicates that projected average energy use for these buses on a 12 MPH route would be 2.8kWh/mi.

Electric bus energy economy testing conducted by the Federal Transit Authority's New Model Bus Testing program indicates that there is a significant range in average energy use (kWh/mi) for different commercially available buses today[5]. One of the tested buses averaged 15% less energy per mile on the test routes than the bus model which LACMTA is currently operating in service.

In addition, all bus manufacturers interviewed indicated that electric buses will become more efficient over time, as the technology continues to mature.

Based on all of the above information, this analysis assumes that MY2025 – MY2034 electric buses will use an average of 2.5_kWh/mi in LACMTA service, MY2035 – MY2044 electric buses will use an average of 2.4 kWh/mi, and MY2045+ electric buses will use an average of 2.3 kWh/mi. These values reflect a 5% reduction in "industry average" energy usage per decade, compared to current buses.

The above values were used to calculate electricity use and cost. To calculate expected range per charge 10% was added to these figures, to account for driver and route variability.

2.1.3 Battery Life & Depth of Discharge

One electric bus manufacturer currently offers a 12-year warranty on their batteries, which guarantees that after 12 years in service the battery pack will retain at least 70% of its original name plate capacity (kWh). This implies 2.5% loss of capacity per year. This manufacturer also indicated that there is no restriction on daily depth of discharge.

The other manufacturers are less aggressive with respect to claims of battery life, offering only a standard 5-year warranty which guarantees no less than 80% of initial name plate capacity after that time, and recommending 80% depth of discharge as a planning factor in order to maximize effective battery life. One manufacturer indicated that actual capacity loss after 6 years in service indicates the possibility of a 10-year life, but they are not ready to guarantee that level of performance. This manufacturer also indicated that their battery management system limits depth of discharge to no more than 80% in the first few years of bus life, but opens that up over time, to allow 95% depth of discharge after year 5. In this way, buses are able to achieve consistent daily range even though the pack is losing effective capacity over time.

LACMTA currently keeps their buses in service for 14 years. For electric buses to be reliably usable over their entire life, the expected capacity loss must be included in calculations of the practical range

---

5 Bus Testing and Research Center, Pennsylvania Transportation Institute; Federal Transit Bus Test; Report Number LTI-BT-R1307, June 2014; Report Number LTI-BT-R1405, July 2015; Report Number LTI-BT-R1406, May 2015.

per charge. One option is to assume that batteries will last 14 years without replacement, but the range calculation would then need to assume a usable capacity of only 65% - 70% of battery nameplate capacity. The other option would be to assume that batteries will be replaced at bus mid-life (7 years). Under this scenario LACMTA will incur additional costs for battery replacement, but they will need fewer buses because range per charge can be based on approximately 80% of battery nameplate capacity.

Analysis indicates that buying fewer buses, but planning to replace the battery packs at 7 years, will be the least costly option for LACMTA. Thus, this is the scenario on which projected range per charge was calculated for this analysis.

2.1.4 Electric Bus Range per Charge

Based on projected nameplate battery capacity, protected in-service energy use, and expected battery degradation, as discussed above, this analysis assumes that the practical, reliable electric bus range per charge for buses used in LACMTA service will be 126 miles for MY2025-MY2034 buses, 142 miles for MY2035 -2044 buses, and 161 miles for buses purchased after MY2045. These values represent expected range per charge at the end of year 7 with 95% depth of discharge.

2.2 LACMTA Bus Assignments & Electric Bus Replacement Ratio

Figures 2 and 3 show a summary of LACMTA's week-day scheduled bus assignments. An "assignment" is a piece of work encompassing the time and mileage from when a bus first leaves a depot and enters service to when that bus returns to the depot. Figure 2 plots the weekday bus assignments based on accumulated mileage (miles) before the bus returns to the depot, and Figure 3 plots the assignments based on the accumulated time (hours) before the bus returns to the depot.

There are 2,878 daily bus assignments handled by 1,908 peak buses. That means that approximately 938 buses (49%) do one assignment per day, and 970 buses (51%) do two assignments per day. In general buses that do two assignments per day go out early in the morning to cover the morning peak period, return to the depot in late morning, and then leave the depot again in mid-afternoon to cover the afternoon peak. These buses generally spend three to six hours parked at the depot during mid-day and most will also be parked at the depot for three to six hours again in the late evening/early morning.

As shown on Figures 2 and 3, about 30% of all assignments are longer than 12 hours and 125 miles, and these are the assignments that are typically handled by buses that do only one assignment per day. These assignments average 165 miles and 15 hours per day in service. The remaining 70% of assignments, which are typically handled by buses that do two assignments per day, average 62 miles and 4.7 hours per day in service. That means that the buses that handle these assignments (two per day) generally average 124 miles and 9.4 hours per day in service.

Figure 2. LACMTA Weekday Bus Assignments, Percent versus Accumulated Miles in Service

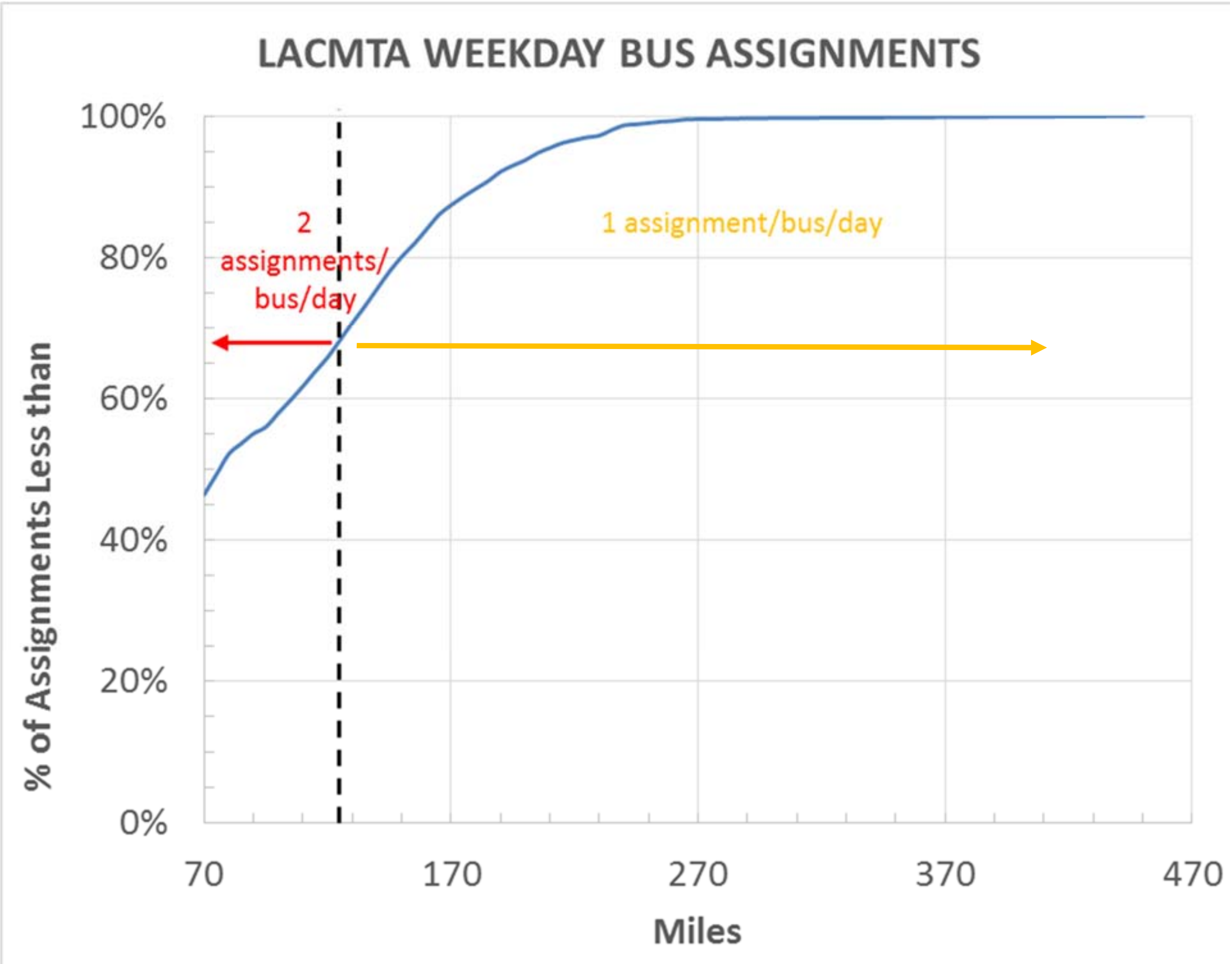
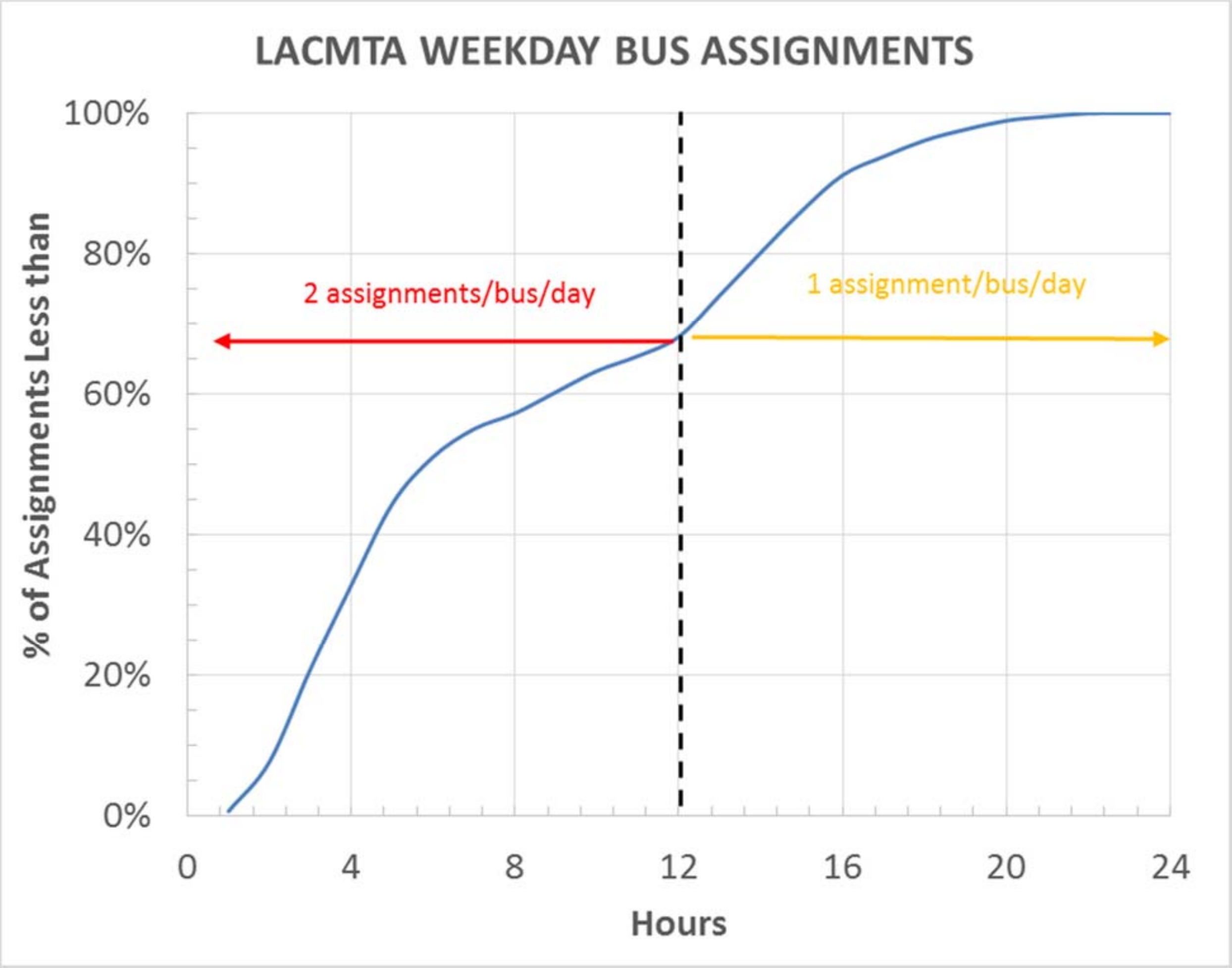


Figure 3. LACMTA Weekday Bus Assignments, Percent versus Accumulated Time in Service



When at the depot, LACMTA buses are parked nose-to-tail in adjacent parking lanes. As such, bus pull-outs for service are based on first-in, first-out; i.e. when a bus operator leaves for his or her assignment they take the first bus in line. When they return from service they park the bus in whatever spot is available. Given this, it is difficult, if not impossible, to dedicate specific buses to specific routes or assignments, except on a limited basis. Every bus of a given size assigned to a depot must be usable for every assignment operated from the depot on which that size bus is used. This means that in practical terms: 1) electric buses must have sufficient range per charge to handle every daily assignment, or 2) long assignments (miles) must be broken up into shorter assignments to accommodate actual electric bus range, or 3) depot charging of electric buses must be supplemented by in-route charging. Option 2, the break-up of long bus assignments into shorter assignments will increase the number of peak buses required compared to the current fleet of CNG buses (i.e. the electric bus replacement ratio will be greater than 1).

As discussed above in Section 2.1, this analysis assumes that model year 2025 – 2034 electric buses will have a practical, reliable range of 124 miles/charge in LACMTA service throughout their service life. This is a 34% increase from the current generation of electric buses (model year 2016) which are estimated to have a reliable range of 85 – 100 miles per charge in LACMTA service[6]. The analysis assumes that battery technology will continue to improve in future years, such that model year 2035 – 2044 electric buses will have a reliable range of 142 miles/charge and model year 2045 – 2055 electric buses will have a reliable range of 161 miles/charge.

Electric buses can replace current CNG buses one-for-one on daily bus assignments, or combinations of assignments, with shorter accumulated mileage than the assumed range per charge. Daily bus assignments longer than the assumed range per charge will need to be reconfigured to create more, shorter assignments, thus increasing the total number of peak buses required, if only depot charging is used.

To determine the number of electric buses required to replace CNG buses in the depot-charging only scenario, the authors calculated the percentage of current daily bus assignments shorter than the assumed range per charge, and then calculated the percentage of peak buses that would be used for these assignments. The percentage of peak buses is smaller than the percentage of assignments, because most if not all buses used for these short assignments do two assignments per day. Next the authors calculated the average daily mileage for all assignments longer than the assumed miles/charge, and the electric bus replacement ratio that would be required to accommodate these longer assignments. Finally the authors calculated a fleet average electric bus replacement ratio, which is a weighted average of peak buses needed to accommodate short assignments (1:1 replacement) and buses needed to accommodate the current long assignments (greater than 1:1 replacement ratio). The results of this analysis are shown in Table 4.

Table 4. Estimated Electric Bus Replacement Ration for Depot charging-only Scenario

	Model Year 2016	Model Year 2025 - 2034	Model Year 2035 - 2044	Model Year 2045 - 2054
Projected Electric Bus range/charge [miles]	93 mi	126 mi	142 mi	161 mi
% of Bus Assignments <range/charge	55%	68%	75%	84%
% of Peak Buses with daily mileage < range per charge	42%	51%	55%	59%
Average Daily Mileage for Bus Assignments > range/charge	152 mi	168 mi	177 mi	190 mi
Replacement Ratio for Assignments > range/charge	1.70	1.34	1.27	1.19
FLEET AVERAGE REPLACEMENT RATIO	**1.41**	**1.17**	**1.12**	**1.08**

6 Projected range varies by bus manufacturer based on differences in installed battery capacity (kWh) and projected average energy use (kWh/mi).

As shown in Table 4, in the 2025 – 2034 time frame 1.17 electric buses would be required to replace one CNG bus if charging is done only at the depot. In the 2035 – 2044 time frame this electric bus replacement ratio drops to 1.12, and it drops further to 1.08 after 2045.

2.3 Other Assumptions

Table 5 lists the major assumptions used in the fleet cost and emissions models, as well as the source of these assumptions.

All costs in Table 5 are shown in 2015$. For each year the model escalates these values based on assumed annual inflation, to calculate yearly total costs in nominal dollars. For net present value calculations these annual nominal dollar totals are then discounted back to 2015$ based on an assumed discount rate.

