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

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REVISED
REGULAR BOARD MEETING
MAY 25, 2017

SUBJECT: BIOMETHANE PROVIDER

ACTION: AWARD BIOMETHANE SUPPLIER CONTRACT

RECOMMENDATION

AUTHORIZE the Chief Executive Officer to:

A. AWARD five (5) year, Indefinite Delivery/Indefinite Quantity Contract No. OP7396000 for a **Biomethane Gas Provider to Clean Energy Renewables**, the lowest responsive and responsible bidder for a not-to-exceed amount of $1,240,520 for the base year (for one bus division as a pilot) and a not-to-exceed amount of $54,808,110 for a four (4) year option, for a total contract amount of $56,048,630 (for all bus divisions if the pilot is successful), subject to resolution of protest(s), if any; and

B. EXECUTE individual Task Orders (Transaction Confirmations) and changes within the Board approved contract amount.

ISSUE

Metro became the largest compressed natural gas bus fleet in the nation after retiring its last diesel bus in 2011. However, the transit industry is already looking ahead to new technologies and cleaner fuel sources that offer improved efficiency and environmental benefits. Metro's long-term plan to achieve California's ambitious air quality and greenhouse gas (GHG) goals is to explore and procure for Zero Emission Buses (ZEBs). The recent ZEB procurement and testing continue to be used by our agency to gain first-hand experience through the rapidly growing space of electric vehicle and battery technology. While this occurs, our agency's immediate term strategy includes the use of Low ~~Nitrous~~ Nitrogen Oxides (NOx) "Near Zero" CNG engines and procuring for renewable natural gas (i.e., biomethane). Based on our modeling efforts, this short-term strategy yields significant regional air quality benefits and greenhouse gas emissions reductions in a timely and cost-effective manner.

DISCUSSION

Biomethane is natural gas derived from landfills, dairies, and wastewater treatment plants rather than being extracted or mined from the ground. Therefore, biomethane has a much lower carbon intensity

(CI) when compared to traditional forms of natural gas (i.e., “fossil natural gas”). The CI of a fuel is a measure of its GHG emissions over the lifecycle of that fuel’s production, including extraction, refinement, transportation, and consumption. Regardless of extraction or production, natural gas is already considered a lower carbon fuel than diesel or gasoline. Alternative sourcing, such as those associated with biomethane, reduce natural gas’ carbon intensity with improved greenhouse gas benefits.

In June 2013, the Board adopted the Biomethane Implementation Plan (Attachment C). This is staff’s comprehensive analysis of the technical, environmental, and financial merits of transitioning to a renewable source of natural gas for Metro’s bus fleet. In May 2014, the Board approved a staff recommendation to pursue Pathway 2 of the Biomethane Implementation Plan whereby Metro would contract with an energy provider as a means of achieving a transition to biomethane. In the same report, staff demonstrated that the use of biomethane in our CNG buses would not need any new fueling infrastructure or fleet retrofits.

As a fuel, biomethane will be delivered in the same quality and grade for immediate use by our fleet. Biomethane suppliers will deliver the fuel to Metro bus divisions using existing natural gas pipelines. Metro’s current natural gas provider, Southern California Gas Company (Gas Company) allows for Core Aggregation Transportation (CAT) services whereby Core Transport Agents (CTAs) provide procurement services to Gas Company Customers such as Metro. In this arrangement, CTAs are responsible for balancing natural gas delivery and quality meeting stringent California Public Utilities Commission (CPUC) guidelines. Many transit agencies are already using biomethane under this or similar models including Santa Monica’s Big Blue Bus (BBB), Orange County Transportation Authority (OCTA), San Diego Metropolitan Transportation System (MTS), and Torrance Transit.

Transitioning to biomethane provides enormous GHG emissions reduction benefits for Metro’s bus emissions and overall carbon footprint. Reducing greenhouse gas emissions is not only an important goal for Metro but a substantial component of California’s climate change policies. Pending ZEB rules from the California Air Resources Board (CARB) will mandate a shift in bus technology in coming years. The attached report (Attachment D) from Ramboll/Environ outlines different fleet technology options for Metro including high-level cost assessments and emissions impacts for electric buses, fuel cell buses, and Low NOx CNG with biomethane. Highlights of the report particularly relevant to this document include:

- Low NOx CNG engines fueled with biomethane reduces fleet emissions by two-thirds when compared to the current baseline over the next 40 years; and
- Compared with the Electric Buses scenarios, Low NOx CNG with biomethane achieves approximately 39% greater reductions in GHG emissions at half the cost.

In addition to improving the agency’s sustainability performance, a biomethane short-term strategy is an excellent example of exercising fiscal discipline in the area of energy supply. According to Metro’s

2016 Energy and Resource Report, the agency spends over $22M each year on natural gas for its bus fleet. While this expense is susceptible to price volatility outside of the agency's control, there are measures Metro can take in order to reduce risk and manage future costs. One such measure is to procure for a long-term supply contract for natural gas under The Gas Company's CAT service. Under such a contract, Metro can secure a competitive rate tied to a natural gas index. Tying natural gas prices to the natural gas index provides rate transparency for Metro's natural gas hedging initiatives.

Finally, Metro's use of biomethane makes our agency eligible for accumulating additional carbon credits under state and federal programs. These credits can be sold in open credit markets. Revenues from these sales have already funded additional cost-saving and value creating projects under our sustainability capital program, providing additional value to our agency.

DETERMINATION OF SAFETY IMPACT

This Board action will not have an adverse impact on safety standards for Metro.

FINANCIAL IMPACT

If Contract no. OP84203485 is awarded, Metro will realize two distinct financial benefits summarized in the table below. It should be noted that these figures utilize current (March 2017) projections for natural gas pricing and consumption, environmental commodity pricing, and credit generation rates.

Case	**Natural Gas Costs**	**Environmental Commodities**
Business-As-Usual (BAU)	$64,325,174	$7,044,474
OP84203485	$56,048,630 (1)	$$29,436,460 (2)
Value Added	*$8,276,544*	*$22,391,985*
	Total Value Added	**$30,668,529**

Notes:

(1) Cost savings for shifting to natural gas index vs. Gas Company average cost of gas pricing

(2) Additional carbon credits available due to shift to less carbon intensive natural gas product

Natural Gas Cost Savings

Moving away from The Gas Company's procurement services affords a number of financial benefits to Metro. In addition to securing a competitive rate, Metro requires under the new award that the price the agency pays for natural gas is tied to a natural gas index rather than The Gas Company's average cost of gas. Further, this move provides for additional savings and transparency for Metro's natural gas hedging program. In total, Metro is projected to realize over $8M in reduced costs for natural gas over the term of the contract.

Optimized Environmental Commodities

Under CARB's Low Carbon Fuel Standard (LCFS) program, Metro is currently generating credits through the dispensing of natural gas for bus fueling and use of electricity for light and heavy rail propulsion. Natural gas that comes from renewable sources have substantially lower CI value compared to fossil natural gas, and our use of biomethane provides us with the opportunity to get many more credits than those from fossil natural gas use. Our agency will get a competitive share of these credits for our part in the transaction as a transportation fuel end-user. Additional credits will also be generated under the federal Renewable Fuel Standard (RFS) program. In total, these credits have been valued at over $29M over the term of the contract, if awarded.

These environmental commodities can be sold in respective credit markets. Our agency has been participating in the LCFS credit market since 2014, selling over 290,000 credits bringing in nearly $28M in revenue used in value-creating and cost-saving projects. Part of our optimization plan for these credits is a key performance indicator (KPI) to monitor the success of the carbon credits program:

Key Performance Indicator	**Metric**	**Current Performance**	**Goal**
Portfolio-wide average	$/credits sold	$96.54	Above Market Average ($81)

The FY17 adopted budget includes $19,329,625 for the purchase of compressed natural gas under Project 306002 Bus Operations Maintenance, cost center 3365, and Account 50402 Fuel CNG - Revenue Equipment. Since this is a multi-year contract, the Project Manager and Cost Center Manager will be responsible for budgeting in future fiscal years. Upon approval of Recommendation A, future gas costs will be budgeted against this project. Anticipated natural gas cost savings of $8,276,544 are based on the natural gas index pricing at the time of bid.

Impact to Budget

Metro will realize a reduction in annual natural gas costs over the duration of this Contract. Based on index projections, these savings will total over $8M over the term of the Contract. Further, Metro will generate additional environmental commodities valued at over $22M over the term of the contract. Together, the execution of Contract No. OP84203485 will add over $30M in value for our agency.

This contract will be funded by project number 306002 - Bus Operations, which is funded by Operations eligible sources such as Prop C40%, Measure R 20%, TDA 4, STA and other local sources. No other funding sources were considered.

ALTERNATIVES CONSIDERED

If Contract No. OP84203485 is not awarded, Metro will continue to receive natural gas procurement services from The Gas Company. As a result, Metro will not have the opportunity to get a competitive rate for natural gas nor choose the source of its natural gas until The Gas Company offers their own biomethane service. We do not anticipate The Gas Company to offer a biomethane service any time soon. If not awarded, we will also not realize the short-term greenhouse gas gains we anticipate from a Low NOx and biomethane strategy. This is key to our continued clean air success during a possible transition towards a zero emissions fleet.

NEXT STEPS

After the recommended Board Action is approved, staff will execute the contract and commence biomethane delivery at one bus division. Staff will evaluate the performance of the contract over the next year and determine whether to exercise the four-year option.

ATTACHMENTS

Attachment A - Procurement Summary
Attachment B - DEOD Summary
Attachment C - Biomethane Implementation Plan April 2013
Attachment D - Ramboll Environ Report September 29, 2016

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Chief Executive Officer

PROCUREMENT SUMMARY

BIOMETHANE PROVIDER / OP7396000

1.	**Contract Number**: OP7396000	
2.	**Recommended Vendor(s)**: Clean Energy Renewables	
3.	**Type of Procurement (check one):** ☒ IFB ☐ RFP ☐ RFP–A&E ☐ Non-Competitive ☐ Modification ☐ Task Order	
4.	**Procurement Dates**:	
	A. Issued: 5/13/15	
	B. Advertised/Publicized: 5/11/15	
	C. Pre-proposal/Pre-Bid Conference: 5/20/15	
	D. Proposals/Bids Due: 2/13/17	
	E. Pre-Qualification Completed: 3/15/17	
	F. Conflict of Interest Form Submitted to Ethics: 2/17/1 7	
	G. Protest Period End Date: 4/21/17	
5.	**Solicitations Picked up/Downloaded**: 24	**Bids/Proposals Received**: 2
6.	**Contract Administrator**: Nathan Jones III	**Telephone Number**: (213) 922-6101
7.	**Project Manager**: Evan Rosenberg	**Telephone Number**: (213) 922-7326

A. Procurement Background

This Board Action is to approve a Contract No. OP739600 for the procurement of a Biomethane Provider of Renewable Natural Gas (RNG) to support Metro's bus fleet.

IFB No. OP84203485 was issued in accordance with Metro's Acquisition Policy and the contract type is a Fixed Unit Price, Indefinite Delivery, Indefinite Quantity (IDIQ).

Eight amendments were issued during the solicitation phase of this IFB:

- Amendment No. 1, issued on May 19, 2015, to revise the Instructions to Bidders, Insurance Requirements, Pre-Qualification Application, and the Required Certifications;
- Amendment No. 2, issued on May 27, 2015, to revise the Statement of Work;
- Amendment No. 3, issued on December 18, 2015, to revise the bid due date;
- Amendment No. 4, issued on January 7, 2016, to revise Exhibit C, Bid Form, Schedule of Quantities and Prices;
- Amendment No. 5, issued on February 3, 2016, to change the bid due date;
- Amendment No. 6, issued on January 4, 2017, to revise the Contract, Bid Forms, and the bid due date;
- Amendment No. 7, issued on January 4, 2017, to revise the due date for Bidders' comments and questions; and
- Amendment No. 8, issued on January 27, 2017, to revise the due date for Metro's formal responses to Bidders' questions, Bid Forms and revise the bid due date.

The Two Step Seal Bid process, as defined in Metro's Acquisition Policy, was used for this acquisition. Step 1 required potential bidders to submit a technical proposal for Metro to evaluate and to make a determination on whether the bidder was technically qualified. In response to Step 1, Metro received three formal technical proposals, and Metro evaluated each technical proposal and made individual final determinations that each bidder was technically qualified to furnish RNG. A formal notification was issued to each bidder advising them that they were deemed technically qualified and were invited to participate in Step 2 by submitting a formal bid price.

Prior to the public bid opening due date, Metro received a formal letter from one of the technically qualified bidders advising Metro that it had elected to No Bid. A total of two bids were received on the bid due date, February 13, 2017. One of the bids was rejected for material changes to the IFB requirements.

B. Evaluation of Bids

The firm recommended for award is Clean Energy Renewables (Clean Energy) which was found to be in full compliance with the IFB requirements.

Bidder Name	Base	Option	Total Contract Price
Clean Energy	$1,240,520.00	$54,808,110.00	$56,048,630.00

The Base period is for one year and to cover supplying RNG for all buses at one Metro bus division. The Option is for four years to supply RNG for all buses at all Metro bus divisions.

C. Price Analysis

The recommended total bid price was determined to be fair and reasonable based upon adequate price competition and selection of the lowest responsive and responsible bidder. There are three components to this price analysis: gas commodity price, environmental commodities value, and total bid price. The IFB required the vendor to supply the total bid price that is the net of the gas commodity price and environmental commodities value. The lowest total bid price gets awarded the contract. The table below provides these information.

While the lowest total bid price is the basis for award, the contract value to be awarded is based on the gas commodity price.

Low Bidder Name	Bid Amount	Metro ICE
Clean Energy	$26,612,169 (1)	$34,414,674

Bid Breakdown	Bid Amount	Metro ICE
Gas Commodity Price	$56,048,630 (2)	$57,008,630
Environmental Commodities Value	$29,436,460	$22,593,956
Total Bid Price	$26,612,169	$34,414,674

Notes:
(1) Basis for award
(2) Contract value

D. Background on Recommended Contractor

The recommended firm, Clean Energy, has over seven years of experience in biomethane industry, including biomethane production, marketing, sales and distribution. Clean Energy is the only company that has built, owns and operates biomethane production facilities and is a registered Energy Service Provider with SoCalGas. Since 2009, Clean Energy has delivered biomethane to customers at customer owned stations as well as Clean-Energy owned public access stations. The firm meets and exceeds Metro's specified IFB minimum technical qualification requirements for supplying biomethane. Some of Clean Energy's customers include Foothill Transit, City of Santa Monica (Big Blue Bus), Sacramento Municipal Utilities District, City of Sacramento, and University of California, San Diego, and Atlas Refuel. Clean Energy has been a Metro supplier of natural gas products and commodities for over 20 years and their services to Metro have been satisfactory.

DEOD SUMMARY

BIOMETHANE PROVIDER / OP7396000

A. Small Business Participation

The Diversity and Economic Opportunity Department (DEOD) did not recommend a Disadvantaged Business Enterprise (DBE) goal for this solicitation, which involves the purchase of a commodity (natural gas), to be delivered via existing pipelines to Metro. DEOD explored subcontracting opportunities and determined that opportunities for subcontracting were not apparent. It is expected that Clean Energy Renewables will perform the scope of work with their own workforce.

B. Living Wage and Service Contract Worker Retention Policy Applicability

The Living Wage and Service Contract Worker Retention Policy is not applicable to this Contract.

C. Prevailing Wage Applicability

Prevailing wage is not applicable to this Contract.

D. Project Labor Agreement/Construction Careers Policy

Project Labor Agreement/Construction Careers Policy is not applicable to this Contract.

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

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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%.

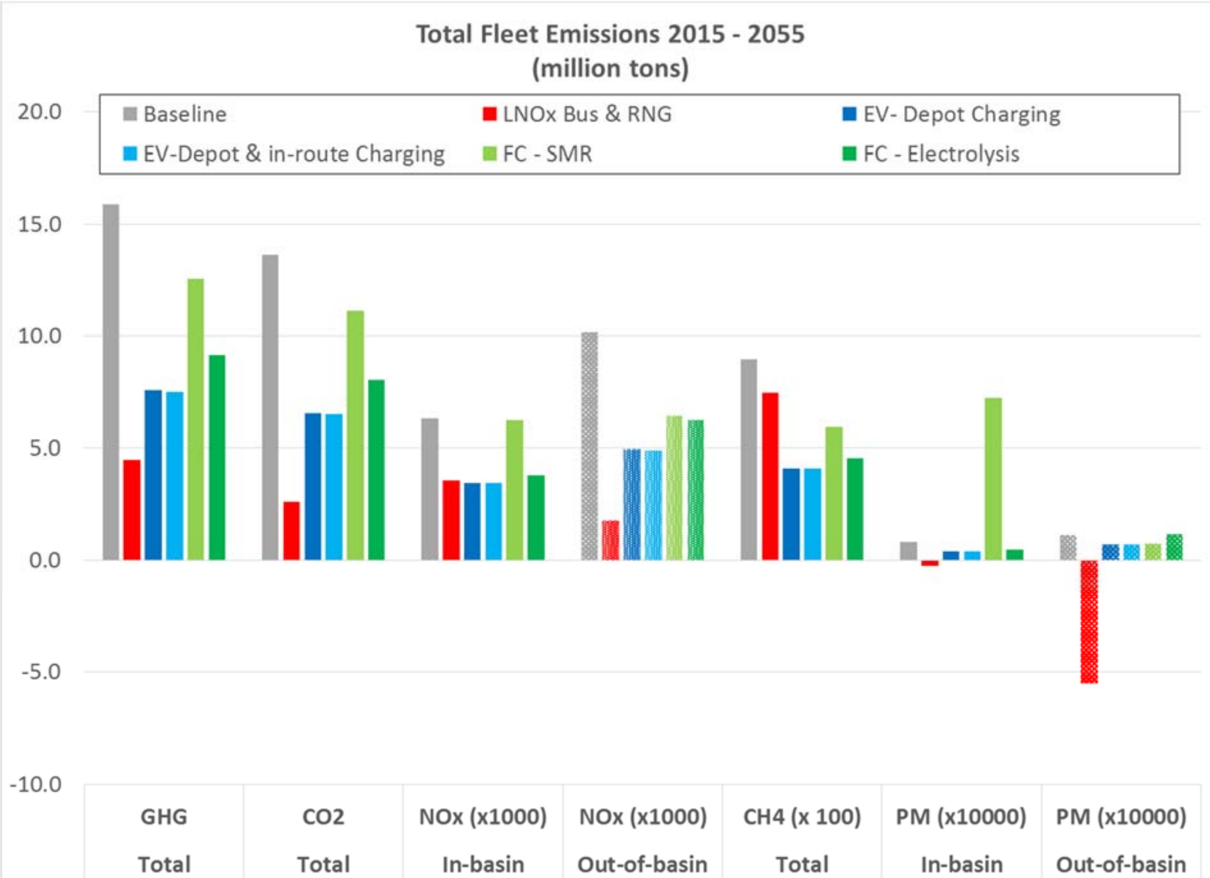
Compared to the baseline the transition to electric buses is projected to reduce NOx emitted within the South Coast Air Basin over the next 40 years by 45% -46%, and to reduce NOx emitted outside of the South Coast Air Basin over the next 40 years by 51% - 52%. It will also reduce PM emitted within the 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)

		LNOx Bus & RNG	Electric Bus: Depot Charging	Electric Bus: Depot & In-route Charging	Fuel Cell Bus: SMR	Fuel Cell Bus: 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.