Table 5a. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – LACMTA System Characteristics

5A: LACMTA SYSTEM CHARACTERISTICS		
Metric	*Data Sources*	*Values/Notes*
Average Annual Total Miles per bus	LACMTA, National Transit database, 2013	38,000 miles
Average Annual Revenue Miles per bus	LACMTA, National Transit database, 2013	32,000 miles
Fleet Spare Factor	LACMTA policy	20%
Average Daily Total Miles per Bus	MJB&A analysis	130 miles; (annual miles/bus ÷ (365 day/yr x (1-spare factor))
Average In-service Bus Speed (MPH)	LACMTA, National Transit database, 2013	12.1 MPH; total bus miles ÷ total bus hours
Average Daily in-Service Hours per bus	LACMTA, National Transit database, 2013; MJB&A analysis	10.8 hours; average daily miles ÷ average in-service speed
Bus Retirement age	LACMTA policy	14 years
In-service Bus Lay-over Time	LACMTA Service Planning	10 minutes per hour of driving
Total Lay-over (Terminal) Locations, System-wide	LACMTA Service Planning	280 = 140 bus lines x 2 Terminal/line (one at each end)
2015 Bus Operator Labor Cost ($/hr)	LACMTA Service Planning	$33.50/hour; includes direct fringe benefits
Bus Operator Availability (%)	LACMTA Service Planning	80%
Bus Operator % of shift time driving	LACMTA Service Planning	83%

Table 5b. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Fuel Costs

5B: FUEL COSTS		
Metric	*Data Sources*	*Values/Notes*
Natural Gas (2015)	LACMTA Fuel report	Actual average cost for 2015, $0.780/therm, includes cost of fuel station maintenance and operation. This price implicitly includes California Low Carbon Fuel Standard (LCFS) credits that can be earned by the natural gas supplier, and which are wholly or partially passed on to LACMTA via commercial market pricing.
Renewable Natural Gas (2015)	LACMTA Procurement	Assume that purchase cost of renewable natural gas will be the same as standard natural gas, at $0.780/therm in 2015. This is based on LACMTA market research showing that there are multiple providers willing to provide renewable gas at this rate today. This price implicitly includes California Low Carbon Fuel Standard (LCFS) credits that can be earned by the RNG fuel supplier, and which are wholly or partially passed on to LACMTA via commercial market pricing.
Electricity (2015)	Southern California Edison, *Schedule TOU-8, Time-of-Use General-Service Large; Cal. PUC Sheet No. 53221-E* California Air Resources Board, Final Regulation Order, Subchapter 10 Climate Change, Article 4 Regulations to Achieve Greenhouse Gas Emission Reductions, Subchapter 7 Low Carbon Fuel Standard MJB&A Analysis	TOU-8 is the electric rate applicable to large commercial customers in Los Angeles with expected usage greater than 500 kW. The rate is composed of delivery and generation energy charges ($/KWh) which vary by time of day (off-peak, mid-peak, and high-peak) and season (summer, winter). There are also monthly facility demand charges ($/kW) based on over-all peak demand within the month and monthly time-based demand charges ($/kW) based on monthly peak demand within each daily rate period (off-peak, mid-peak, and high-peak) over the month. Based on an analysis of scheduled daily LACMTA service (% of buses in service and at the depot by time of day), MJB&A determined that approximately 64%, 32%, and 5% of electric bus depot charging would occur during off-peak, mid-peak, and high-peak periods, and that approximately 24%, 65%, and 11% of in-route charging would occur during off-peak, mid-peak, and high-peak periods.

5B: FUEL COSTS		
Metric	*Data Sources*	*Values/Notes*
		Based on this charging distribution the average annual cost of electricity in 2015 under Southern California Edison's TOU-8 rate would be \$0.172/kWh for depot charging and \$0.143/kWh for in-route charging. Based on an assumption of constant daily production during only off-peak and mid-peak hours the average annual cost of electricity for hydrogen production in 2015 would be \$0.1061/kWh under the TOU-8 rate. LACMTA can earn credits under California's low carbon Fuel Standard (LCFS) for battery electric bus charging. Available credits in each year were calculated using the procedures outlined in the LCFS Final Regulation Order, and assuming a credit value of \$100 per metric ton of CO_2 reduction, which is the current market value of LCFS credits. These credits were then deducted from LACMTA's projected cost of purchasing electricity, to yield their net cost of electricity for battery bus charging. Projected LCFS credits are \$0.118/kWh in 2015, increasing to \$0.127/kWh in 2055 as the projected carbon intensity of electricity production falls over time. LACMTA's net electricity costs for battery bus charging are projected to be \$0.053/kWh for depot charging and \$0.025/kWh for in-route charging in 2015.
Hydrogen (2015)	National Renewable Energy Laboratory, *H2FAST: Hydrogen Financial Analysis Scenario Tool,* April, 2015, Version 1.0 California Air Resources Board, Final Regulation Order, Subchapter 10 Climate Change, Article 4 Regulations to Achieve Greenhouse Gas Emission Reductions,	Hydrogen production via steam reforming (SMR) assumes 1.7 therms NG and 10 kWh electricity input per kg or hydrogen produced. The model also assumes \$0.25/kg maintenance and operating cost, which equates to approximately \$300,000 per station/year with one station per depot. Hydrogen production via electrolysis assumes 50 kWh electricity input per kg hydrogen produced in 2015, falling to 44.7 kWh/kg in 2025 and later years. The 2025 value is consistent with US Department of Energy research and development targets and equates to 75% net efficiency (the theoretical minimum energy requirement is 33 kWh/kg). The model also assumes \$0.35/kg maintenance and operating

5B: FUEL COSTS		
Metric	*Data Sources*	*Values/Notes*
	Subchapter 7 Low Carbon Fuel Standard MJB&A Analysis	cost, which equates to approximately $420,000 per station/year with one station per depot. Using these assumptions LACMTA's cost of hydrogen production is projected to be $2.64/kg using SMR and $5.65/kg using electrolysis in 2015, not including amortized capital costs for the production equipment, which is calculated separately and included in capital costs. LACMTA can earn credits under California's low carbon Fuel Standard (LCFS) for fuel cell bus hydrogen production. Available credits in each year were calculated using the procedures outlined in the LCFS Final Regulation Order, and assuming a credit value of $100 per metric ton of CO_2 reduction, which is the current market value of LCFS credits. These credits were then deducted from LACMTA's projected cost of producing hydrogen, to yield their net cost of producing hydrogen. Projected LCFS credits are $1.03/kg in 2015, resulting in net hydrogen production costs in 2015 of $1.60/kg for SMR and $4.62/kg for electrolysis.
Annual Fuel Cost Inflation	Energy Information Administration, Annual Energy Outlook 2016 early release, *Table 3.9, Energy Prices by Sector & Source, Pacific region, May 2016*	Projections for % change in annual nominal price of natural gas and electricity used for transportation (reference case), through 2040; for 2041 – 2055 assumed average rate for 2031 – 2040.

Table 5c. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Emissions Factors

5C: EMISSIONS FACTORS		
Metric	*Data Sources*	*Values/Notes*
CNG bus tailpipe NOx, PM, CH_4 (g/mi)	California Air Resources Board, EMFAC2014	Season - annual; Sub area - Los Angeles (SC); vehicle class – UBUS; Fuel – NG; Process – RUNEX; Speed Time - Weighted average of bins 5 through 30 to simulate urban bus duty cycle with 12.5 MPH average speed. Values calculated for each model year in each calendar year.
Low NOx CNG bus tailpipe NOx, PM, CH_4 (g/mi)	California Air Resources Board Executive Orders A-021-0631 and A-021-0629	NOx, PM, and CH_4 g/mi emissions assumed to be proportionally lower than emissions from standard CNG buses of the same model year based on model year 2016 certified engine emissions for Low NOx and standard CNG engines. NOx emissions assumed to be 92% lower (0.01 g/bhp-hr vs 0.13 g/bhp-hr), CH_4 g/mi emissions assumed to be 72% lower (0.56 g/bhp-hr vs 1.97 g/bhp-hr) and PM emissions assumed to be 50% lower (0.001 g/bhp-hr vs 0.002 g/bhp-hr).
CNG and Low NOx CNG bus tailpipe CO_2 (g/mi)	U.S. Department of Energy, *Alternative Fuels & Advanced Vehicles Data Center* (www.afdc.energy.gov/afdc/fuels/properties.html)	5,593 g CO_2/therm, assuming NG with 22,453 btu/lb (high heating value) and 75.5% carbon by weight (90% methane and 10% ethane by volume). Gram/mile emissions = Fuel use (therm/mi) x g CO_2/therm.
Natural Gas Upstream CO_2, NOx, PM, CH_4 (g/therm)	Argonne national Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model,* as modified by California Air Resources Board to reflect California conditions (CAGREET)	CA GREET was used to calculate upstream emission rates (g/mmbtu, g/therm) for pipeline natural gas and renewable natural gas. The emission rates for renewable natural gas assume the following mixture of production sources: 100% landfill, 0% animal waste, and 0% wastewater treatment plant. These assumptions are conservative; LACMTA has not yet determined actual production sources for commercially available RNG. Inclusion of gas produced from wastewater treatment plants and/or food waste would further reduce emissions of both GHG and NOx compared to current assumptions.
Renewable Natural Gas Upstream CO_2, NOx, PM, CH_4 (g/therm)		
Hydrogen Production CO_2, NOx, PM, CH_4 (g/kg)	G. Saur and A. Milbrandt, National Renewable Energy Laboratory, *Renewable Hydrogen Potential from Biogas in the United States*,	

5C: EMISSIONS FACTORS		
Metric	*Data Sources*	*Values/Notes*
	NREL/TP-5400-60283, July 2014	CA GREET was used to calculate upstream emission rates (g/mmbtu, g/kg) for production of hydrogen using SMR. All upstream emission rates for natural gas, renewable natural gas and SMR hydrogen are assumed to be constant throughout the analysis period. For production of hydrogen using electrolysis, emission rates (g/kg) were determined by multiplying the electrical energy required for production (kWh/kg) by emission rates for electricity generation (g/kWh). For standard natural gas, including the natural gas used for production of hydrogen via SMR, the following components of upstream NOx and PM emissions are assumed to be emitted within the South Coast Air Basin: 7.4% of emissions from “natural gas transmission to fueling station” (50 out of 680 pipeline miles) and 100% of emissions from compression. The following components of natural gas upstream NOx and PM emissions are assumed to be emitted outside of the South Coast Air Basin: 100% of emissions from natural gas recovery and processing; and 92.6% of emissions from natural gas transmission to fueling station (630 out of 680 pipeline miles). For RNG, 25% of NOx and PM emissions from “natural gas transmission to fueling station” (50 out of 200 pipeline miles) are assumed to be in-basin, as well as 100% of emissions from RNG compression. Emissions from production and processing of RNG are attributed as in-basin or out-of-basin depending on the location of the RNG sources. The model assumes that in 2018 100% of RNG will be from out-of-basin sources, but that over time a greater percentage of RNG will be from in-basin sources, rising to 30% by 2055. NREL’s

5C: EMISSIONS FACTORS		
Metric	*Data Sources*	*Values/Notes*
		projections of bio-methane potential from all sources shows that approximately 30% of potential bio-methane in California is attributed to sources located within the South Coast Air basin. All emissions from production and compression of hydrogen produced via SMR are assumed to be in-basin.
Electricity Generation CO_2, NOx, PM, CH_4 (g/kWh)	Argonne national Laboratory, *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model,* as modified by California Air Resources Board to reflect California conditions (CAGREET) ARB targets for renewable generation through 2050 ABB Velocity Suite™ database of electric generating units within CAISO	CA GREET was used to calculate 2015 and 2020 emission rates (g/kWh) for each discrete electric generating source type used in California: wind, solar, geothermal, hydroelectric, nuclear, biomass, natural gas, and coal. For each pollutant in each calendar year the model uses source-weighted average emissions factors calculated by multiplying the emission factor for each source type by the assumed percentage of electricity produced by that source type in California that year. The assumptions for percentage of generation by source type match the California Air Resources Board's published targets for increases in zero-emitting and renewable resources through 2050. For example, the model assumes that there will be no electricity generation using coal after 2027, and that zero-emitting sources will increase from 46% of total generation in 2015 to 78% in 2050. At the same time, generation with natural gas will fall from 53% of total generation in 2015 to 22% in 2050. CA Greet indicates that emission rates (g/kWh) of NOx, PM, CO_2, and CH_4 will fall between 2015 and 2020 for nuclear, natural gas, biomass, and coal generating sources, presumably based on improvements in efficiency and/or addition of emission controls in response to regulation. The difference in emission rates between 2015 and 2020 were used to calculate an annual adjustment factor for each pollutant and generating source,

5C: EMISSIONS FACTORS		
Metric	*Data Sources*	*Values/Notes*
		which was applied in each year of the analysis – i.e. emission rates were assumed to continue to improve at the same annual rate through 2055, which is a conservative assumption. To determine the percentage of NOx and PM emissions emitted within the South Coast Air Basin from electricity generation under each scenario, the ABB Velocity Suite™ database was used to determine the percentage of current generation (MWh) within the California Independent System Operator (CAISO) territory produced by generating plants located in the South Coast Air Basin. In 2013 approximately 22.2% of total CAISO generation by natural gas-fired plants was from plants within the basin, while O% of coal generation was from plants within the basin and 9.4% of biomass generation was from plants within the basin. These percentages were applied separately to the emission factors for each type of generation to calculate weighted average NOx and PM emission factors (g/kWH) within and outside the basin. The analysis assumes that total gas generation will fall each year through 2050, while total biomass generation will increase; however the percentage of total generation from plants of each type within the basin is assumed to stay constant.

Table 5d. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – CNG Buses

5D: CNG BUSES		
Metric	*Data Sources*	*Values/Notes*
Purchase Cost (2015 $)	LACMTA Maintenance Department	$490,000 per bus. This is the actual price paid by LACMTA for 40-ft CNG bus purchases in 2013.
Mid-Life Overhaul Cost (2015 $)	LACMTA Maintenance Department	$35,000 per bus. This is the actual average cost for overhauls completed in 2014.
Maintenance Cost ($/mi)	LACMTA maintenance records for 2013 - 2014	Average cost of $0.850/mile for buses near mid-life (7 years old). 35% of costs ($0.30/mi) attributed to propulsion system (engine, transmission, brakes) and 65% attributed to all other bus systems ($0.55/mi).
Fuel Use (therm/mi)	LACMTA fueling records	Average of 0.476 therm/mi.

Table 5e. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Low NOx CNG Buses

5E: LOW NOx CNG BUSES		
Metric	*Data Sources*	*Values/Notes*
Purchase Cost (2015 $)	Environ discussion with Cummins, Inc.	Incremental cost of Low NOx CNG bus compared to standard CNG bus $10,000 through MY2035, falling to $5,000 after MY2045 due to technology maturity.
Repower Cost (2015 $)	LACMTA Maintenance Department	Assume $112,000/bus for repowers in 2015 – 2034, falling to $102,000/bus for repowers in 2045 – 2054. Current cost of repowering LACMTA CNG buses averages $100,000/bus. Low NOx repowers assumed to be more expensive due to incremental cost of Low NOx engine ($10,000) and $2,000/bus for up-front engineering and design work ($200,000 spread over 1,000 buses). Incremental cost of Low NOx engine assumed to decline over time as technology matures.
Mid-Life Overhaul Cost (2015 $)	LACMTA Maintenance Department	Assume that mid-life overhauls for Low NOx engine buses will be $38,000/bus, which is $3,000/bus greater than current mid-life overhaul costs for standard CNG buses. Costs assumed to be higher due to higher cost for re-building Low NOx engine.
Maintenance Cost ($/mi)	LACMTA Maintenance Department	Assume that non-propulsion maintenance costs will be the same as current CNG buses ($0.553/mi) and that propulsion related maintenance costs will be 10% higher ($0.327/mi) for Low NOx engines purchased 2015 – 2024, due to technology immaturity. Assumes that by MY2035 propulsion related maintenance costs for Low NOx engines will be the same as for current buses.
Fuel Use (therm/mi)	California Air Resources Board Executive Orders A-021-0631 and A-021-0629	Assume that fuel use for Low NOx engines will be 0.4% higher than fuel use of current NG engines, based on certified CO_2 emissions of model year 2016 Low NOx engines compared to standard engines (465 g/bhp-hr vs 463 g/bhp-hr).

Table 5f. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Electric Buses

5F: ELECTRIC BUSES		
Metric	*Data Sources*	*Values/Notes*
Purchase Cost (2015 $)	Air Resources Board, Mobile Source Control Division, *Advanced Clean Transit,* May 2015 BYD bus purchase quote to LACMTA Discussion with battery electric bus manufacturers, BYD, Proterra, and New Flyer	Current costs (MY2016) are estimated to be $760,000 per bus for depot-only charging and $810,000 per bus for depot and in-route charging. The increased cost for in-route charging is for inductive charge receiver on the bus. Based on discussion with bus manufacturers, industry average battery bus purchase costs (depot charging, 2015$) are projected to fall to $657,000 in MY2025, $632,000 in MY2035, and $631,000 in MY2045. These costs reflect significant projected reductions in battery pack costs ($/kWh, 2015$), but also significant increases in battery pack size (kW) over time, based on increased energy density. The model assumes no reduction in costs (2015$) over time for bus systems other than the battery pack; the majority of the cost of a bus is in items and systems (steel structure, doors, windows, suspension system, etc.) that will be common between electric and CNG buses, which are not expected to change. Increases in battery energy density are projected based on current research efforts by battery manufacturers. Reductions in battery costs are projected based on research efforts as well as projected increases in manufacturing volume, primarily based on increased sales of light-duty electric vehicles. Cell level battery costs are projected to fall from an industry average of $417/kWh (2015$) today to $150/kWh in 2025 and $100/kWh in 2035 and later years (2015$). Total battery pack costs (including physical structure, battery management system, and manufacturing labor and overhead) are projected to fall from an industry average of $740/kWh today to $358/kWh in 2025, $275/kWh in 2035, and $258/kWh in 2045 (all in 2015$).