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[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

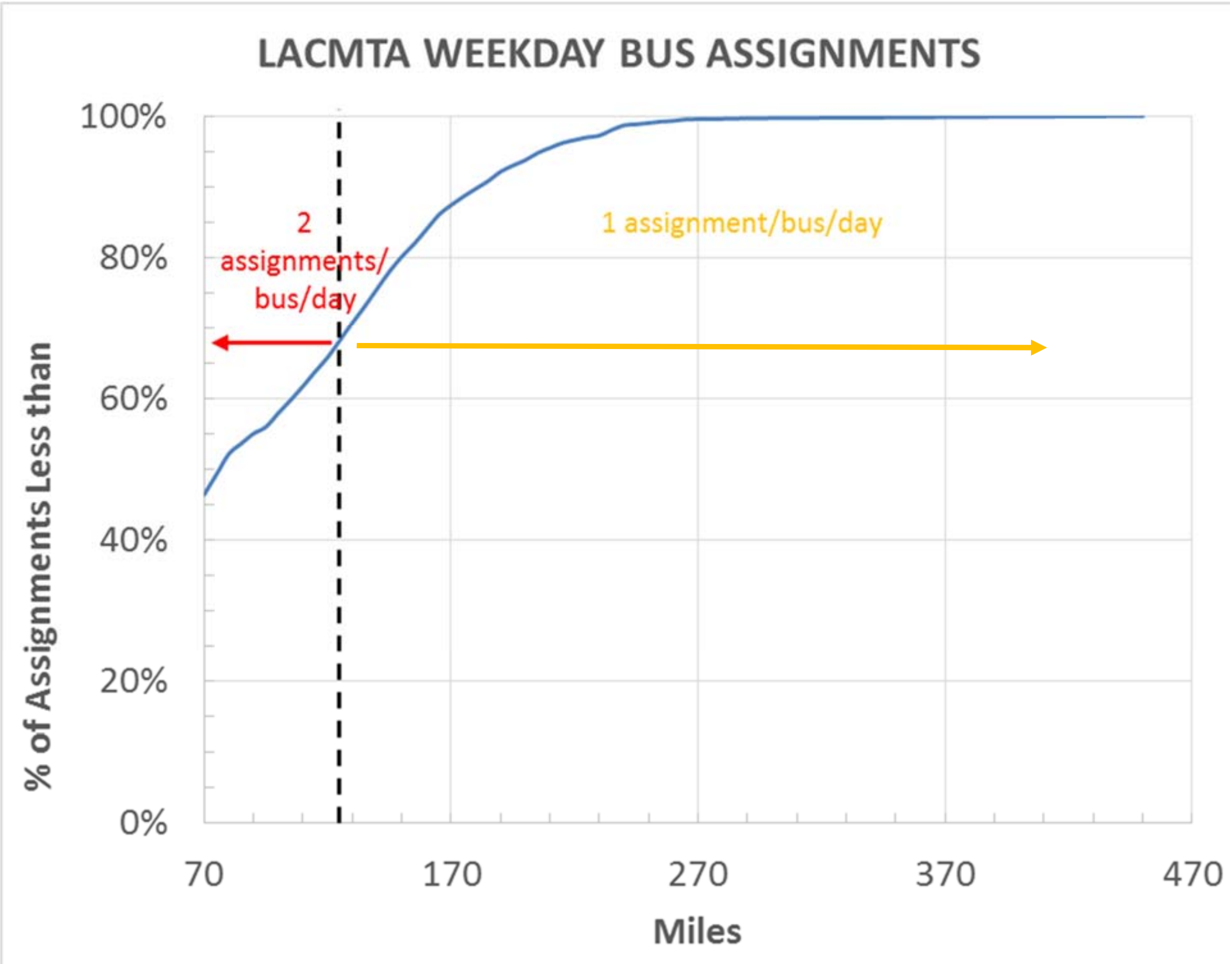
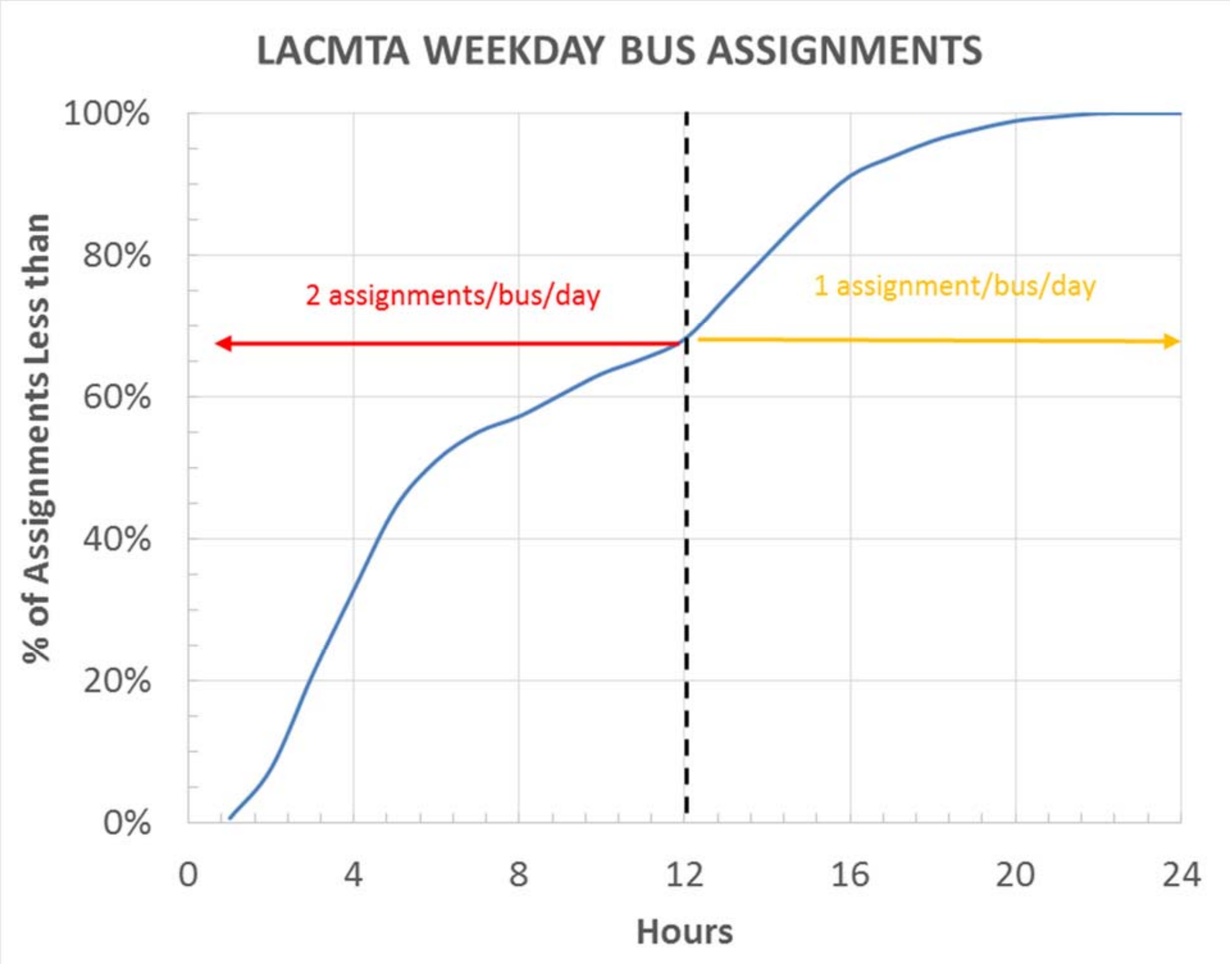


Figure 3. LACMTA Weekday Bus Assignments, Percent versus Accumulated Time in Service



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 0% 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

<table>
<tr><th colspan="3">5I: FUELING INFRASTRUCTURE – FUEL CELL BUSES</th></tr>
<tr><th>Metric</th><th>Data Sources</th><th>Values/Notes</th></tr>
<tr><td>SMR Cost ($/kg/day)</td><td rowspan="2">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</td><td rowspan="2">$5,150/kg/day for stations built 2025 – 2034, and $3,370/day for stations built after 2034. These values represent a 70% and 80% reduction in costs, respectively, compared to recently built hydrogen fuel stations.</td></tr>
<tr><td>Electrolyzer Cost ($/kg/day)</td></tr>
<tr><td>Required Capacity (kg/day)</td><td>MJB&A analysis</td><td>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.</td></tr>
</table>

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)

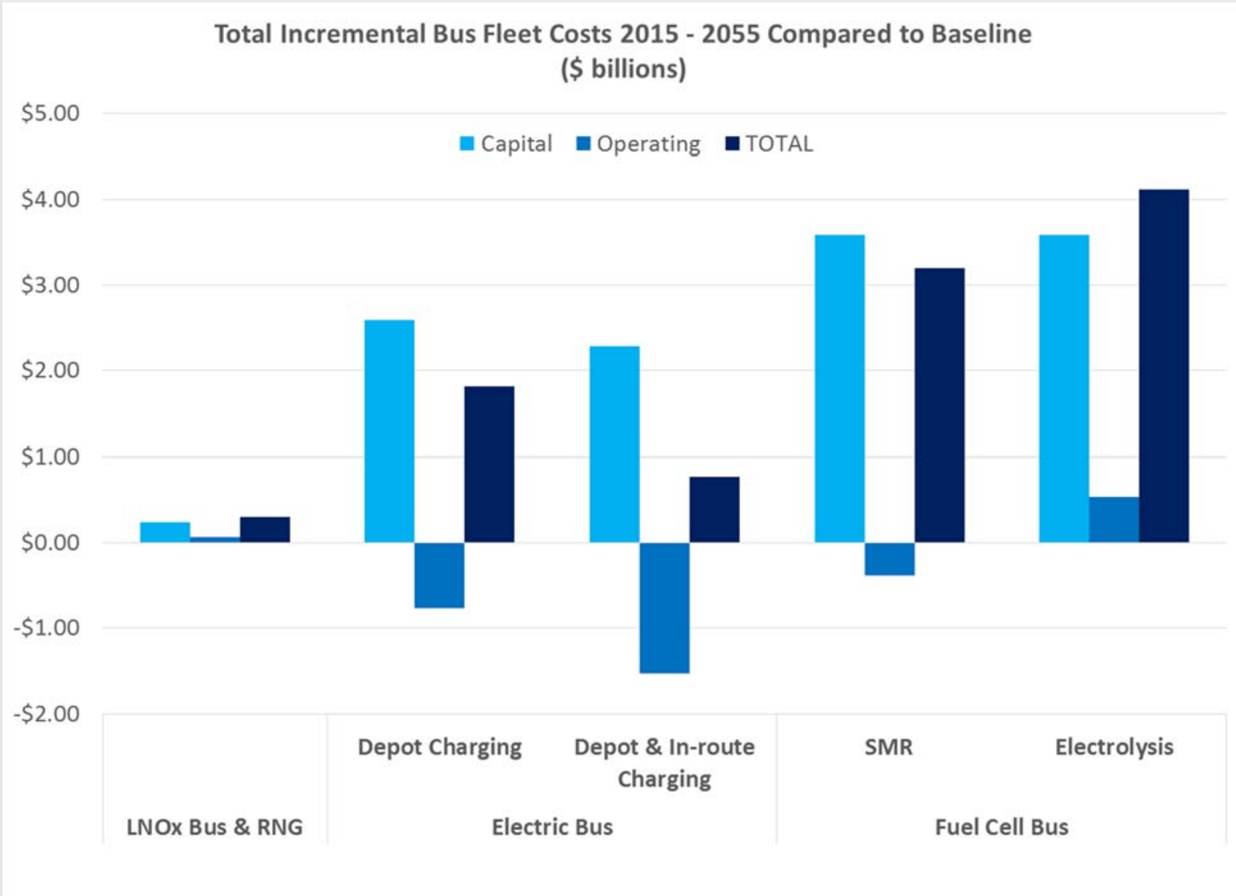
Cost Element		BASELINE	RENEW NG	LOW NOx CNG BUS & REPOWER		ELECTRIC BUS		FUEL CELL BUS	
		Std CNG Bus Conv NG	Std CNG Bus RNG	LNOx Bus Conv NG	LNOx Bus RNG	Depot Charging	Depot & In-Route Charging	H_2 by SMR	H_2 by Electrolysis
Capital	Bus Purchase	$5,177.9	$5,177.9	$5,250.0	$5,250.0	$7,094.2	$6,889.2	$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.

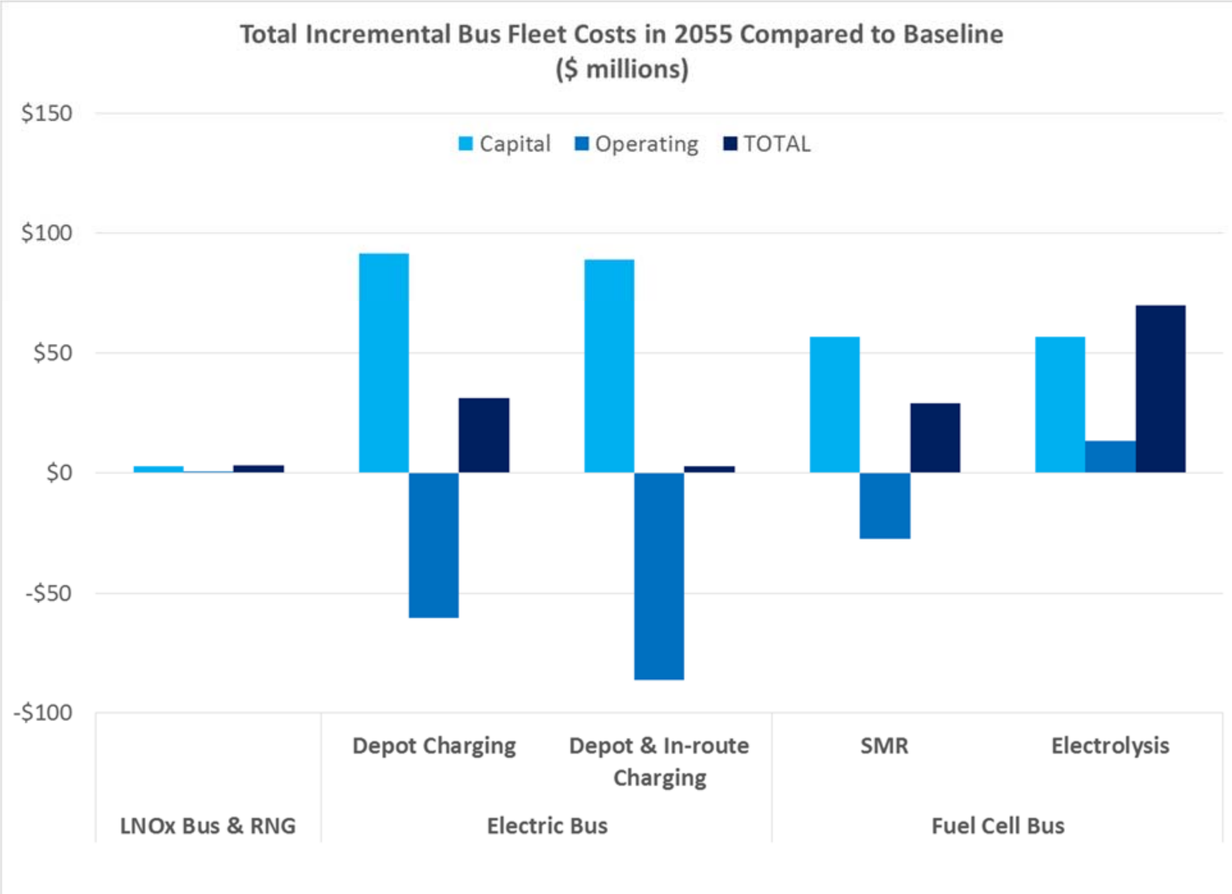
The use of electric buses with depot-only charging is projected to increase on-going annual fleet costs by $31 million, an increase of 2.5% over projected baseline costs. The use of electric buses with depot and in-route charging is projected to increase on-going annual fleet costs by $2.7 million, an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

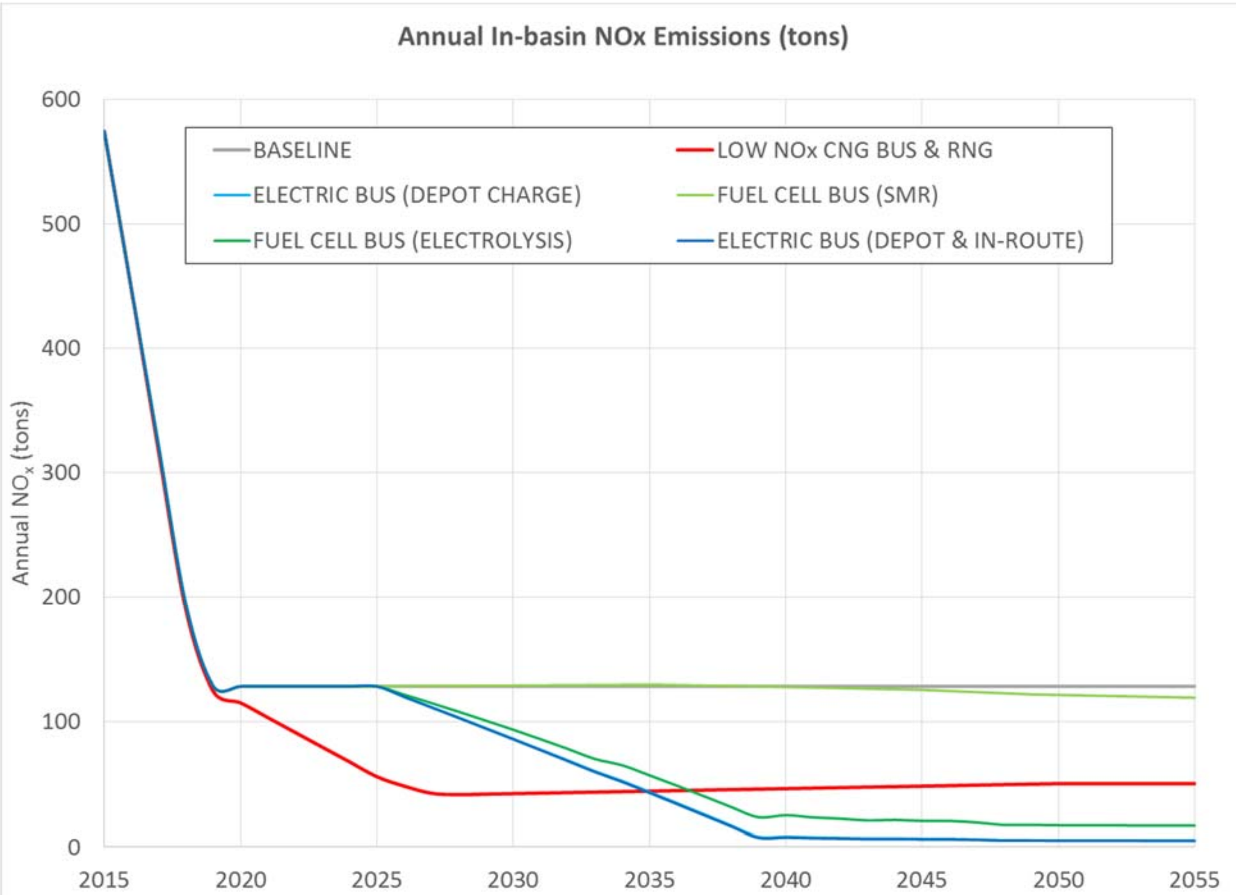


Figure 7. Estimated Annual Fleet Emissions of out-of-basin NOx (tons), 2015 – 2055