5F: ELECTRIC BUSES		
Metric	*Data Sources*	*Values/Notes*
		Installed battery pack size is projected to increase from an industry average of 330 kWh today to 420 kWh in 2025, 450 kWh in 2035, and 482 kWh in 2045. The above values represent a conservative, but realistic assessment of industry average costs. There was a significant range of values provided by different bus manufacturers, with some stated projections significantly more optimistic than others (lower battery cost and higher energy density).
Mid-Life Overhaul Cost (2015 $)	BYD purchase quote to LACMTA Discussion with battery electric bus manufacturers, BYD, Proterra, and New Flyer	Based on discussion with bus manufacturers, this analysis assumes that the drive motor and inverter on electric buses will need to be replaced/overhauled at mid-life at a cost of $30,000. This analysis also assumes that all electric buses will have their battery packs overhauled at mid-life by replacing the battery cells (but not the physical structure). See discussion of battery life in section 2.1.3. Mid-life battery overhaul costs are based on pack size (kW) and assumed cell costs ($/kWh) discussed above under electric bus Purchase Cost, plus 30% for labor. This results in total mid-life overhaul costs of $84,600 for MY2025-MY2034 electric buses, $88,500 for MY2035 – MY2044 electric buses, and $92,700 for MY2045 – MY2054 electric buses.
Maintenance Cost ($/mi)	MJB&A analysis	Non-propulsion related costs assumed to be same as CNG, $0.553/mi. Propulsion-related costs (drive motor, inverter, brakes) assumed to be half the cost of CNG buses ($0.149/mi).
Fuel Use (kWh/mi)	40-ft electric bus in-service test at LACMTA Bus Testing and Research Center, Pennsylvania Transportation Institute; Federal Transit Bus Test;	MY 2025 electric buses used in LACMTA service are projected to average 2.5 kWh/mi energy use; this fleet average is projected to fall to 2.4 kWh/mi for MY2035 buses and 2.3 kWh/mi for MY2045 buses. See section 2.1.2 for discussion of how these values were derived.

5F: ELECTRIC BUSES		
Metric	*Data Sources*	*Values/Notes*
	Report Number LTI-BT-R1307, June 2014; Report Number LTI-BT-R1405, July 2015; Report Number LTI-BT-R1406, May 2015 Discussion with electric bus manufacturers BYD, Proterra, and New Flyer MJB&A Analysis	
Range (mi/charge)	Discussion with battery electric bus manufacturers, BYD, Proterra, and New Flyer MJB&A Analysis	MY 2025 electric buses are assumed to have range per charge of 126 miles, increasing to 142 miles for MY2035 and 161 miles for MY2045. These values represent industry average, reliable daily range at bus mid-life. See Section 2.1 for a full discussion of how these values were derived.

Table 5g. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Fuel Cell Buses

5G: FUEL CELL BUSES		
Metric	*Data Sources*	*Values/Notes*
Purchase Cost (2015 $)	Letter from New Flyer to Air Resources Board Air Resources Board, Mobile Source Control Division, *Advanced Clean Transit,* May 2015 E. den Boer, et al, CE Delft, *Zero emissions trucks: An overview of state-of-the-art technologies and their potential,* Report Delft, July 2013	Current cost (MY 2016) is $1,300,000 per bus. Per a letter from New Flyer to Air Resource Board the cost for MY2025 buses (2015$) is assumed to be $920,000, falling to $690,000 in MY2035 (-25%) and $598,000 in MY2045 (-35%). Assumed cost reductions for MY2035 and MY2045 are per estimates by CE Delft.
Mid-Life Overhaul Cost (2015 $)	LACMTA Maintenance Department E. den Boer, et al, CE Delft, *Zero emissions trucks: An overview of state-of-the-art technologies and their potential,* Report Delft, July 2013 MJB&A Analysis	Mid-life overhaul costs assumed to be the same as for CNG bus mid-life plus the cost of replacing the fuel cell stack. Fuel cell stack replacement assumed to be $300,000 for MY2025 – MY2034 buses, $125,000 for MY2035 – MY2044 buses, and $50,000 for MY2045 – MY2054 buses, based on projected future cost differential between CNG and fuel cell buses at time of overhaul.
Maintenance Cost ($/mi)	L. Eudy and M. Post, National Renewable Energy Laboratory, *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fourth Report,* July 2015	Non-propulsion related costs assumed to be same as CNG, $0.553/mi. Current generation fuel cell buses have propulsion related costs at least 33% higher than diesel buses. For this analysis propulsion related costs assumed to be 20% higher than CNG buses for MY2025 – MY2034 buses, falling to only 10% higher for MY2045-MY2054 buses due to technology maturity.

5G: FUEL CELL BUSES		
Metric	*Data Sources*	*Values/Notes*
H_2 Fuel Use (kg/mi)	L. Eudy and M. Post, National Renewable Energy Laboratory, *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fourth Report*, July 2015	Average H_2 fuel use for current generation buses is 0.156 kg/mi. This value used for MY2025 – MY2034 buses. Assumed 5% reduction for MY2035-MY2044 buses, and 10% reduction for MY2045 -MY2054 buses due to technology maturity.

Table 5h. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Fueling Infrastructure – Electric Buses

5H: FUELING INFRASTRUCTURE – ELECTRIC BUSES		
Metric	*Data Sources*	*Values/Notes*
Depot Chargers ($/kW)	J. Agenbroad, Rocky Mountain Institute, *Pulling Back the Veil on EV Charging Station Costs,* April 29, 2014 *http://blog.rmi.org/blog_2014_04_29_pulling_back_the_veil_on_ev_charging_station_costs* Recent LACMTA experience installing chargers for BYD electric buses	LACMTA facilities department estimates a cost of $500/kW to upgrade depot electrical infrastructure, plus $10,000 per bus for the charge adapter, based on a full depot roll-out of electric buses. This equates to $30,000/bus for required 40 kW chargers. Model assumes 2,000 depot chargers will be required, one for each daily in-service bus. Daily in-service buses = Fleet assignment x (1-spare factor %). Annual maintenance costs for depot chargers are assumed to be 10% of installed capital cost.
In-route Chargers ($/kW)		Installed cost of $4,000/kW, based on $80,000 for public, 20 kW DC inductive fast-charger. In-route chargers assumed to be more expensive than depot-based chargers due to need to secure right-of-way, longer feeder runs, and installation of inductive charging pad. Model assumes that 308 in-route chargers will be required, which is one at each terminal point of 140 bus routes, plus 10%; some existing terminal locations routinely hold more than one bus at a time and would require more than one charger. Annual maintenance costs for in-route chargers are assumed to be 10% of installed capital cost.
Size (kW)	MJB&A analysis	Charger size (depot and in-route) based on average daily energy requirement (kWh) and available charging time (hr). Average daily energy requirement based on average daily miles times average energy use (kWh/mi). Depot charger size is 40 kW; In-route charger size is 20 kW.

Table 5i. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Fueling Infrastructure – Fuel Cell Buses

5I: FUELING INFRASTRUCTURE – FUEL CELL BUSES		
Metric	*Data Sources*	*Values/Notes*
SMR Cost ($/kg/day)	M. Melaina and M. Penev, National Renewable Energy Laboratory, *Hydrogen Station Cost Estimates, Comparing Hydrogen Station Cost Calculator Results with other Recent Estimates,* Technical Report NREL/TP-5400-56412, September 2013	$5,150/kg/day for stations built 2025 – 2034, and $3,370/day for stations built after 2034. These values represent a 70% and 80% reduction in costs, respectively, compared to recently built hydrogen fuel stations.
Electrolyzer Cost ($/kg/day)		
Required Capacity (kg/day)	MJB&A analysis	Required hydrogen production/dispensing capacity based on number of buses, daily mileage (mi/day), and average fuel use (kg/mi). Early buses will require 20 kg/bus/day and later buses will require only 18 kg/bus/day based on improved fuel economy due to technology maturity.

Table 5j. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Depot Expansion and Modifications

5J: DEPOT EXPANSION AND MODIFICATIONS		
Metric	*Data Sources*	*Values/Notes*
Depot Expansion ($/incremental bus)	LACMTA Engineering Department	$67,500/bus, applicable only to fleet expansion for electric buses with depot-only charging. Fleet expansion is required because electric buses cannot replace current buses one-for one due to limited range. This cost is based on $500/sf for depot maintenance bays and $100/sf for bus parking areas, but is discounted by 50% due to potential excess capacity within the system based on future operational changes.
Depot Parking Expansion ($/charger)	LACMTA Engineering Department	Assumes that each depot-based electric charger will require 200 square feet of space for installation in depot parking areas. This will require expansion of parking areas to maintain bus parking capacity. Cost of new bus parking areas assumed to be $100/sf. Total cost of additional bus parking space is $20,000 per charger.
Maintenance & Diagnostic Equipment ($/bus)	BYD electric bus quote to LACMTA for electric bus diagnostic equipment	Average cost of $200/bus, applicable to all new Electric and Fuel Cell buses, based on recent BYD quote.
H_2 Detection and Ventilation Upgrade Cost ($/bus)	L. Eudy and M. Post, National Renewable Energy Laboratory, *Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fourth Report*, July 2015	Average costs of $28,000/bus, applicable to all new Fuel Cell buses. This is based on costs of $350,000 per maintenance bay incurred by AC Transit, and an average of one maintenance bay per 12.6 buses.

Table 5k. Major Assumptions and Data Sources Used in Fleet Cost & Emissions Model – Global Economic Assumptions

5K: GLOBAL ECONOMIC ASSUMPTIONS		
Metric	*Data Sources*	*Values/Notes*
Annual Inflation, Bus and Infrastructure Purchase and Maintenance and Bus Operator Labor	Energy Information Administration, Annual Energy Outlook 2016, *early release, Table 20 Macroeconomic Indicators*	Projections for average annual % change in annual Wholesale Price Index, Industrial Commodities Excluding Energy (reference case), through 2040; value used is 1.8%.
Discount Rate for Net Present Value Calculations	LACMTA Policy	Value of 4% intended to represent average borrowing cost for LACMTA capital bonds. Note that this rate is generally consistent with the Energy Information Administration's projection of interest rates for 10-year treasury notes over the next 25 years (AEO2016 reference case).
Methane Global Warming Potential (GWP_{100})	Intergovernmental Panel on Climate Change, *Fifth Assessment Report*, 2013	Global warming potential of methane over 100 years relative to CO_2. Value is 25.

3. RESULTS

This section summarizes the detailed results of the fleet cost and emissions analysis for each modeled bus technology/fuel purchase scenario.

3.1 Fleet Costs 2015 - 2055

Table 6 summarizes the total estimated fleet costs from 2015 – 2055 under each scenario in nominal dollars, during the transition to the different bus and fuel technologies. Incremental costs for each scenario compared to baseline are also plotted in Figure 4. See the Executive Summary for the net present value of estimated fleet costs in current dollars (2015).

As shown, the use of RNG by itself is not projected to increase total fleet costs. The use of RNG and the transition to LNOx buses is projected to increase total fleet costs over the next 40 years by $297 million, an increase of 0.8% over projected baseline costs. The increased costs are due to slightly higher fuel and maintenance costs, as well as slightly higher bus purchase and overhaul costs.

The transition to electric buses is projected to increase total fleets costs by $764 million - $1.82 billion over the next 40 years, an increase of 2.1% - 4.9% over projected baseline costs. Exclusive depot charging is projected to be more expensive than depot and in-route charging during the transition.

The electric bus scenarios have increased costs relative to the baseline projection primarily due to increased capital costs for bus purchase and overhaul and for required depot modifications and installation of required fueling infrastructure.

For electric buses total operating costs are projected to be lower than baseline operating costs due to reduced fuel and maintenance costs. For depot-only charging these operating cost reductions are offset by higher bus operator labor costs due to the need to operate a greater number of buses because of electric bus operating range restrictions. Depot-only charging is projected to be more expensive than depot and in-route charging due to this increase in operator labor, as well as increased costs for purchasing a greater number of buses, which more than offsets higher infrastructure costs for route-based chargers.

Table 6. LACMTA Zero Emission Bus Estimated Total Fleet Costs 2015 - 2055 (nominal $ million)

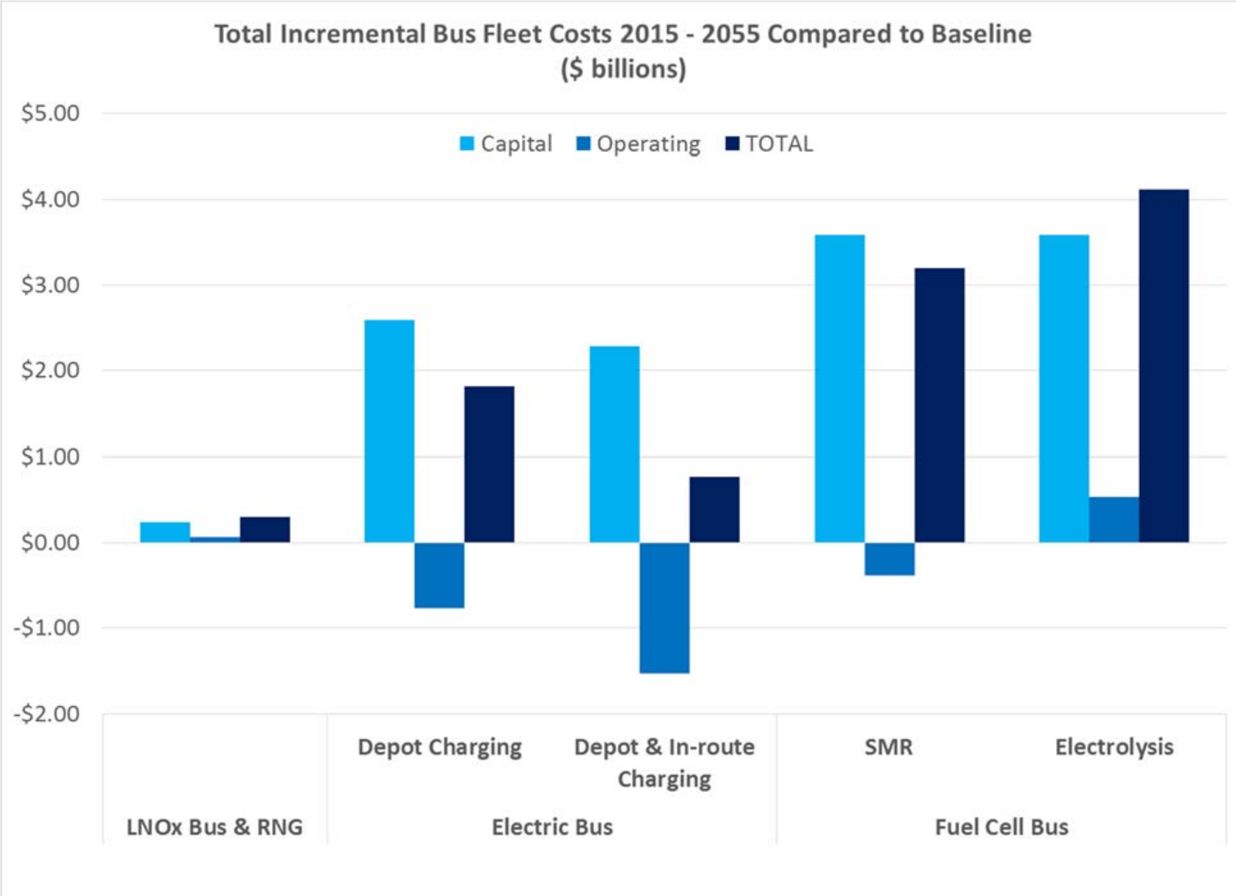
Cost Element		BASELINE	RENEW NG	LOW NOx CNG BUS & REPOWER		ELECTRIC BUS		FUEL CELL BUS	
		Std CNG Bus Conv NG	Std CNG Bus RNG	LNOx Bus Conv NG	LNOx Bus RNG	Depot Charging	Depot & In-Route Charging	H_2 by SMR	H_2 by Electrolysis
Capital	Bus Purchase	$5,177.9	$5,177.9	$5,250.0	$5,250.0	$7,094.2	$6,889.2	$7,101.5	$7,101.5
	Bus Repower			$135.7	$135.7				
	Bus mid-life OH	$369.9	$369.9	$395.1	$395.1	$823.4	$744.1	$1,603.6	$1,603.6
	Depot Mods					$118.7	$72.8	$100.8	$100.8
	Fuel Infra	$0.0	$0.0	$0.0	$0.0	$99.4	$127.7	$324.9	$324.9
	sub-total	*$5,547.8*	*$5,547.8*	*$5,780.9*	*$5,780.9*	*$8,135.7*	*$7,833.7*	*$9,130.7*	*$9,130.7*
Operating	BO Labor	$23,515.6	$23,515.6	$23,515.6	$23,515.6	$24,174.3	$23,515.6	$23,515.6	$23,515.6
	Fuel	$2,958.4	$2,958.4	$2,968.8	$2,968.8	$1,733.3	$1,680.5	$2,396.6	$3,317.9
	Maintenance	$4,793.8	$4,793.8	$4,846.9	$4,846.9	$4,591.7	$4,549.5	$4,968.8	$4,968.8
	sub-total	*$31,267.8*	*$31,267.8*	*$31,331.3*	*$31,331.3*	*$30,499.3*	*$29,745.6*	*$30,881.0*	*$31,802.2*
TOTAL		**$36,815.6**	**$36,815.6**	**$37,112.2**	**$37,112.2**	**$38,635.0**	**$37,579.3**	**$40,011.7**	**$40,933.0**
INCREASE		**NA**	**$0.00**	**$296.59**	**$296.59**	**$1,819.44**	**$763.73**	**$3,196.17**	**$4,117.40**

The transition to fuel cell buses is projected to increase total fleets costs by $3.2 - $4.1 billion over the next 40 years, an increase of 8.7% - 11.2% over projected baseline costs.

Fuel cell buses are projected to have slightly higher maintenance costs and significantly higher capital costs than the baseline. Fuel costs are projected to be either lower or higher than the baseline, depending on the method of hydrogen production; making hydrogen using electrolysis is projected to be significantly more expensive than making hydrogen using SMR.

Capital costs are higher due to the projected cost of fueling infrastructure, as well as significantly higher bus purchase and overhaul costs.

Figure 4. LACMTA Zero Emission Bus Estimated Incremental Fleet Costs 2015 - 2055 (nominal $)



3.2 Annual Fleet Costs After 2055

Table 7 summarizes the total estimated fleet costs in 2055 under each scenario in nominal dollars. Incremental costs for each scenario compared to baseline are also plotted in Figure 5. This data represents projected on-going annual costs for each bus/fuel technology after fully transitioning the fleet.

As shown, the use of RNG by itself is not projected to increase on-going annual fleet costs. The use of RNG and LNOx buses is projected to increase on-going annual fleet costs by $3.3 million (2055 $), an increase of 0.3% over projected baseline annual costs. The increased costs are due to slightly higher annual fuel costs, as well as slightly higher annual bus purchase and overhaul costs.

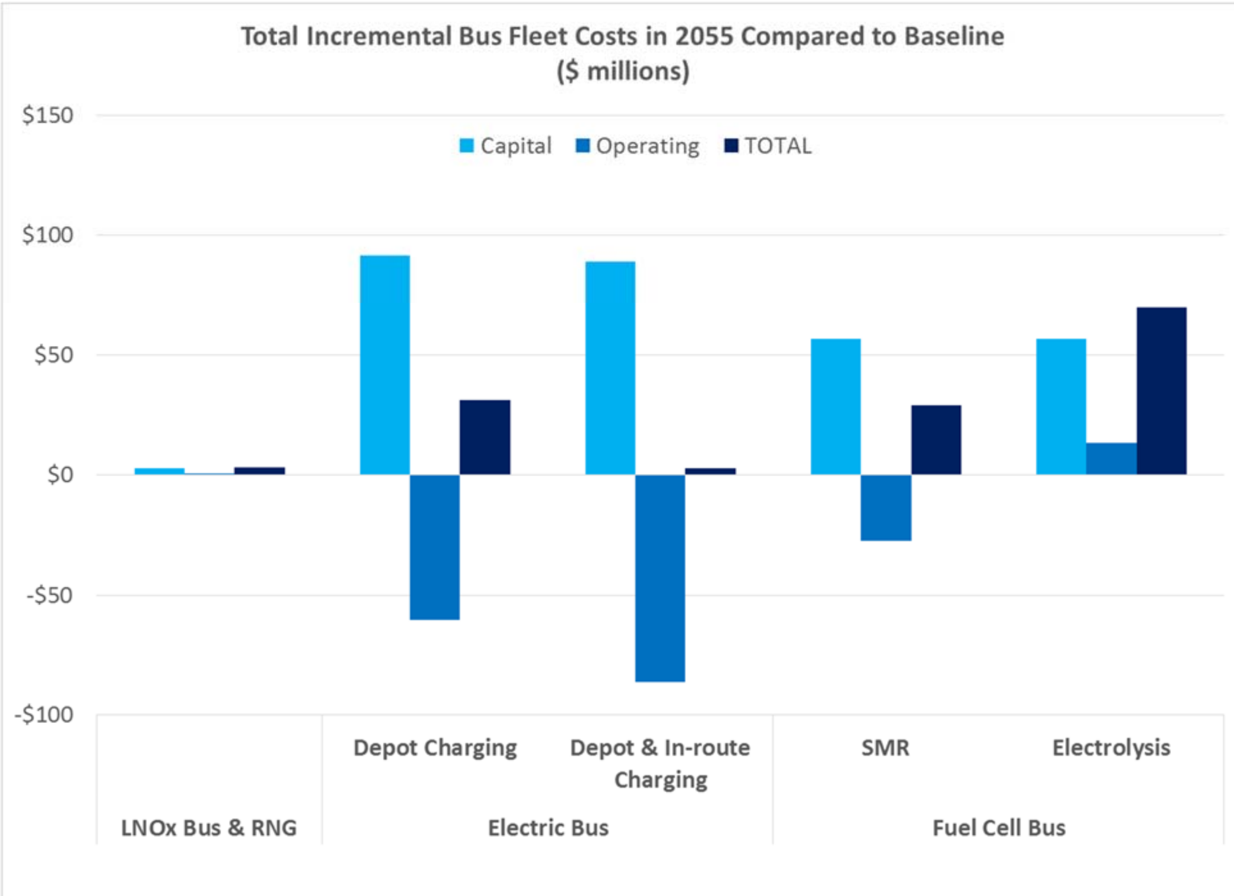
The use of electric buses with depot-only charging is projected to increase on-going annual fleet costs by $31 million, an increase of 2.5% over projected baseline costs. The use of electric buses with depot and in-route charging is projected to increase on-going annual fleet costs by $2.7 million, an increase of 0.2% over projected baseline costs.

The electric bus scenarios have increased on-going annual costs relative to the baseline projection primarily due to continuing higher annual capital costs for bus purchase and overhaul. These scenarios have significantly lower annual operating costs for fuel and maintenance, but these savings do not outweigh the increase in amortized capital costs.

Table 7. LACMTA Zero Emission Bus Estimated Annual Fleet Costs in 2055 (nominal $ million)

Cost Element		BASELINE	RENEW NG	LOW NOx CNG BUS & REPOWER		ELECTRIC BUS		FUEL CELL BUS	
		Std CNG Bus Conv NG	Std CNG Bus RNG	LNOx Bus Conv NG	LNOx Bus RNG	Depot Charging	Depot & In-Route Charging	H_2 by SMR	H_2 by Electrolysis
Capital	Bus Purchase	$175.3	$175.3	$177.1	$177.1	$243.6	$243.7	$213.9	$213.9
	Bus Repower			$0.0	$0.0				
	Bus mid-life OH	$12.5	$12.5	$13.6	$13.6	$35.8	$33.1	$30.4	$30.4
	Depot Mods					$0.0	$0.0	$0.0	$0.0
	Fuel Infra	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	sub-total	*$187.8*	*$187.8*	*$190.6*	*$190.6*	*$279.3*	*$276.9*	*$244.3*	*$244.3*
Operating	BO Labor	$796.0	$796.0	$796.0	$796.0	$818.9	$796.0	$796.0	$796.0
	Fuel	$114.6	$114.6	$115.1	$115.1	$45.8	$43.8	$80.8	$121.5
	Maintenance	$162.3	$162.3	$162.3	$162.3	$147.7	$146.6	$168.8	$168.8
	sub-total	*$1,072.9*	*$1,072.9*	*$1,073.3*	*$1,073.3*	*$1,012.4*	*$986.5*	*$1,045.5*	*$1,086.2*
TOTAL		**$1,260.7**	**$1,260.7**	**$1,264.0**	**$1,264.0**	**$1,291.7**	**$1,263.3**	**$1,289.8**	**$1,330.5**
INCREASE		**NA**	**$0.00**	**$3.32**	**$3.32**	**$31.08**	**$2.67**	**$29.13**	**$69.88**

Figure 5. LACMTA Zero Emission Bus Estimated Incremental Annual Costs in 2055 (nominal $)



The use of fuel cell buses is projected to increase on-going annual fleet costs by $29 - $70 million, an increase of 2.3% - 5.5% over projected baseline costs.

The fuel cell bus scenarios have increased on-going annual costs relative to the baseline projection primarily due to continuing higher annual capital costs for bus purchase and overhaul, as well as slightly higher annual maintenance costs.

On-going annual fuel costs for fuel cell buses are projected to be lower than the baseline projection if hydrogen is produced using SMR, but higher than baseline fuel costs if hydrogen is produced using electrolysis.

3.3 Fleet Emissions 2015 - 2055

Annual estimated fleet emissions of in-basin NOx, out-of-basin NOx, in-basin PM, out-of-basin PM CH_4, CO_2, and GHG between 2015 and 2055 under each bus technology/fuel purchase scenario are shown in figures 6 – 12.

As shown in these figures, under the baseline scenario there is a significant reduction in annual in-basin NOx emissions, and a smaller reduction in CH_4 and GHG emissions, between 2015 and 2020, while CO_2, out-of-basin NOx, and in-basin and out-of-basin PM hold steady. This NOx and CH_4 reduction is due to the retirement of LACMTA's oldest CNG buses, which have significantly higher tailpipe NOx and CH_4 emissions than the new CNG buses that will replace them under the baseline scenario. After 2020 the baseline scenario shows only minor year-to-year changes in annual emissions of all pollutants from the LACMTA bus fleet.

Figure 6. Estimated Annual Fleet Emissions of in-basin NOx (tons), 2015 – 2055

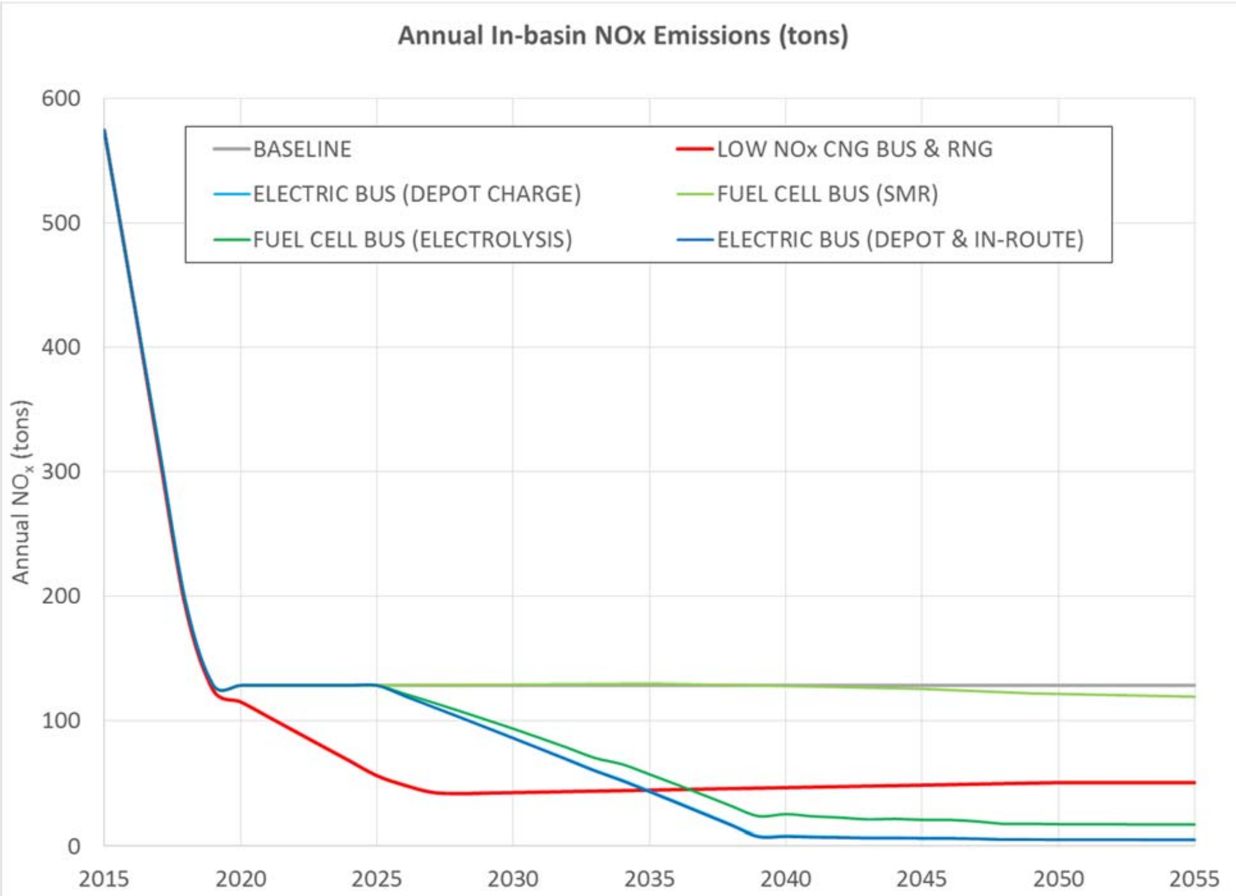


Figure 7. Estimated Annual Fleet Emissions of out-of-basin NOx (tons), 2015 – 2055