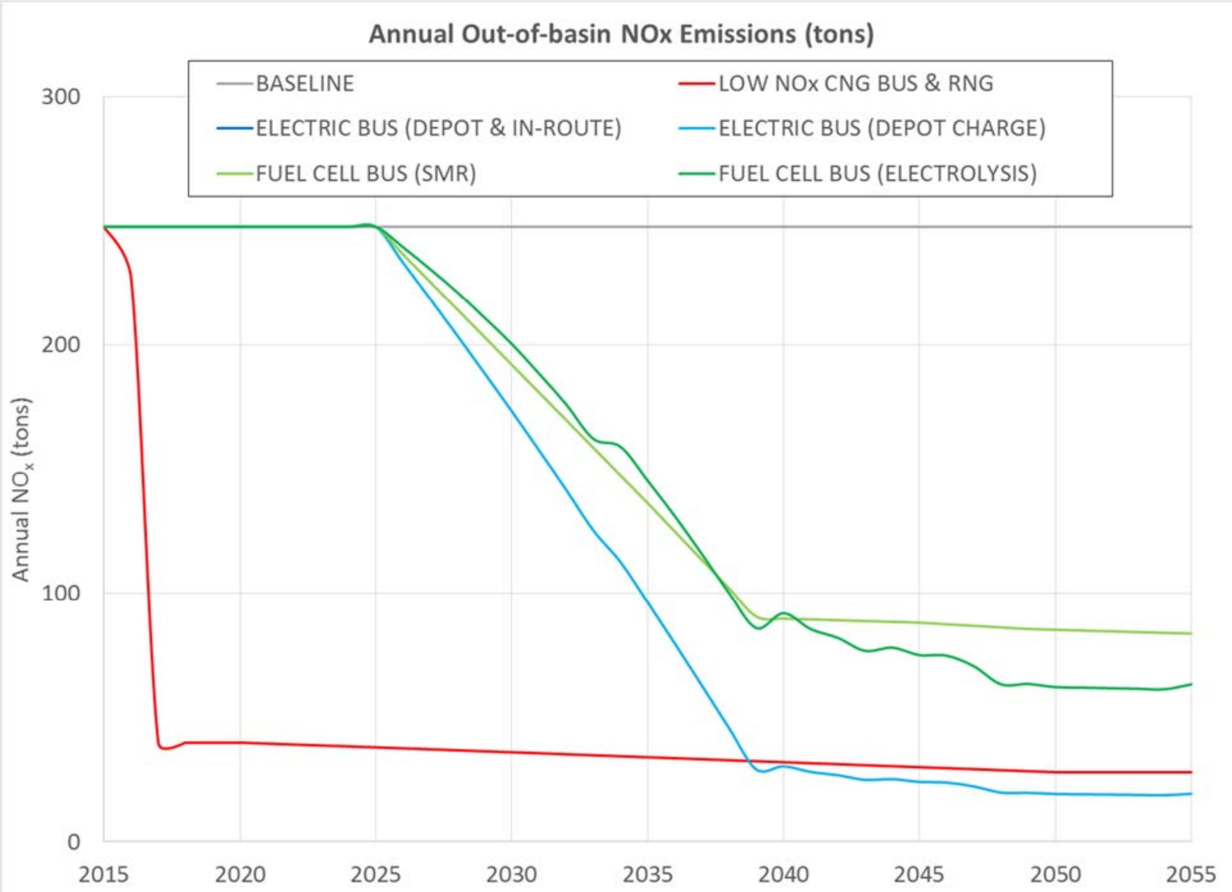


Figure 8. Estimated Annual Fleet Emissions of in-basin PM (tons), 2015 - 2055

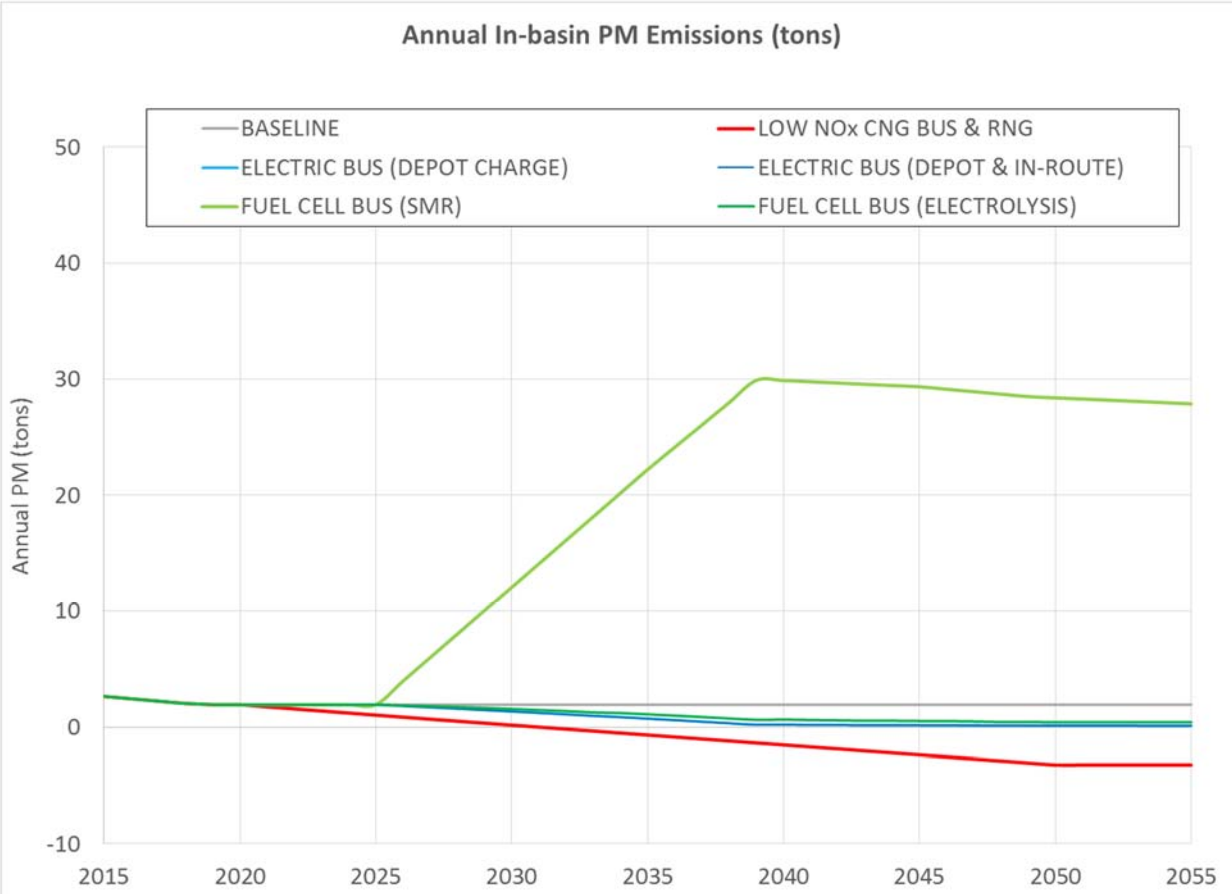


Figure 9. Estimated Annual Fleet Emissions of out-of-basin PM (tons), 2015 - 2055

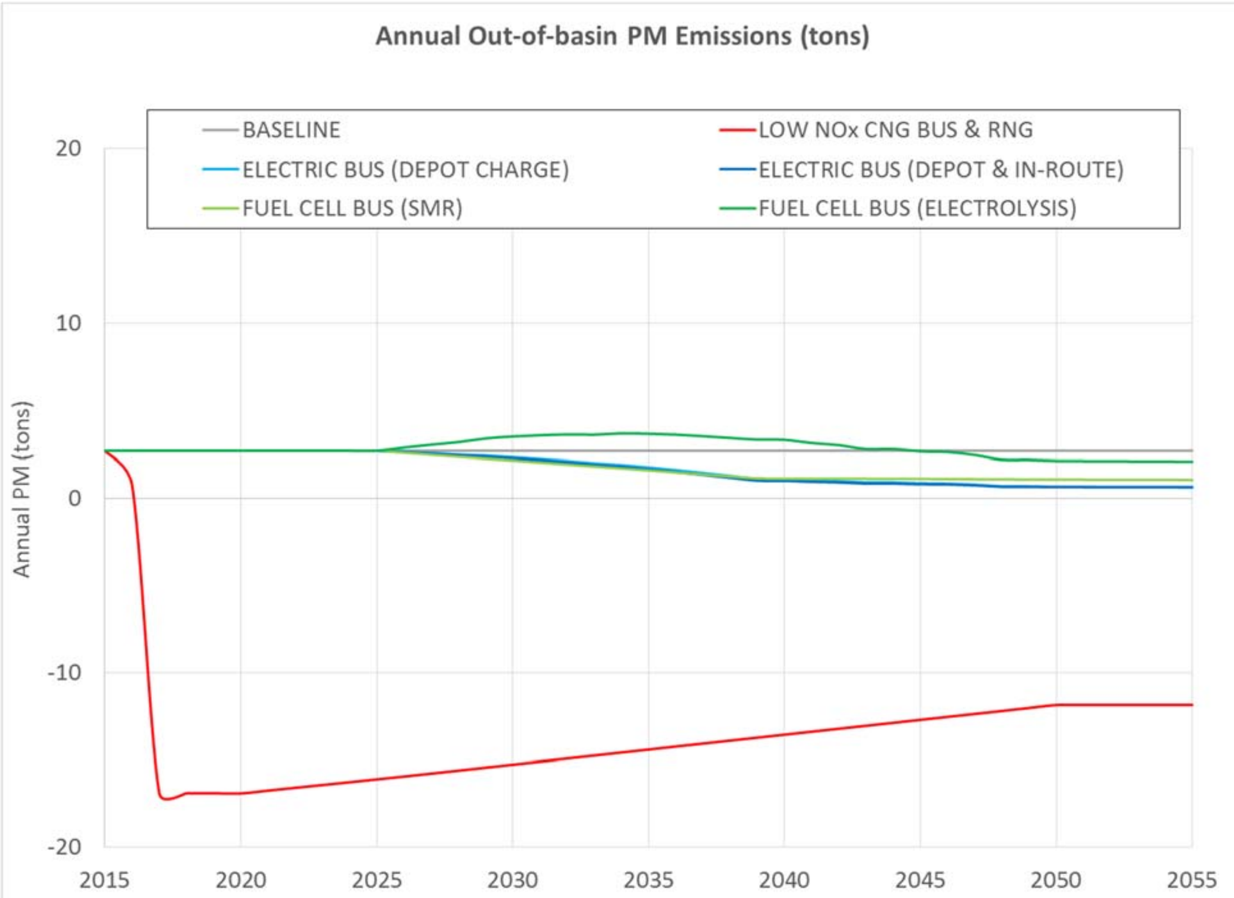


Figure 10. Estimated Annual Fleet Emissions of CH_4 (tons), 2015 - 2055

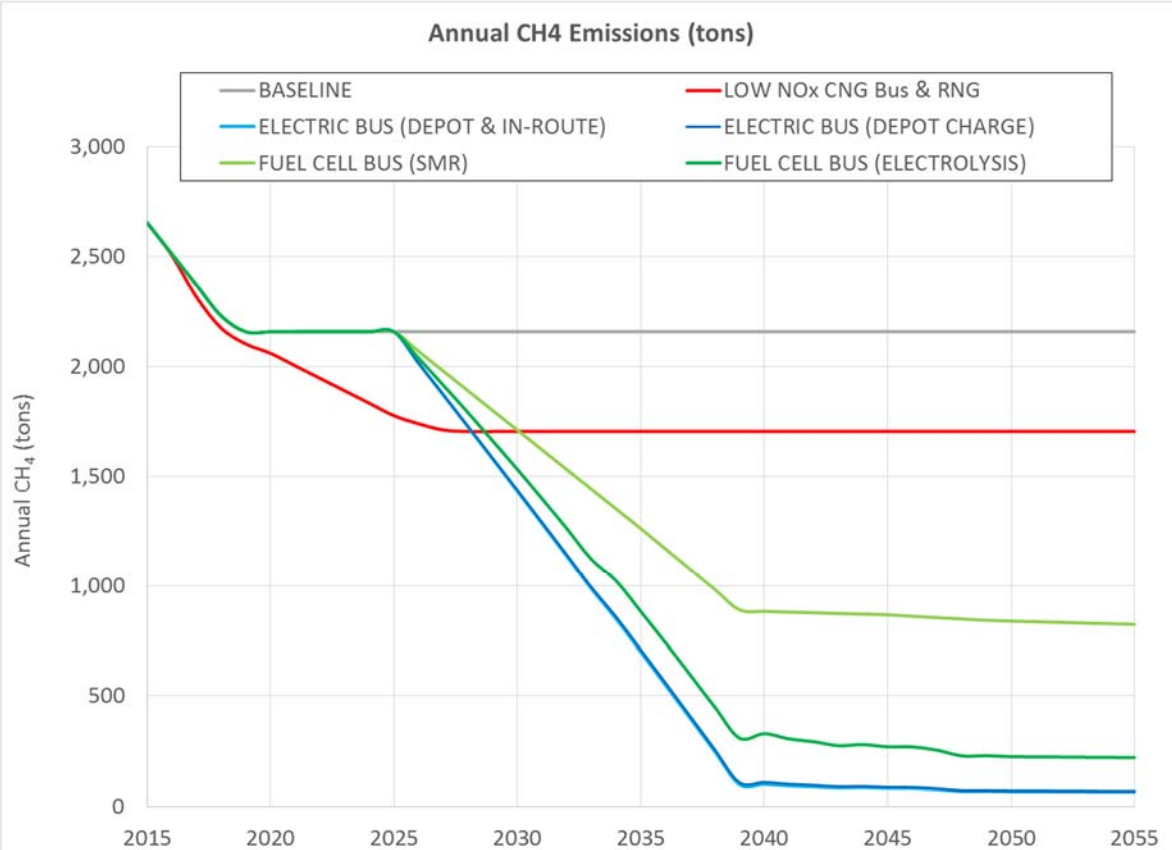


Figure 11. Estimated Annual Fleet Emissions of CO_2 (tons), 2015 - 2055

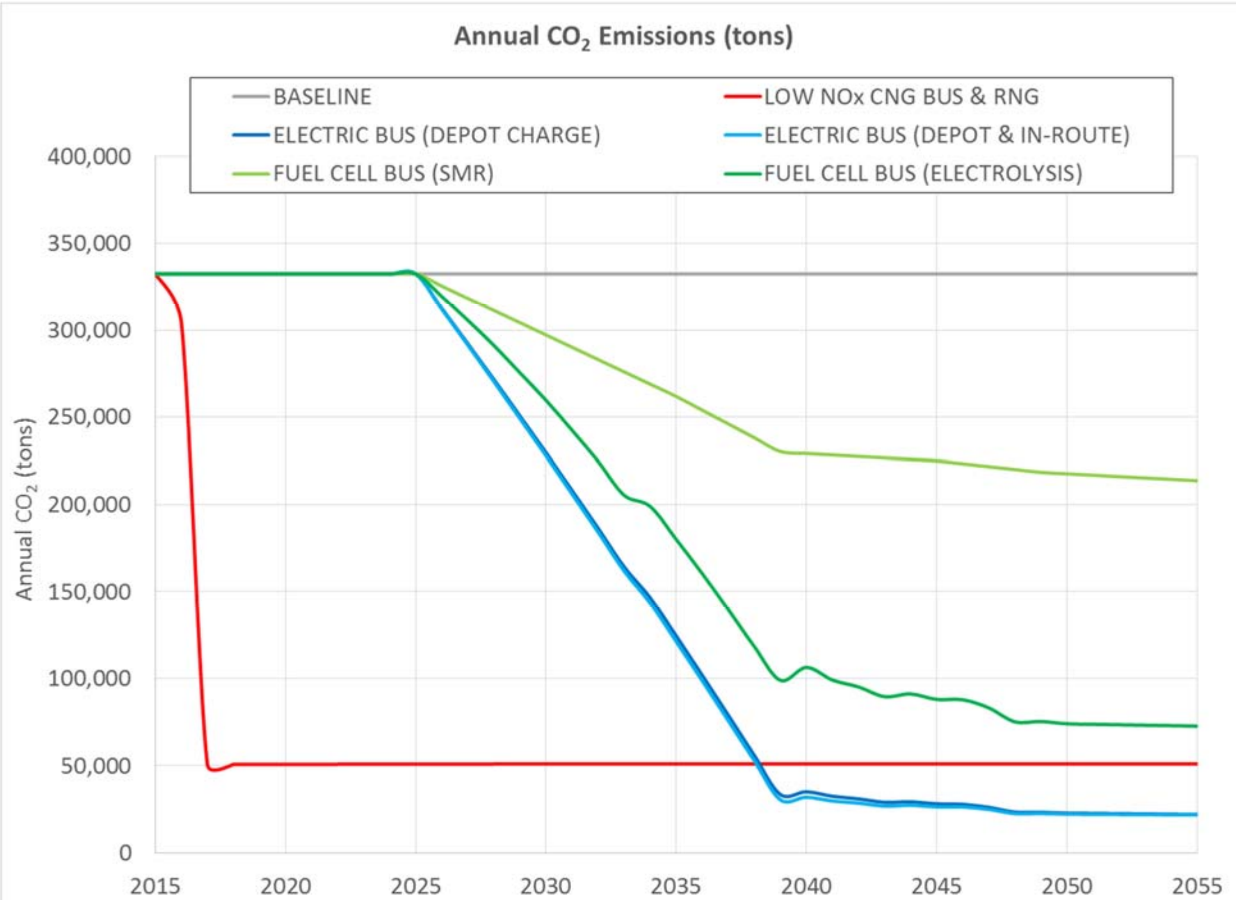
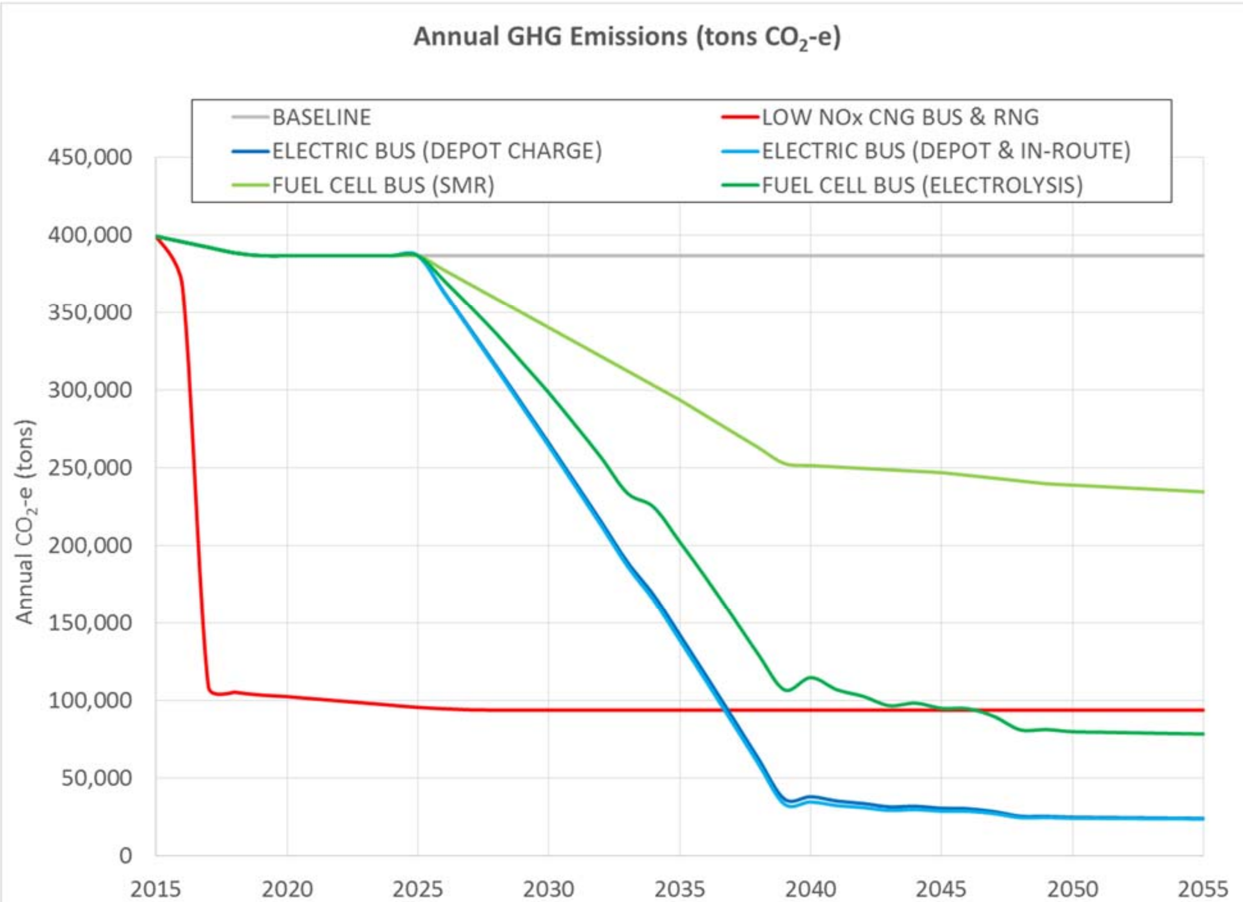


Figure 12. Estimated Annual Fleet Emissions of GHG (tons CO2-e), 2015 - 2055

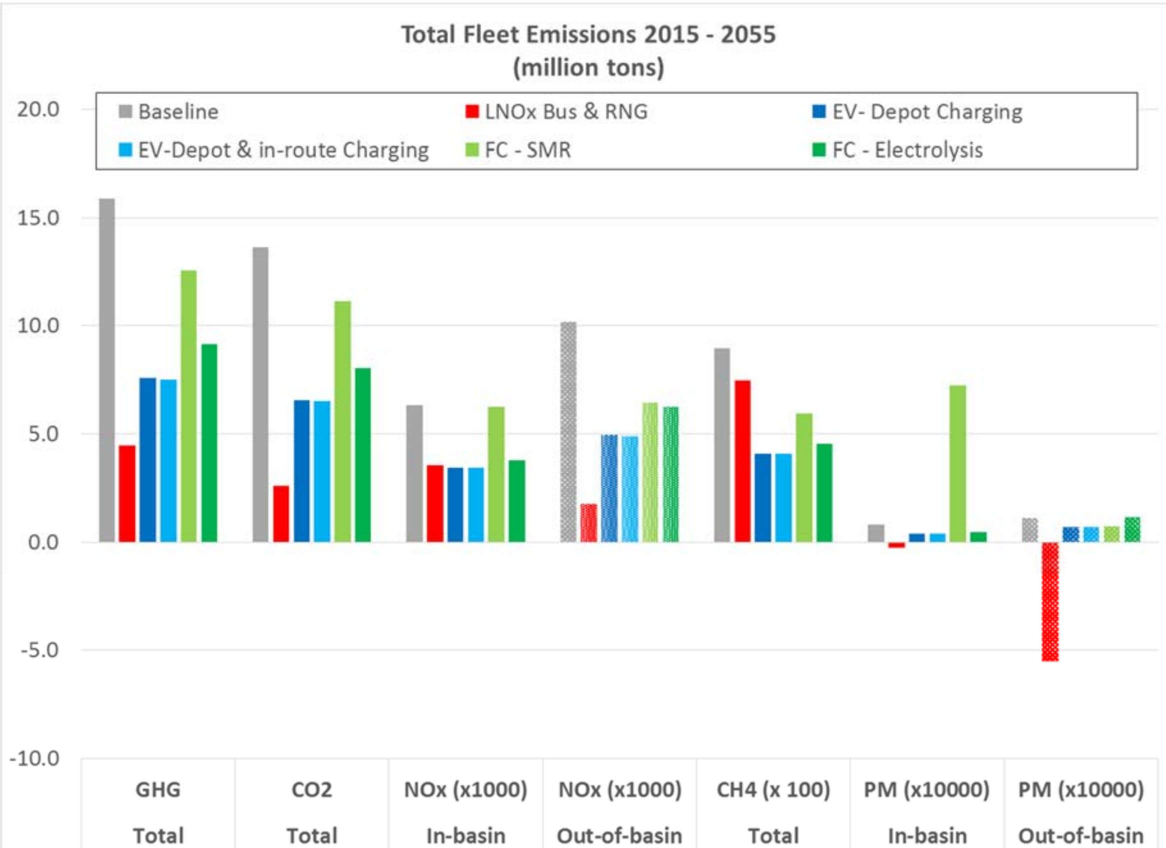


Under the LNOx Bus + RNG scenario annual estimated out-of-basin NOx and PM, CH_4, CO_2 and GHG emissions fall dramatically between 2016 and 2018 compared to the baseline, as the entire existing bus fleet is transitioned to RNG. These reductions are the result of lower upstream emissions from RNG production 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

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[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)