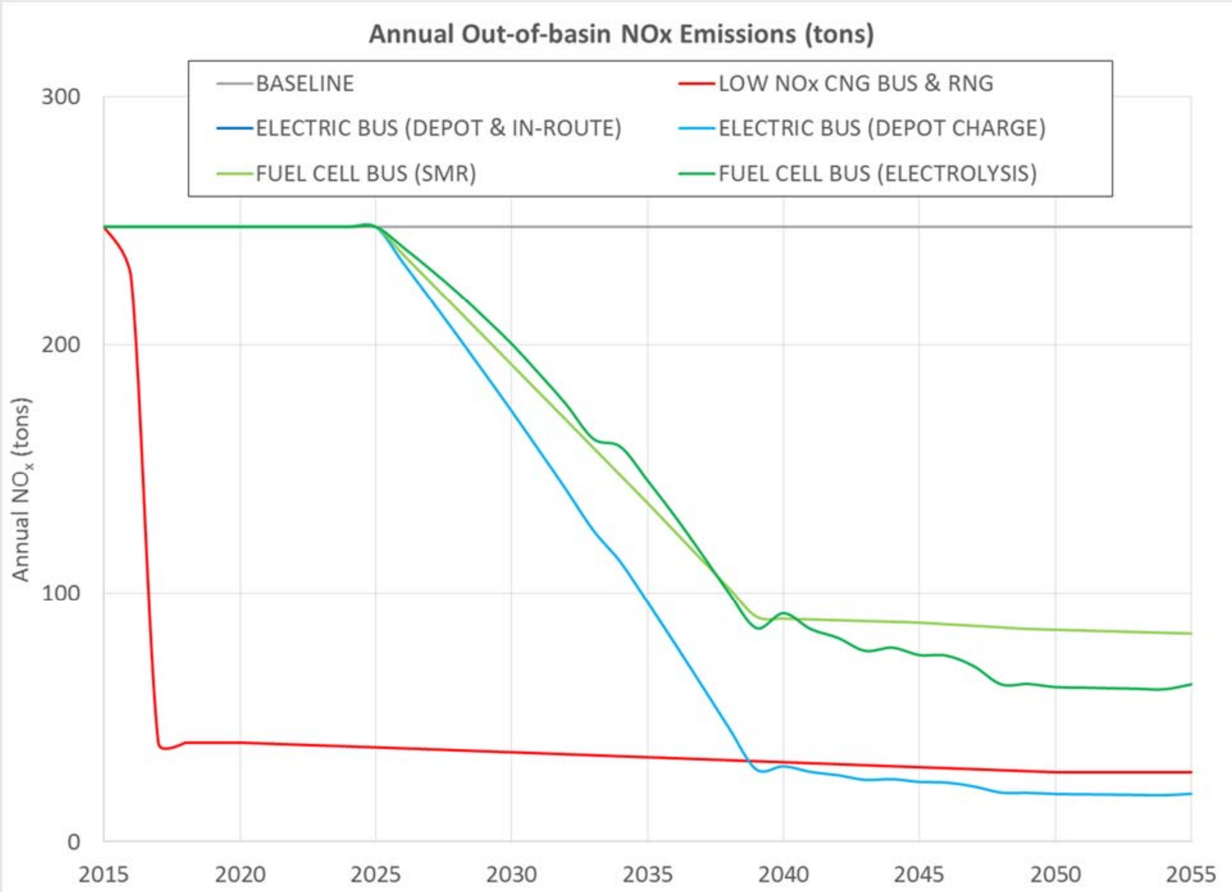


Figure 8. Estimated Annual Fleet Emissions of in-basin PM (tons), 2015 - 2055

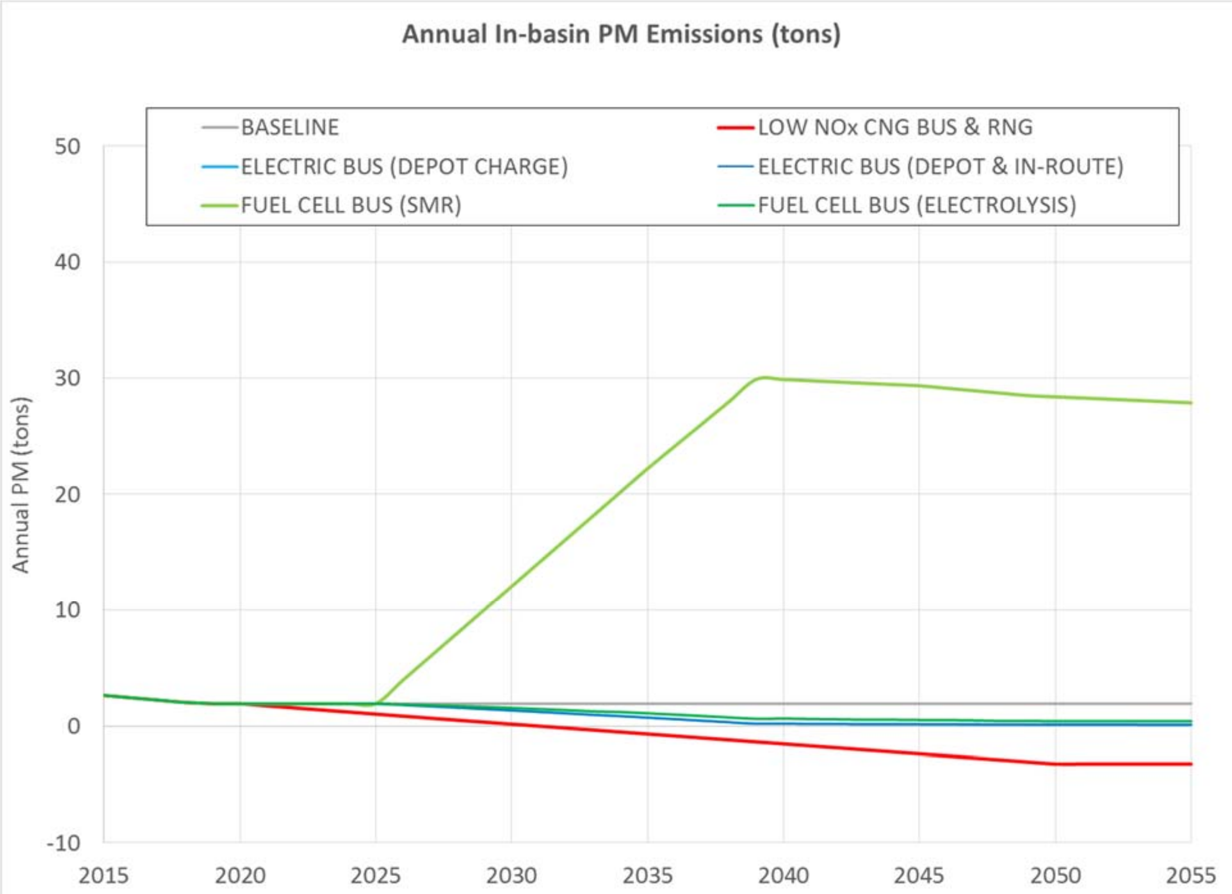


Figure 9. Estimated Annual Fleet Emissions of out-of-basin PM (tons), 2015 - 2055

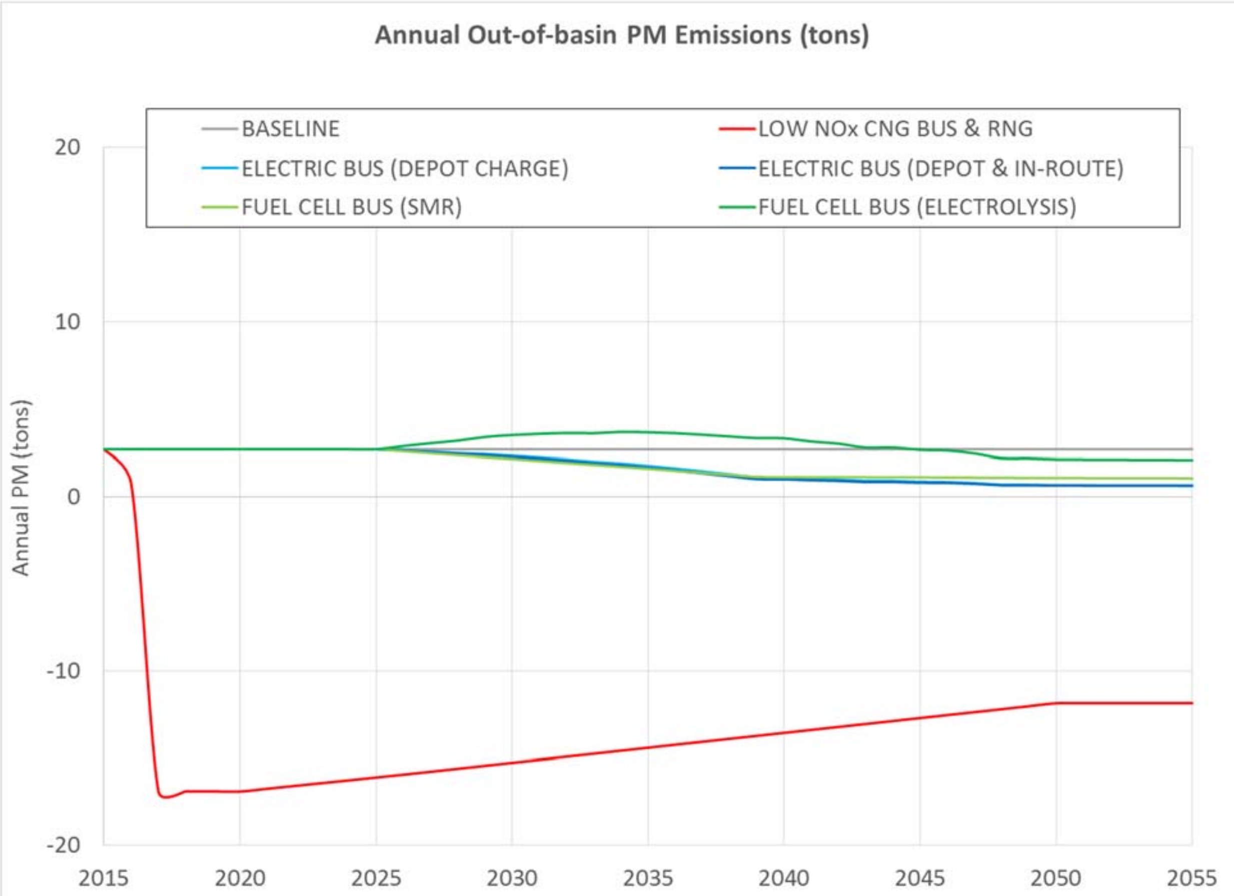


Figure 10. Estimated Annual Fleet Emissions of CH_4 (tons), 2015 - 2055

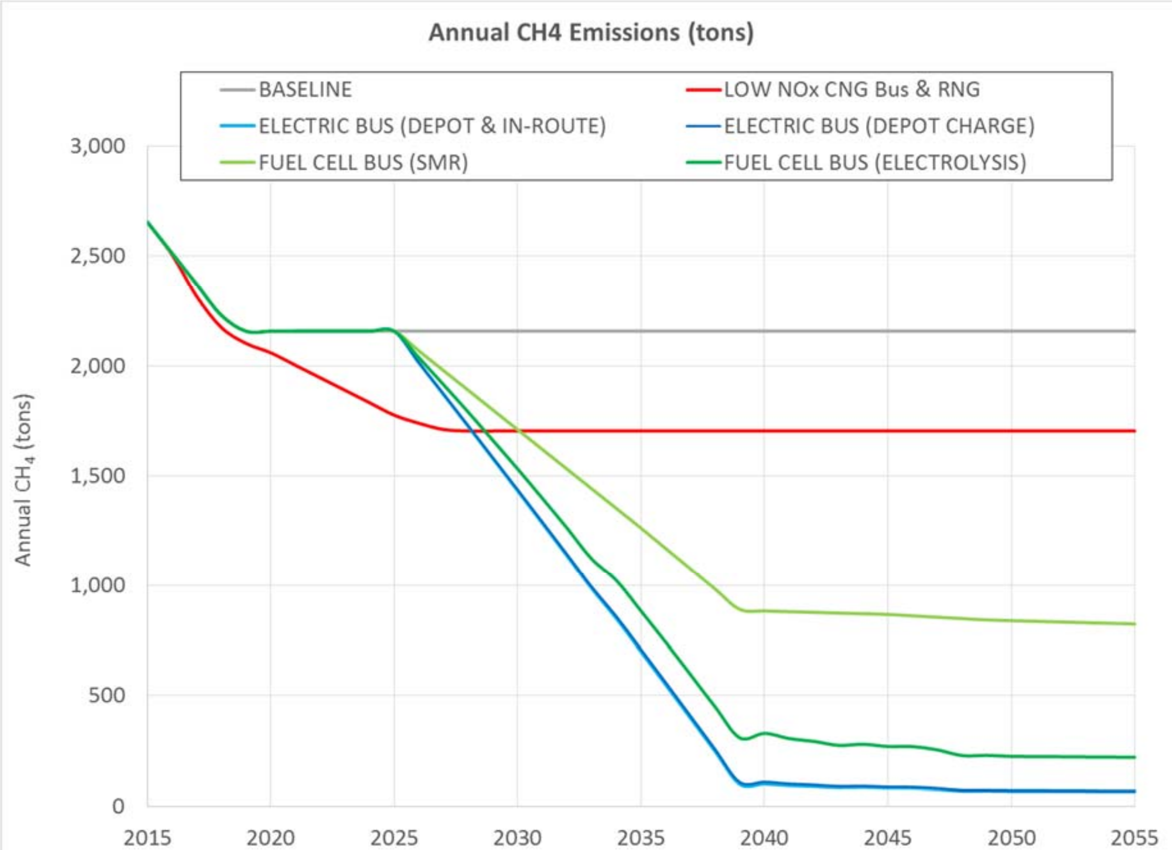


Figure 11. Estimated Annual Fleet Emissions of CO_2 (tons), 2015 - 2055

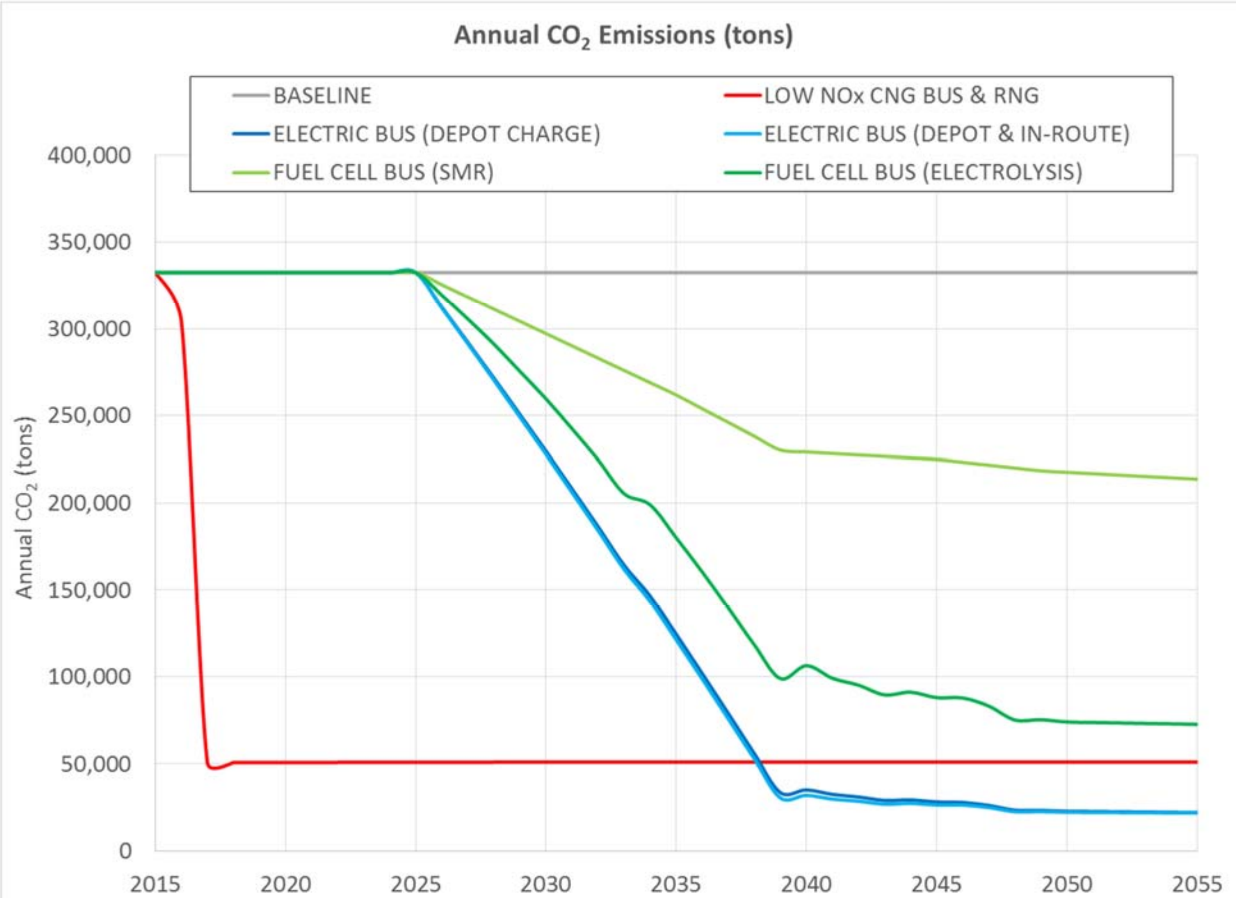
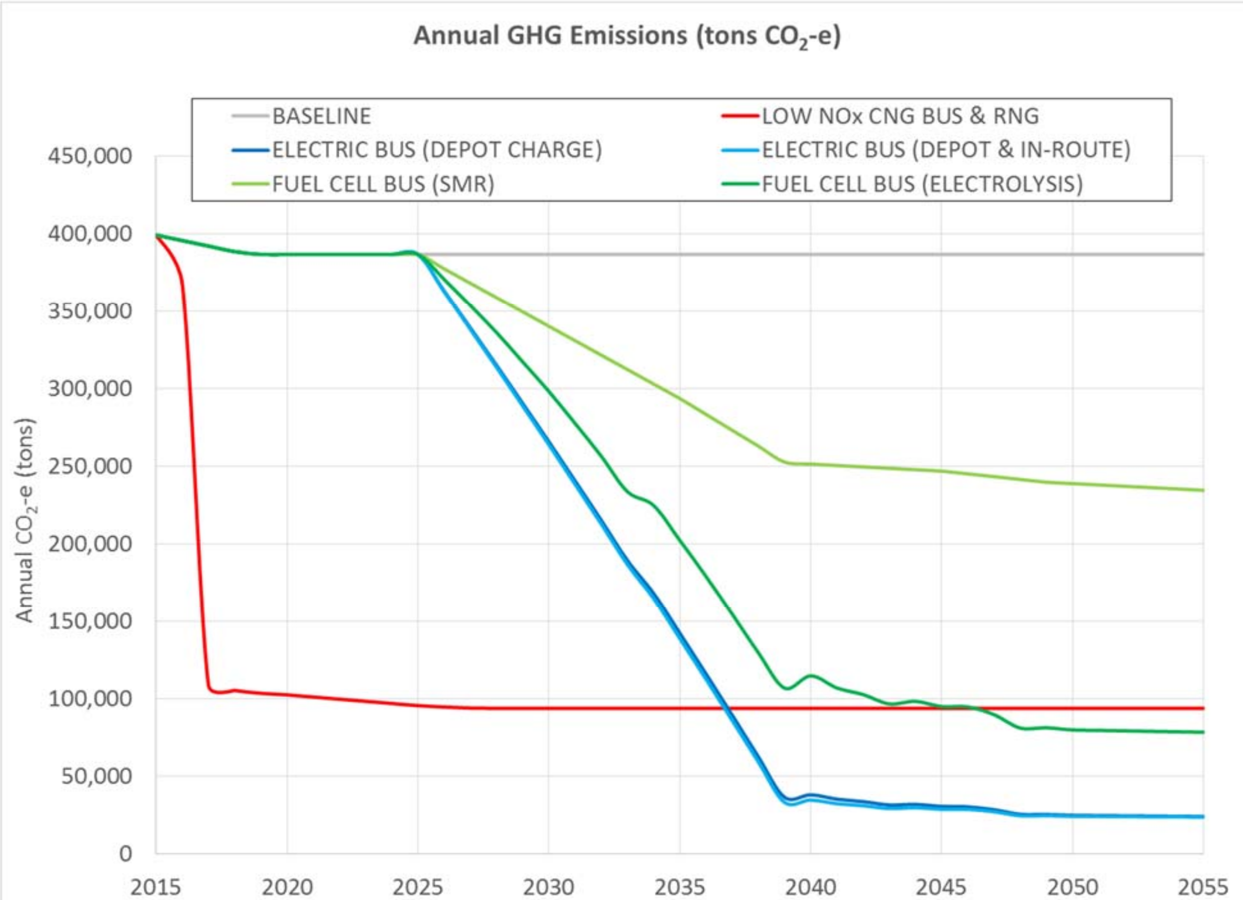


Figure 12. Estimated Annual Fleet Emissions of GHG (tons CO2-e), 2015 - 2055

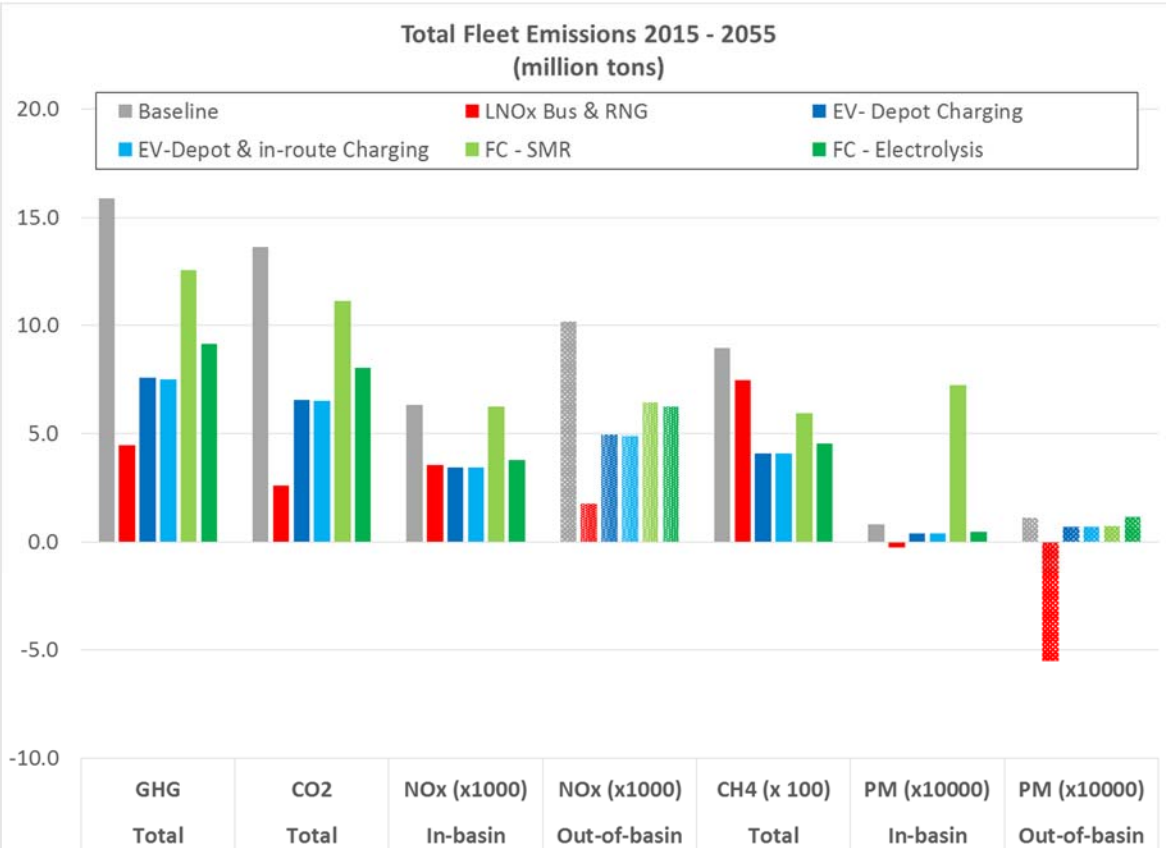


Under the LNOx Bus + RNG scenario annual estimated out-of-basin NOx and PM, CH_4, CO_2 and GHG emissions fall dramatically between 2016 and 2018 compared to the baseline, as the entire existing bus fleet is transitioned to RNG. These reductions are the result of lower upstream emissions from RNG production and transport compared to production and transport of standard natural gas. Annual out-of-basin PM emissions from this scenario are negative due to upstream PM credits for RNG production. Over the time period 2018 – 2028 annual in-basin NOx, in-basin PM, and CH_4 emissions continue to fall as the bus fleet transitions from standard natural gas engines to Low NOx natural gas engines with lower tailpipe emissions of NOx, PM, and CH_4. Between 2028 and 2055 in-basin PM and NOx under this scenario increase slightly year-to-year, while out-of-basin PM and NOx decrease slightly, due to assumed transition to a greater percentage of RNG produced by in-basin sources.

Under the electric bus and fuel cell bus scenarios annual NOx, CH_4, CO_2, and total GHG emissions start to fall in 2025 compared to the baseline, with significant year-to-year reductions through 2038 as the fleet transitions to electric or fuel cell buses. After 2038 annual emissions continue to fall, but at a lower rate. These continuing annual reductions after 2038 are due to continuing reductions in upstream emission rates (g/kWh) for electricity production, based on greater use of zero-emission renewable energy sources (solar, wind). With the exception of the fuel cell scenario with hydrogen fuel produced via SMR the electric and fuel cell scenarios produce significant reductions in both in-basin and out-of-basin NOx. When hydrogen is produced via SMR, out-of-basin NOx emissions fall year-to-year, but annual in-basin NOx emissions are similar to those under the baseline scenario throughout the analysis period.

With the exception of the fuel cell scenario when hydrogen is produced via SMR the electric and fuel cell scenarios also show reduced in-basin and out-of-basin PM emission compared to the baseline. When hydrogen production is by SMR out-of-basin PM emissions fall relative to the baseline, but in-basin PM emission increase significantly year-to-year through 2039 and then start to fall slightly. These increased in-basin PM emissions are due to the upstream emissions from producing hydrogen via SMR at the depots, and they outweigh reductions in tailpipe PM emissions from CNG buses.

Figure 13. LACMTA Zero Emission Bus Total Fleet Emissions (million tons) 2015 -2055



Total fleet emissions from each scenario over the period 2015 – 2055 are summarized in Figure 13. As shown, over the next 40 years total estimated fleet emissions of in-basin and out-of-basin PM, out-of-basin NOx, CO_2, and GHG are projected to be lower from the use of RNG and transition to LNOx buses than from transition to electric or fuel cell buses, while total fleet emissions of in-basin NOx are projected to be slightly higher and total fleet emissions of CH_4 are projected to be moderately higher.

Note that this analysis assumes that the RNG purchased by LACMTA will be 100% landfill gas, with 100% sourced from outside of the South Coast Air Basin in the near term, transitioning to 30% sourced from within the basin after 2050. According to the California Air Resources Board[7] RNG produced from wastewater treatment plants or food waste would have lower NOx and lower GHG

[7] California Low Carbon Fuel Standard

emissions than landfill gas. The use of RNG from these sources could further reduce total GHG and NOx emissions for the LNOx Bus + RNG scenario, compared to the data shown in Figure 11. The proportion of total NOx emitted in-basin and out-of-basin under the LNOx Bus + RNG scenario would be affected by both the RNG source type and the RNG source location.

3.4 Fleet Emissions After 2055

Table 8 summarizes the total estimated fleet emissions in 2055 under each scenario; this data is also plotted in Figure 14. This data represents projected on-going annual LACMTA fleet emissions for each bus/fuel technology after fully transitioning the fleet.

Table 8. Projected LACMTA Annual Fleet Emissions in 2055 (tons)

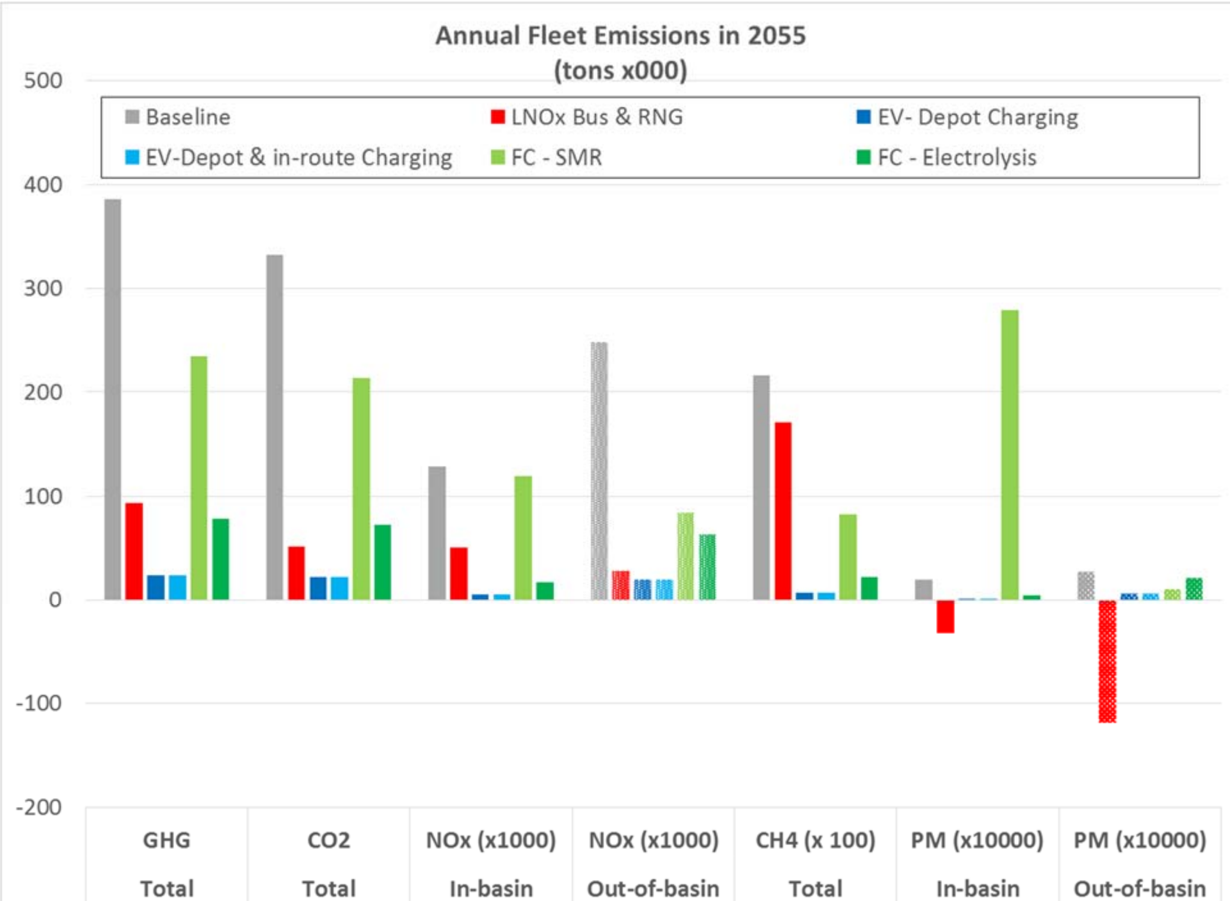
Pollutant	BASELINE	RENEW NG	LOW NOx CNG BUS & REPOWER		ELECTRIC BUS		FUEL CELL BUS	
	Std CNG Bus Conv NG	Std CNG Bus Renew NG	LNOx Bus Conv NG	LNOx Bus Renew NG	Depot Charging	Depot & In-Route Charging	H_2 by SMR	H_2 by Electrolysis
NOx (in-basin)	128.6	136.6	42.5	50.5	5.1	5.1	119.6	16.9
PM (in-basin)	1.94	-3.13	1.87	-3.22	0.13	0.13	27.87	0.42
CH_4	2,157.3	2,101.8	1,759.4	1,703.7	67.1	66.3	824.2	220.2
CO_2	332,622	50,795	333,958	50,999	22,151	21,896	213,790	72,708
GHG (CO_2-e)	386,554	103,340	377,942	93,591	23,829	23,554	234,395	78,213
NOx (Out-of-basin)	247.7	27.9	248.7	28.0	19.3	19.1	83.8	63.4
PM (out-of-basin)	2.69	-11.83	2.70	-11.88	0.63	0.63	1.05	2.08

In 2055 and later years electric buses are projected to have the lowest annual GHG emissions, approximately 94% lower than the baseline, and 75% lower than RNG plus LNOx buses. Fuel cell buses are projected to have GHG emissions 16% lower than RNG plus LNOx buses if the hydrogen fuel is produced by electrolysis, but 148% higher if the hydrogen fuel is produced by SMR.

Despite higher annual emissions after 2055, total cumulative GHG emissions would be lower from the transition to RNG and LNOx buses than from the transition to electric buses through 2099 due to lower emissions between 2015 and 2055. After 2099 electric buses would start to accrue net GHG reductions relative to RNG and LNOx buses.

Fuel cell buses would not start to accrue net GHG reductions relative to RNG and LNOx buses until 2358, even if hydrogen fuel was produced using electrolysis.

Figure 14. Projected LACMTA Fleet Emissions in 2055 (tons x000)



In 2055 and later years electric buses are projected to have the lowest annual in-basin and out-of-basin NOx emissions, approximately 96% and 92% lower than the baseline respectively. In 2055 in-basin NOx emissions from electric buses are projected to be 90% lower than from RNG plus LNOx buses. Fuel cell buses are projected to have in-basin NOx emissions 66% lower than RNG plus LNOx buses if the hydrogen fuel is produced by electrolysis, but 136% higher if the hydrogen fuel is produced by SMR.

ATTACHMENT D

List Of Transit Operators Running ZEB's

	State	City	Property	ZEB Type	Start	Notes	Currently Operating
1	Alabama	Birmingham	Jefferson County Transit Authority	Fuel cell	2016	1 - Fuel cell EVA bus. BYD or Proterra buses coming soon.	1
2	California	Anaheim	Anaheim Resort Transportation	Battery	2001	10 - 22' trolley buses from Ebus in 2001. 4 - BYD leased buses.	4
3	California	Antioch	Tri Delta Transit		2016	AC Transit buses.	0
4	California	Burbank	Burbank Bus	Fuel cell	2012	1 - Proterra plug in fuel cell bus demo.	0
5	California	Gardena	Gardena Transit	Battery	2015	1 - BYD 40' bus. 1 - CCW converted bus. 4 - CCW buses on order for 2017.	2
	California	Irvine	OCTA	Fuel cell	2016	1- El Dorado bus for 2 year demonstration	1
6	California	Irvine	UDI Transportation and Distribution Services	Fuel cell	2015	1 - El Dorado 40' bus with Ballard fuel cell	1
7	California	Lancaster	AVTA	Battery	2015	2 - BYD 40' buses 2015. Option from LA order.	2
8	California	Long Beach	Long Beach Transit	Battery	2016	10 - BYD buses coming in 2016	10
9	California	Los Angeles	Cal State LA	Fuel cell	2015	Hydrogen fueling station installed 2014. 2 - FC shuttle bus demo in 2015.	0
10	California	Los Angeles	LA Metro	Battery	2015	5 - BYD 40' buses	5
11	California	Los Angeles	LADOT	Battery	2014	2014 - BYD demo for DASH.	0
12	California	Mountain View	Mountain View Community Shuttle	Battery	2015	4 - 16 passenger shuttle buses with Google, Feb 2015	4
13	California	Oakland	AC Transit	Fuel cell	2012	12 - Van Hool 40' buses	12
14	California	Pomona	Foothill Transit	Battery	2010	15 - Proterra 35' buses. 2 - Proterra 40' buses. Line 291 from Pomona.	17
15	California	Porterville	Porterville Transit	Battery	2016	2 - Proterra 40' buses. GreenPower building a plant in Porterville	2
16	California	Salinas/Monterey	Salinas Transit	Battery	2016	June 2016, electric trolley bus	1
17	California	San Francisco	SFMTA	Fuel cell	2011	1 - Orion VII bus.	0
18	California	Santa Barbara	Santa Barbara Metro	Battery	1991	20 - battery buses of various makes and sizes. 14 from ebus. Reached a million miles in 2002.	20
19	California	Stanford	Stanford University	Battery	2014	23 - BYD buses. 13 - 40', 10 - 30'	23
20	California	Stockton	San Joaquin Regional Transit District	Battery	2013	2-Proterra buses 2013, 5-40' Proterra buses 2016	7
	California	Thousand Palms	Sunline	Fuel cell	2003	A variety of fuel cell buses starting in 2003. 3 - FC older buses and 5 more from NFA. 1 battery bus demo from BYD is first battery bus.	9
21	California	Vallejo	Solano County Transit	Battery	2016	July 2016 - 2 - BYD 40' buses	2
22	Canada	Montreal	Societe de Transport	Battery	2016	3 - Nova 40' battery electric with opportunity charging	3
23	Canada	Winnipeg	Winnipeg Transit	Battery	2016	4 - NFA 40' battery buses for airport	4
24	Connecticut	Hartford	CT Transit	Fuel cell	2007	5 buses. First bus in 2007, option order on AC transit 40' Van Hool buses	5
25	Delaware	Newark	University of Delaware	Battery	2010	2 - Daimler fuel cell bus demo. University study on electric school buses. 1 - GE hybrid fuel cell bus. 6 - Proterra buses for Delaware Transit	6
26	Florida	Tallahassee	Star Metro	Battery	2013	5 - Proterra buses since 2013	5
27	Illinois	Chicago	Chicago Transit Authority	Battery	2014	2 - NFA 40' buses since 2014. Ongoing procurement for 20-30 buses. 1 - demo ElDorado fuel cell bus 2012.	2
28	Indiana	Indianapolis	IndyGO	Battery	2015	21 - buses from CCW, converted Gilligs.	21
29	Kentucky	Lexington	Lexington Transit Authority	Battery	2015	5 - Proterra buses	5
30	Kentucky	Louisville	Transit Authority of River City	Battery	2015	15 - Proterra buses. 6 - in July 2016.	15
31	Maryland	Frederick County	TransIT	Battery	2016	5 - Gillig buses from CCW	5
32	Maryland	Howard	Regional Transit Authority of Central Maryland	Battery	2016	3 - 35' buses with WAVE charging	3
33	Massachusetts	Boston	Massachusetts Bay Transportation Authority	Fuel cell	2004	28 - Neoplan trolley buses. 1 - NFA 60' battery bus next year. 1 - ElDorado 40' fuel cell bus demo	2
34	Massachusetts	Worcester	Worcester Regional Transit Authority	Battery	2015	6 - Proterra	6
35	Michigan	Flint	Mass Transportation Authority	Fuel cell	2015	1 - El Dorado 40' bus with Ballard fuel cell	1
36	Minnesota	Duluth	Duluth Transit Authority	Battery	2016	6 - Proterra	6
37	Missouri	Columbia	CoMo	Battery	2015	4 - BYD buses	4
38	Missouri	St. Louis	University of Missouri, St. Louis		2015	Using CoMo buses	0
39	Montana	Missoula	ASUM Transportation	Battery	2016	2 - Proterra buses.	2
40	Nevada	Reno	RTC Washoe County	Battery	2015	4 - Proterra buses	4
41	New York	Ithaca	Tompkins Consolidated Area Transit	Fuel cell	2015	1 - El Dorado 40' bus with Ballard fuel cell	1
42	Ohio	Canton	Stark Area Regional Transit Authority	Fuel cell	2015	2 - El Dorado 40' bus	2
43	Ohio	Columbus	Ohio State University	Fuel cell	2015	1 - SARTA bus used on University for a year. Same as STARK?	1
44	Oregon	Portland	Trimet	Battery	2015	4 - NFA 40' battery buses - July 2016. 2 week BYD test in 2014.	4
45	Pennsylvania	Philadelphia	Southeastern Pennsylvania Transportation Authority	Battery	2017	25 - Proterra 40' buses for 2017.	0
46	S. Carolina	Seneca	CatBus	Battery	2015	4 - Proterra buses	4
47	Tennessee	Chattanooga	Chattanooga Area Regional Transportation Authority	Battery	1994	18 - shuttle buses for downtown. Since 1994	18
48	Tennessee	Nashville	Nashville Metropolitan Transit Authority	Battery	2015	7 - Proterra	7
49	Texas	Austin	Capital Metro	Fuel cell	2015	1 - Proterra plug in fuel cell bus.	1
50	Texas	Dallas	Dallas Area Rapid Transit	Battery	2016	7 - Proterra	7
51	Texas	McAllen	McAllen Metro	Battery	2015	2 - CCW battery buses with WAVE.	2
52	Texas	San Antonio	VIA Metro	Battery	2015	3 - Proterra buses	3
53	Utah	Salt Lake City	Utah Transit Authority	Battery	2018	5 - NFA battery buses in 2018	0
54	Washington	Richland	Ben Franklin Transit	Battery	2013	1 - CCW bus, 2013.	1
55	Washington	Seattle	King County Metro	Battery	2016	3 - Proterra buses	3
56	Washington	Wenatchee	Link Transit	Battery	2015	4 - BYD 35' buses	4
57	Washington DC	DC	Georgetown University	Fuel cell	1994	3 - 30' and 2 - 40' foot fuel cell buses until 2011.	0
							280

Identified ZEB Suppliers

Company	Buy America	Location	Models	Battery
BYD	Y	46147 BYD Blvd, Lancaster, CA	20,30, 40, 45, 60 ft battery electric	up to 520 kWh
CCW	Y	1863 Service Ct, Riverside, CA	30, 35, 40 ft rebuilt	311 kWh
ebus	Y	9250 Washburn Rd, Downey, CA	22, 40 ft battery electric	
El Dorado	Y	9670 Galena St, Riverside, CA	40' battery bus	
GreenPower	N	37-2 Haijing East Road, China. ST 240-209 Carrall St, Vancouver , BC	30, 40, 45, 60 ft battery electric	210-400 kWh
Linkker	N	Koritie 2, 15540 Villahde, Finland	12 m, low floor battery electric	48 kWh
NFA	Y	6200 Glenn Carlsen Dr., St. Cloud, MN	40' 60' battery buses	
Proterra	Y	1815 Rollins Rd., Burlingame, CA	35', 40' battery bus	Up to 300kWh
Van Hool	N	Bernard Van Hoolstraat 58, Loningshooikt, Belgium	40' fuel cell bus	H2
Nova/Volvo	Y	260 Banker Rd, Plattsburgh, NY	40' battery bus	40 kWh

ATTACHMENT F

NOISE LEVEL COMPARISON OF CONVENTIONAL AND ZEB's

Altoon test data

	CNG						Electric				
Measured in dBA Scale	New Flyer XN40 - 2014	Nova Bus LFS 40 - 2013	NABI 40-LFW - 2013	Orion EPA 10 - 2011	New Flyer XN60 - 2011	Average	Proterra BE40 - 2014	New Flyer XE40 - 2014	BYD K9 - 2013	Average	Difference for Electric Buses
Interior											
Driver	71.7	71.4	74.8	75.5	71.5	73.0	74.8	69.3	68.3	70.8	-2.2
Passengers	75.8	79.5	74.8	77.9	74.0	76.4	75.6	70.2	71.1	72.3	-4.1
Exterior											
Curb Side	73.6	72.4	67.9	71.3	71.5	71.3	66.1	66.1	63.0	65.1	-6.3
Street Side	73.9	72.2	68.9	71.5	77.7	72.8	66.6	66.1	61.3	64.7	-8.2

Weekday Metro Bus Mileage Summary by Division
June 26, 2016

ATTACHMENT G

Div.	Line	One-Way Trip Mi.	Total Blocks	Weekday Bus Mileage Totals <150	> 150 <200	> 200 <250	<250 and UP	Shortest Run Time	Longest Run Time	Weekday Ridership	Off-Street Terminals	Comments
Div 1	16	12.6	20	17	3	0	0	0:57	21:53	16,821	1	Maple Lot
Div 1	18	13.0	31	30	1	0	0	0:45	17:46	14,042	2	6th and Oxford & Montebello Metro Link Sta
Div 1	20	17.5	15	15	0	0	0	1:23	17:19	8,223	1	Maple Lot
Div 1	45	20.2	12	9	3	0	0	2:04	18:03	13,034	0	
Div 1	53	16.6	25	20	4	1	0	1:47	19:19	8,617	1	Beaudry & Temple
Div 1	62	26.3	13	6	5	2	0	2:15	19:40	3,681	1	Beaudry & Temple
Div 1	66	13.0	25	24	1	0	0	1:03	19:20	35,663	2	6th and Oxford & Montebello Metro Link Sta
Div 1	460	40.3	12	9	3	0	0	3:23	16:11	2,290	2	Maple Lot & Disneyland
Div 1	760	11.5	12	6	6	0	0	1:40	16:30	2,290	0	
Division 1 Vehicle Totals			165	136	26	3	0			104,661		
Division 1 Percentages				82%	16%	2%	0%					
Div 2	4	20.7	7	7	0	0	0	3:25	15:25	15,869	1	Terminal 28
Div 2	10	19.9	13	9	4	0	0	1:51	19:31	13,036	1	On-Street Adjacent to Division 7
Div 2	55	13.2	14	10	4	0	0	1:36	17:36	8,566	1	Rosa Parks/Willowbrook Station
Div 2	51	17.6	45	39	6	0	0	1:28	15:34	26,191	3	Harbor Gateway TC, MLK TC Compton, 6th & Shatto Pl
Div 2	60	25.6	31	30	1	0	0	1:42	16:10	15,678	1	Artesia Blue Station
Div 2	105	16.0	16	12	4	0	0	2:44	19:08	11,280	2	Divison 7 Yard & Vernon Yard
Div 2	200	6.3	17	16	1	0	0	1:44	20:44	13,291	0	
Div 2	611	14.6	4	2	2	0	0	3:41	17:12	1,647	0	
Div 2	612	16.3	4	2	0	2	0	8:30	20:24	1,374	2	Clockwise Shuttle with Termial at Willowbrook Station.
Div 2	705	14.8	9	8	1	0	0	2:08	15:51	6,363	2	Divison 7 Yard & Vernon Yard
Division 2 Vehicle Totals			160	135	23	2	-			113,295		
Division 2 Percentages				84%	14%	1%	0%					
Div 3	28	21.1	13	11	2	0	0	0:41	16:04	10,996	0	
Div 3	45	20.2	15	15	0	0	0	1:59	15:05	16,149	0	
Div 3	81	19.9	27	17	7	3	0	1:53	19:55	16,090	0	
Div 3	83	15.1	7	7	0	0	0	1:32	17:18	2,888	1	Terminal 28
Div 3	175	5.2	2	2	0	0	0	1:08	4:06	864	0	
Div 3	180	18.6	16	11	4	1	0	2:44	20:40	8,710	2	Hollywood Vine Sta. **(Sierra Madre Villa Sta - Rte 181 only**
Div 3	201	11.6	3	2	1	0	0	15:02	15:20	1,166	1	Wilshire / Vermont Red Line Station
Div 3	206	14.0	5	4	1	0	0	2:09	15:52	13,145	0	
Div 3	251	14.6	15	13	2	0	0	0:51	17:11	8,739	1	On-Street adjacent to Division 3
Div 3	252	8.9	5	2	3	0	0	0:52	16:12	2,453	0	
Div 3	258	28.4	7	0	1	6	0	14:19	17:30	1,771	0	
Div 3	751	10.2	9	9	0	0	0	3:27	14:52	5,533	2	Palm / Seville & **On Street adjacent to Division 3**
Div 3	780	22.1	21	9	12	0	0	2:40	15:31	9,095	1	Washington / Fairfax Terminal
Division 3 Vehicle Totals			145	102	33	10	0			97,599		
Division 3 Percentages				70%	23%	7%	0%					
Div 5	102	18.5	7	4	2	1	0	3:54	19:46	2,614	2	Lax City Bus Terminal & Palm and Seville Terminal
Div 5	108	24.1	34	21	10	3	0	1:59	18:39	16,770	0	
Div 5	110	21.2	22	18	4	0	0	2:02	18:36	9,598	0	
Div 5	204	12.6	12	12	0	0	0	2:07	15:55	22,173	0	
Div 5	206	14.0	12	7	4	1	0	3:16	20:13	13,145	0	
Div 5	207	14.2	12	10	1	1	0	2:12	21:37	18,048	0	
Div 5	209	14.7	3	0	3	0	0	13:52	16:10	1,059	1	Oxford & 6th Terminal
Div 5	212	14.7	26	23	3	0	0	1:52	20:00	13,476	1	On-Street adjacent to Hollywood / Vine Station.
Div 5	740	12.7	9	4	5	0	0	1:45	17:41	2,781	1	South Bay Transit Center
Div 5	754	12.5	20	17	3	0	0	2:31	16:30	20,575	0	
Div 5	757	14.3	20	16	4	0	0	2:00	15:09	13,104	0	
Division 5 Vehicle Totals			177	132	39	6	0			133,343		
Division 5 Percentages				75%	22%	3%	0%					

Weekday Metro Bus Mileage Summary by Division
June 26, 2016

			Weekday Bus Mileage Totals									
Div.	Line	One-Way Trip Mi.	Total Blocks	<150	> 150 <200	> 200 <250	<250 and UP	Shortest Run Time	Longest Run Time	Weekday Ridership	Off-Street Terminals	Comments
Div 7	2	28.9	25	22	3	0	0	1:25	19:25	15,909	1	Terminal 28.
Div 7	4	20.7	11	9	2	0	0	2:09	19:03	15,869	1	Terminal 28.
Div 7	10	19.9	16	14	2	0	0	1:30	15:39	13,036	1	On-street adjacent to Division 7
Div 7	14	19.8	41	38	3	0	0	1:31	18:24	19,054	1	Washington / Fairfax Terminal
Div 7	16	12.6	23	21	1	1	0	2:23	21:53	22,938	1	Maple Lot
Div 7	20	17.5	11	11	0	0	0	3:44	15:18	15,455	1	Maple Lot
Div 7	28	21.1	13	12	1	0	0	1:17	17:50	10,996	0	
Div 7	30	15.3	7	7	0	0	0	2:15	16:48	13,807	1	On-street adjacent to Division 7
Div 7	33	19.6	8	8	0	0	0	2:48	13:20	11,062	2	Maple Lot & Jackson st. Terminal
Div 7	35	15.0	17	13	4	0	0	2:07	18:58	9,715	2	Washington / Fairfax Terminal
Div 7	217	14.5	15	15	0	0	0	0:58	17:14	7,002	1	On-street adjacent to Hollywood & Vine Terminal
Div 7	534	26.5	16	12	4	0	0	2:03	8:30	2,689	1	Washington / Fairfax Terminal
Div 7	704	19.7	9	8	1	0	0	2:44	15:54	12,389	1	Jackson Street Terminal
Div 7	705	14.8	8	6	0	1	1	2:06	19:44	6,363	2	On-street adjacent to Division 7 Yard & Vernon Yard.
Div 7	733	19.7	5	5	0	0	0	4:27	4:46	11,451	1	Jackson Street Terminal
Division 7 Vehicle Totals			225	201	21	2	1			187,735		
Division 7 Percentages				89%	9%	1%	0%					
Div 8	150	18.1	20	10	8	1	1	2:12	21:59	9,189	2 / 4	Universal / Studio City Sta./ On-Street Warner Cntr (2 of 4 Terms)
Div 8	152	24.4	17	12	4	1	0	0:45	17:48	11,780	1	North Hollywood Station
Div 8	155	13.4	2	2	0	0	0	7:33	8:40	1,659	1	Burbank Station
Div 8	158	18.9	5	2	2	1	0	2:04	16:13	2,321	1	Chatsworth Wtation
Div 8	161	22.4	8	5	2	1	0	1:42	13:28	1,344	2	Thousand Oaks Transit Center & On-Street Warner Center
Div 8	163	17.2	6	6	0	0	0	4:21	13:08	9,605	1/3	North Hollywood Station (1 of 3 Terminals)
Div 8	164	23.5	12	8	1	3	0	2:15	18:06	6,696	1	Burbank Station
Div 8	165	22.9	18	13	1	3	1	1:21	18:58	8,252	1	Burbank Station
Div 8	166	16.7	9	6	1	2	0	1:47	18:12	2,865	2	Divsiion 15 & Chatsworth Metrolink Station
Div 8	169	33.1	7	2	2	3	0	0:59	17:02	2,497	2	On Street Warner Center & Burbank RITC
Div 8	236	16.6	9	4	3	2	0	1:56	18:24	2,499	1	Sylmar Station
Div 8	237	22.2	3	0	2	1	0	13:38	16:36	N/A	0	
Div 8	239	16.1	2	2	0	0	0	2:15	6:08	976	0	
Div 8	243	19.0	7	4	2	1	0	1:29	15:06	1,857	0	
Div 8	245	16.5	12	10	2	0	0	1:04	15:14	3,170	2	Chatsworth Station on both ends of the line.
Div 8	750	16.1	12	7	2	3	0	1:52	16:58	3,170	2	On Street Warner Center & Universal City Red Line Sta.
Div 8	901	19.8	33	10	9	14	0	2:12	15:21	25,979	3/3	On Street Warner Center, North Hollywood Sta & Chatsworth Sta.
Division 8 Vehicle Totals			182	103	41	36	2			93,859		
Division 8 Percentages				57%	23%	20%	1%					
Div 9	70	16.5	17	9	8	0	0	1:58	18:10	11,064	2	El Monte Station & Terminal 28
Div 9	71	8.3	7	6	1	0	0	3:17	15:39	1,737	1	Terminal 28
Div 9	76	16.3	17	14	3	0	0	2:04	18:12	9,393	2	El Monte Station & Terminal 28
Div 9	78	18.2	27	18	7	1	1	1:44	20:55	70,026	1	Terminal 28
Div 9	176	20.7	5	0	5	0	0	14:16	16:20	1,797	2	Terminal 28 to El Monte Station
Div 9	260	28.5	21	9	5	7	0	1:55	20:08	11,149	1	Artesia Blue Line Station
Div 9	265	16.3	4	1	0	3	0	6:14	17:25	1,705	1	Jackson Street
Div 9	267	17.6	8	0	5	3	0	14:16	16:30	3,217	1	El Monte Station
Div 9	268	23.0	15	11	2	2	0	1:15	17:32	1,906	1	El Monte Station
Div 9	487	31.6	18	11	4	3	0	1:45	15:43	3,709	1/3	El Monte Station (1 of 3 terminals)
Div 9	665	6.7	2	1	1	0	0	6:18	15:53	758	1	Cal State L.A On-Street Transit Station.
Div 9	687	5.9	4	1	3	0	0	15:05	17:40	1,426	0	
Div 9	762	25.0	11	4	2	5	0	2:25	16:32	4,120	1	Artesia Blue Line Station
Div 9	770	16.6	16	6	9	1	0	2:33	16:12	7,651	2	Terminal 28 to El Monte Station
Div 9	910	38.9	33	21	0	4	8	2:19	21:04	16,355	2/3	El Monte Sta, Harbor Gateway Sta (2 of 3 terminals)
Division 9 Vehicle Totals			205	112	55	29	9			53,793		
Division 9 Percentages				55%	27%	14%	4%					

Weekday Metro Bus Mileage Summary by Division
June 26, 2016

Div.	Line	One-Way Trip Mi.	Total Blocks	Weekday Bus Mileage Totals <150	> 150 <200	> 200 <250	<250 and UP	Shortest Run Time	Longest Run Time	Weekday Ridership	Off-Street Terminals	Comments
Div 10	2	28.9	5	5	0	0	0	2:25	11:05	15,909	1	Terminal 28
Div 10	30	15.3	3	3	0	0	0	1:26	5:26	13,807	2/3	Division 7 Yard & Pico Rimpau Terminal (2 of 3 terminals)
Div 10	33	19.6	4	4	0	0	0	2:16	7:39	11,062	2/3	Maple Lot & Jackson Street Terminal (2 of 3 terminals)
Div 10	68	11.3	4	4	0	0	0	1:08	14:02	5,737	3/4	Dozier/Rowan, Maple Lot, ELAC Transit CTR (3 of 4 termials)
Div 10	106	7.5	2	2	0	0	0	15:05	15:27	N/A	2	ELAC Transit Ctr. & On Street USC Medical Center.
Div 10	704	19.7	11	10	1	0	0	2:18	15:32	12,389	1	Jackson Street
Div 10	728	13.3	16	14	2	0	0	2:04	17:35	5,979	1	Jackson Street
Div 10	733	19.7	20	14	6	0	0	2:26	15:46	11,451	1	Jackson Street
Div 10	745	11.3	8	6	2	0	0	2:00	15:59	6,278	2	Jackson Street & Figueroa and 117th (Green Line Station)
Division 10 Vehicle Totals			73	62	11	0	0			82,612		
Division 10 percentages				85%	15%	0%	0%					
Div 13	2	28.9	25	20	5	0	0	1:31	19:22	12,689	1	Terminal 28.
Div 13	4	20.7	9	7	2	0	0	2:56	20:17	15,869	1	Terminal 28.
Div 13	30	15.3	13	12	1	0	0	3:13	20:14	13,807	2/3	Division 7 Yard & Pico Rimpau Terminal (2 of 3 terminals)
Div 13	33	19.6	12	12	0	0	0	2:27	14:17	11,062	2/3	Maple Lot & Jackson Street Terminal (2 of 3 terminals)
Div 13	55	13.2	4	3	1	0	0	4:31	15:49	8,566	1	Rosa Parks / Wilmington Blue Line Station.
Div 13	68	11.3	7	5	2	0	0	3:16	21:11	5,767	3/4	Dozier/Rowan, Maple Lot, ELAC Transit CTR (3 of 4 termials)
Div 13	704	19.7	7	3	4	0	0	7:35	18:52	12,389	1	Jackson Street
Div 13	720	24.6	64	47	11	6	0	2:15	21:13	35,512	0	
Div 13	733	19.7	5	3	2	0	0	9:51	19:20	11,451	1	Jackson Street Terminal
Div 13	745	11.3	9	7	2	0	0	2:14	14:38	6,278	2	Jackson Street & Figueroa and 117th (Green Line Station)
Division 13 Vehicle Totals			155	119	30	6	0			133,390		
Division 13 Percentages				77%	19%	4%	0%					
Div 15	90	32.4	18	7	8	2	1	0:51	19:45	7,856	1	Terminal 28.
Div 15	92	14.3	12	5	7	0	0	3:45	18:05	5,191	1	Burbank Station
Div 15	94	26.0	13	4	2	4	3	2:50	21:34	5,084	1	Terminal 28.
Div 15	152	24.4	10	5	5	0	0	2:00	12:53	11,780	1	North Hollywood Station
Div 15	154	18.0	3	0	3	0	0	14:09	15:20	1,021	1	Burbank Station
Div 15	155	13.4	4	1	3	0	0	13:41	14:38	1,659	1	Burbank Station
Div 15	163	17.2	14	11	3	0	0	2:11	16:36	9,605	1/3	North Hollywood Station (1 of 3 Terminals)
Div 15	164	23.5	5	1	0	4	0	1:30	18:00	6,696	1	Burbank Station
Div 15	165	22.9	7	5	1	1	0	1:46	17:07	8,252	1	Burbank Station
Div 15	166	16.7	11	9	2	0	0	1:29	13:33	5,865	2	Divsion 15 & Chatsworth Metrolink Station
Div 15	183	22.4	6	2	3	1	0	3:05	17:39	2,175	1	Glendale Transportation Center
Div 15	222	17.4	10	7	1	1	1	1:00	20:58	1,801	0	
Div 15	224	16.9	12	10	1	0	1	2:40	21:12	7,681	1	Universal City Red Line Station
Div 15	230	15.4	11	7	3	1	0	0:56	18:27	4,626	0	
Div 15	233	13.7	16	13	3	0	0	2:29	19:13	12,105	0	
Div 15	234	28.6	10	4	2	2	2	2:09	21:17	5,576	0	
Div 15	237	22.2	6	4	2	0	0	1:28	15:53	N/A	0	
Div 15	292	13.1	3	0	1	2	0	13:12	17:22	2,374	2	Burbank Station & Sylmar Station
Div 15	734	24.3	14	3	4	7	0	5:23	17:46	6,456	1	Sylmar Station
Div 15	744	23.4	13	2	7	4	0	8:06	18:15	9,587	0	
Div 15	788	20.2	11	11	0	0	0	3:10	6:04	1,807	0	
Div 15	794	26.0	12	4	2	5	1	2:50	17:16	4,569	2	Sylmar Station & Terminal 28.
Division 15 Vehicle Totals			221	115	63	34	9			121,766		
Division 15 Percentages				52%	29%	15%	4%					

Weekday Metro Bus Mileage Summary by Division
June 26, 2016

				Weekday Bus Mileage Totals								
Div.	Line	One-Way Trip Mi.	Total Blocks	<150	> 150 <200	> 200 <250	<250 and UP	Shortest Run Time	Longest Run Time	Weekday Ridership	Off-Street Terminals	Comments
Div 18	40	20.9	25	17	7	1	0	2:17	20:14	17,671	1	Jackson Street Terminal
Div 18	111	21.1	23	9	9	5	0	2:25	21:40	16,818	2	LAX City Bus Terminal & Norwalk Green Line Station
Div 18	115	22.2	29	20	6	3	0	1:58	19:33	15,628	1	Norwalk Green Line Station
Div 18	117	18.4	13	7	5	1	0	8:42	19:10	8,533	1	LAX City Bus Terminal
Div 18	120	29.7	9	4	2	3	0	6:35	20:51	4,181	1	LAX Aviation / LAX Station
Div 18	126	12.2	2	2	0	0	0	3:48	5:05	204	0	
Div 18	127	10.3	3	1	2	0	0	1:12	14:30	938	2	MLK Compton Transit Ctr & Downey Transit Center
Div 18	202	18.3	3	3	0	0	0	3:16	4:50	245	1	Rosa Parks-Wilmington Station
Div 18	204	12.6	10	9	1	0	0	2:57	18:15	22,173	0	
Div 18	207	14.2	8	8	0	0	0	2:22	15:12	18,048	0	
Div 18	210	19.5	17	7	7	3	0	2:46	22:07	13,104	1	South Bay Transit Center
Div 18	211	14.5	5	5	0	0	0	0:52	5:25	770	2	Marine Green Line Station, South Bay Transit Center
Div 18	246	15.1	9	5	1	1	2	1:42	21:47	2,601	1	Harbor Gateway Transit Center
Div 18	344	19.4	5	4	1	0	0	1:42	13:18	1,709	1	Harbor Gateway Transit Center
Div 18	442	17.1	3	3	0	0	0	2:02	5:44	233	1	Jackson Street Terminal
Div 18	550	23.5	5	3	0	1	1	4:32	18:21	1,546	0	
Div 18	710	15.9	16	10	6	0	0	1:47	15:54	7,285	2	South Bay Transit Center / 6th & Oxford
Div 18	754	12.5	8	8	0	0	0	2:32	13:10	20,575	0	
Div 18	910	38.9	7	4	0	0	3	2:23	15:16	16,355	2/3	El Monte Sta, Harbor Gateway Sta (2 of 3 terminals)
Division 18 Vehicle Totals			200	129	47	18	6			168,617		
Division 18 Percentages				65%	24%	9%	3%					
System Vehicle Totals			**1908**	**1350**	**390**	**146**	**27**			**1,336,780**		
System Percentages				**71%**	**20%**	**8%**	**1%**					

ATTACHMENT H

ELIGIBLE FEDERAL FUNDING SOURCES FOR THE PROCUREMENT OF ZERO-EMISSION BUSES

PROGRAM	ELIGIBILITY REQUIREMENTS	AGENCY/TYPE
Section 5307 Urbanized Area Formula Grants[1]	Buses to be procured must have a nexus with the large urbanized areas (UZA, as defined by the US Census) within Los Angeles County to which the funds are apportioned or allocated, as applicable.	FTA/Formula
Section 5309 Capital Investment Grants[1]	Buses to be procured must be included as part of the initial acquisition of rolling stock for a New Starts/Small Starts bus rapid transit (BRT) system or associated with Core Capacity BRT corridor improvements that increase capacity by not less than 10%. The procurement of buses only, and of buses to be assigned to routes operating on high occupancy vehicle lanes or on high occupancy toll lanes, is an ineligible expense.	FTA/Competitive
Section 5310 Enhanced Mobility of Seniors & Individuals with Disabilities Formula Grants	Buses to be procured must be used to assist with meeting the transportation needs of the elderly and persons with disabilities who travel to/from or within the UZA within Los Angeles County to which the funds are apportioned or allocated, as applicable.	FTA/Formula
Section 5311 Rural Areas Formula Grants	Buses to be procured must be used to support public transportation in rural areas in Los Angeles County with populations less than 50,000.	FTA/Formula
Section 5337 State of Good Repair Grants[1]	Buses to be procured must be for replacements that either operate on existing BRT systems or are used for providing transit service on high occupancy vehicle lanes. Buses to be procured solely for expansion are not eligible.	FTA/Formula
Section 5339 Buses and Bus Facilities Formula Grants	Buses to be procured must have a nexus with the large urbanized areas (UZA, as defined by the US Census) within Los Angeles County to which the funds are apportioned or allocated. Acquisition of buses for fleet replacement and expansion are eligible.	FTA/Formula

ELIGIBLE FEDERAL FUNDING SOURCES FOR THE PROCUREMENT OF ZERO-EMISSION BUSES

PROGRAM	ELIGIBILITY REQUIREMENTS	AGENCY/TYPE
Section 5339 Buses and Bus Facilities Competitive Grants	Acquisition of buses for fleet replacement and expansion are eligible.	FTA/Competitive
Section 5339 Low or No Emission Grants	Acquisition of buses for fleet replacement and expansion are eligible.	FTA/Competitive
Section 149 Congestion Mitigation and Air Quality Improvement [1]	CMAQ funds "transferred" from the Federal Highway Administration (FHWA) to FTA may be used for the procurement of zero-emission buses due to their air quality benefit.	FHWA/Formula
Section 133 Surface Transportation Block Grant[1]	STP funds "transferred" from FHWA to FTA may be used for the procurement of zero-emission buses for improving the conditions and performance of surface transportation.	FHWA/Formula
Transportation Investment Generating Economic Recovery Grant	TIGER funds may be used for the procurement of zero-emission buses if included as part of the scope of work of a BRT project that promises significant economic and environmental benefits to an entire metropolitan area or region.	USDOT/Competitive
Vehicle Technologies Multi-Topic	Requires community-based partnerships among state and local governments and the private sector to accelerate the use of commercially available electric drive and alternative fuel vehicles, including zero-emission buses.	US Department of Energy/Competitive

1. Funding source is currently programmed by Metro for other competing uses.

ELIGIBLE STATE AND LOCAL FUNDING SOURCES FOR THE PROCUREMENT OF ZERO-EMISSION BUSES

PROGRAM	ELIGIBILITY REQUIREMENTS	AGENCY/TYPE
Zero-Emission Truck and Bus Pilot Commercial Deployment	Buses to be procured must provide benefits to disadvantaged communities by operating on routes located within, or directly benefitting, these communities. Buses must meet applicable certification requirements of the California Air Resources Board (CARB).	CARB/Competitive
Hybrid and Zero-Emission Truck and Bus Voucher Incentive	Buses to be procured must be located in a disadvantaged community. The voucher amount depends on the gross vehicle weight rating of the buses. The amount per voucher for a zero-emission bus is currently $110,000 for maximum of 100 buses and $45,000 for each additional bus (up to a maximum of 200 vouchers per fleet). Buses must demonstrate a thirty-five mile all-electric range. If the bus is fast charge compatible, then it must demonstrate a twenty mile all-electric range. Buses must be CARB-certified.	CARB/First-come, First-served
Transit and Intercity Rail Capital	Buses to be procured must provide a direct, meaningful, and assured benefit within and/or to disadvantaged communities.	California State Transportation Agency/Competitive
Low Carbon Transit Operations	Buses to be procured must be used to support new or expanded service. At least 50% of the total funds an agency receives must be expended on projects that will benefit disadvantaged communities.	California Department of Transportation/ Formula
Affordable Housing and Sustainable Communities	Buses to be procured must benefit disadvantaged communities in transit oriented development or integrated community project areas. Requires 50% of available funds to be invested in projects that benefit disadvantaged communities.	Strategic Growth Council/Competitive
Carl Moyer Memorial Air Quality Standards Attainment	The procurement of buses must not be to comply with any regulation, memorandum of understanding, or other legal mandate. The maximum grant amounts for the procurement of each bus for fleet expansion or for replacement are currently limited to 25% of the cost and $60,000, respectively.	South Coast Air Quality Management District/Competitive

ELIGIBLE STATE AND LOCAL FUNDING SOURCES FOR THE PROCUREMENT OF ZERO-EMISSION BUSES

SOURCE	ELIGIBILITY REQUIREMENTS	AGENCY/TYPE
Local Transportation Fund/Transportation Development Act[1]	Acquisition of buses for fleet replacement and expansion are eligible expenses only under TDA Article 4 and must comply with regional transportation plans.	State Board of Equalization/Formula
State Transit Assistance Fund/ Transportation Development Act[1]	Acquisition of buses for fleet replacement and expansion are eligible expenses and must comply with regional transportation plans.	State Controller's Office/Formula
Public Transportation Account[1]	Acquisition of buses for fleet replacement and expansion are eligible expenses funded through the State Transportation Improvement Program.	Caltrans/Formula
General Revenues[1]	Metro revenue from fares, advertisement, lease and other general revenue sources may be used for fleet replacement and expansion.	Metro/Discretionary
Proposition A	Acquisition of buses for fleet replacement and expansion are eligible expenses from the 40% funding allocation category.	Metro/Formula
Proposition C	Acquisition of buses for fleet replacement and expansion are eligible expenses from the 40% funding allocation category.	Metro/Discretionary
Measure R[2]	Acquisition of buses for fleet replacement and expansion are eligible expenses from the 35% funding allocation category.	Metro/Discretionary

1. Funding source is currently programmed by Metro for other competing uses.
2. In June 2013 the Metro Board of Directors approved establishing a life-of-project budget of $30 M for zero-emission buses.