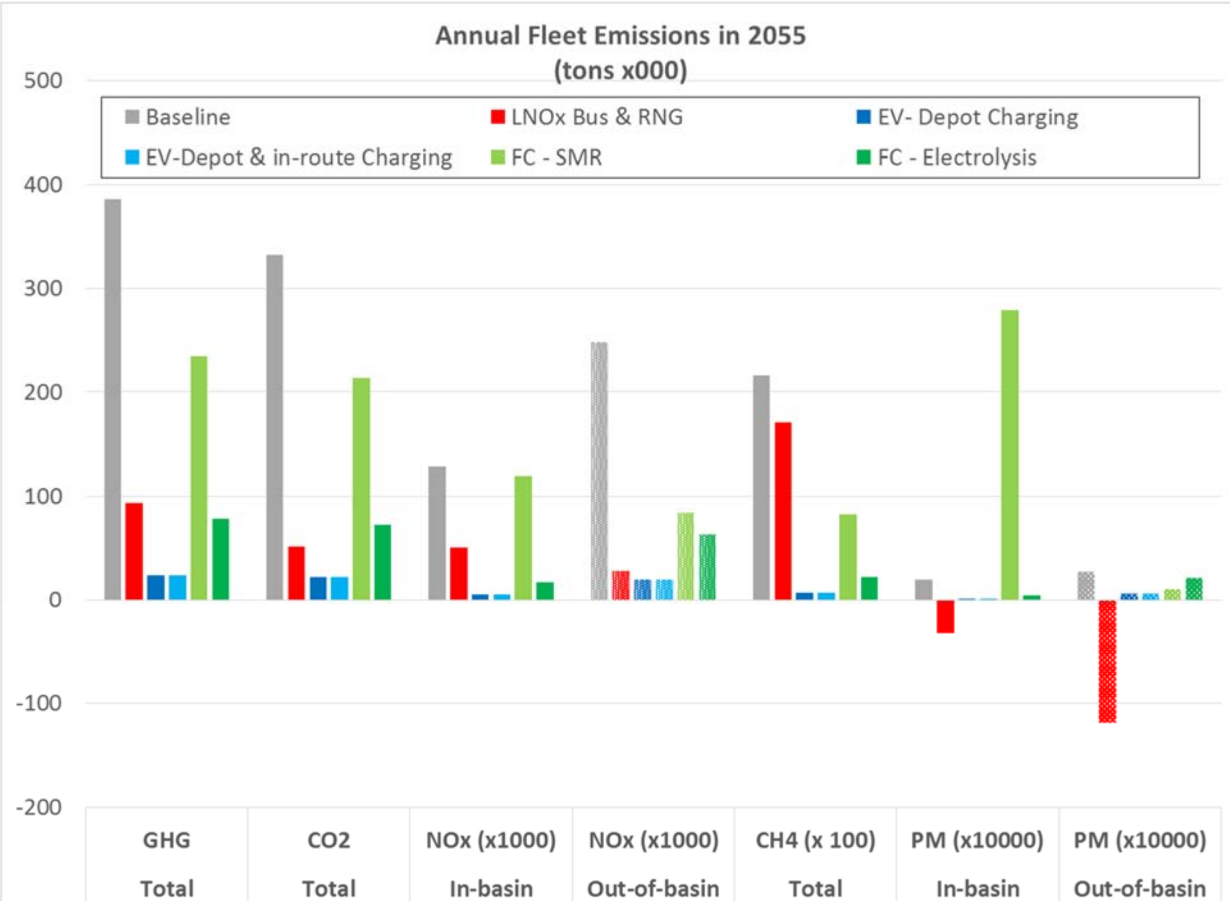
Pollutant	BASELINE	RENEW NG	LOW NOx CNG BUS & REPOWER		ELECTRIC BUS		FUEL CELL BUS	
	Std CNG Bus Conv NG	Std CNG Bus Renew NG	LNOx Bus Conv NG	LNOx Bus Renew NG	Depot Charging	Depot & In-Route Charging	H_2 by SMR	H_2 by Electrolysis
NOx (in-basin)	128.6	136.6	42.5	50.5	5.1	5.1	119.6	16.9
PM (in-basin)	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.

Los Angeles County
Metropolitan Transportation Authority

Biomethane Implementation Plan

APRIL 2013

Metro®

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1. Introduction and Background

Metro has several adopted policies that guide sustainability and energy related actions within the agency. The Metro Sustainability Implementation Plan (MSIP) demonstrates our continuing commitment to sustainability through fiscal responsibility, social equity, and environmental stewardship. Some of the initiatives addressed in the MSIP include energy and resource conservation and greenhouse gas (GHG) management. In 2010, Metro conducted a cost-effectiveness study on GHG reduction strategies which in particular investigated the GHG impacts of Metro operations and fuel use. Metro's comprehensive Energy Conservation and Management Plan (ECMP), developed in 2011, provides a blueprint to direct Metro's overall energy management in a sustainable and cost-effective manner. Metro adopted its Renewable Energy Policy in 2011 which outlines elements to implement comprehensive renewable energy programs including the exploration of creative renewable energy resources and the establishment of a stretch goal of an additional 13% renewable energy use above the current baseline usage of 20% by 2020. A recent report to the Metro Board dated June 29, 2012 includes an outline of Metro's current progress toward achieving such a goal.

These policies and plans make energy efficiency and environmental responsibility priorities in our agency and require us to continually evaluate viable options to use more renewable energy to power transit and facilities operations. Utilizing renewable energy presents opportunities to reduce GHG emissions and meet our adopted renewable energy policy goals.

Metro currently operates the largest alternatively fueled fleet in the nation (and has 100% of its fleet transitioned to compressed natural gas, or CNG). Staff is committed to explore ways that will further improve our operations and reduce our environmental impact, specifically via cost-effective methods. Staff has identified biomethane as a potentially viable alternative to CNG. Biomethane has the same chemical make-up and can be produced with the same fuel specifications as CNG. Biomethane currently has the lowest carbon intensity among alternative fuels included in the suite of options to comply with California's Low Carbon Fuel Standard (LCFS), including CNG. The carbon intensity of a fuel is a measure of its GHG emissions over the lifecycle of production – including processes such as extraction, transportation, and combustion or use in a vehicle.

Based on our current understanding of biomethane, use of this fuel has the potential to help Metro reach our renewable energy goals, reduce our agency's GHG emissions, and generate revenue without changing our current fueling infrastructure, bus fleet, or maintenance operations. However, because of the potentially complex nature of a transition to biomethane, there is a need to conduct a more detailed analysis to better understand the feasibility of the use of biomethane as an alternative form of fuel for our fleet.

2. Summary of Biomethane as a Transportation Fuel

Biomethane refers to pipeline quality natural gas that is conditioned from biogas, a renewable resource derived from a variety of sources including landfills and wastewater treatment plants. The biogas is subsequently upgraded and all impurities are removed before delivery to an end user or injection into an existing natural gas pipeline. The biomethane delivered to an end user such as Metro will meet the same specifications of the natural gas that is currently delivered to our agency via utility pipelines. As a result, there are few infrastructure modifications and no vehicle modifications required if we shift to this fuel. Further, the operation and maintenance of Metro's existing fleet will be unaffected by the use of biomethane.

Metro will likely be an attractive customer for biomethane producers because of the size of its fleet and the predictability of its fuel demand. For instance, transit agencies in Sweden have established themselves as "anchor customers" because of the constant high demand for fuel – this is common with transit agencies and one of the reasons that the natural gas vehicle industry continues to target transit fleets for potential conversion to CNG from diesel. Based on initial research, Metro may have sufficient demand to help spur the investment of or invest in its own biomethane production facility, depending on a variety of factors.

Based on current information, while biomethane appears to be a viable fuel option for Metro, shifting from CNG to biomethane may be more challenging. Further research and analysis are warranted regarding the implications of switching from CNG to biomethane. The following subsections outline the major issues that Metro will consider moving forward to understand the implications of switching from biomethane to CNG for its bus fleet. These issues are highlighted as follows:

- **Biomethane sourcing**: Biogas can be derived from a variety of sources, including but not limited to waste resources such as from landfills, wastewater treatment plants, food processing waste, and manure (e.g., at dairy farms). Biogas can also be derived from purpose grown energy crops, or agriculture and forestry residue. Biogas is generally produced via anaerobic digestion, whereby microorganisms breakdown organic matter in the absence of oxygen. Facilities that are interested in producing biogas generally introduce an anaerobic digester and a collections system.
- **Operational impacts**: For an end-user like Metro, no operational changes to its CNG fueled buses will be required. Neither the fueling stations nor the buses will require any modifications to compress or combust biomethane. The only operational impact would occur if Metro moves away from using CNG buses.
- **Fiscal impacts**: There are multiple fiscal impacts that require consideration regarding biomethane:
  - **Biomethane pricing**: Biomethane is more expensive than the natural gas that Metro currently uses. Unless we have a deal with the provider to offset this price, then it may not make sense fiscally
  - **Procurement**: includes the relationship with the utility and biogas source.
  - **LCFS revenue**: Metro is currently opted into the LCFS as an obligated party dispensing CNG. Displacing CNG with biomethane will impact the potential revenue that could be earned from credits that Metro would generate in the future.

- **Environmental impacts**: There are significant environmental benefits of using biomethane – it has the same air quality benefits as natural gas; however, it also has significant GHG reduction potential, as noted previously. Biomethane is also a renewable resource that can help Metro increase its renewable portfolio. Based on the current suspension of using biomethane to comply with Renewable Portfolio Standards (RPS) in the electricity generation sector, this may be an optimal time for biomethane producers to seek out transportation markets for their product. This could work in Metro's favor, as it would increase its renewable energy profile, while also providing an opportunity to fuel providers seeking demand for their supply.
- **Policy impacts**: Metro has established internal goals and priorities related to renewable energy consumption that will be affected by a decision to transition to biomethane. Despite the many positives associated with switching to biomethane for the bus fleet, there is also the potential that switching could have an impact on Metro's relationship with its utility providers.

Based on Metro's initial review of the potential to transition to biomethane, we outlined three potential options:

- **A rapid transition to biomethane in the next 1-2 years**: A rapid transition to biomethane will likely offer Metro the most cost competitive biomethane purchasing – and enable us to maintain the potential for revenue from the LCFS; however, the potential impacts to other operational impacts within Metro requires advance planning that will delay the implementation of a rapid transition for at least one year based on our current best estimates.
- **A scheduled transition to biomethane over a defined time period**: Although this approach minimizes impacts to Metro operations, it reduces the potential for more competitive pricing. As noted previously, Metro's fleet is particularly attractive to biomethane producers because it has high volume demand. Through a measured transition, Metro would likely need to provide the appropriate assurances to the biomethane producer with a clearly defined schedule for increased consumption. Metro could also use the measured transition approach as a way to solicit multiple bids for the procurement of biomethane – this would help introduce cost control measures and potentially offset the higher costs of not transitioning more rapidly. A slower implementation schedule would allow Metro's operations staff to plan for the transition to biomethane, while also providing our procurement team to consider bids from multiple suppliers.
- **No transition to biomethane**: In this third pathway considered, Metro could continue to run its fleet of buses using conventional natural gas. Although this is the path of least resistance, Metro has a goal of reducing the environmental footprint of its operations through the introduction of renewable energy and achieving lower emissions from buses. In order to achieve these goals through its bus operations, and assuming that there are no changes to CNG buses, then Metro will have to explore alternatives that will reduce air quality pollutants and GHG emissions.

3. Biomethane Implementation Plan

3.1. Introduction

Metro's fleet of transit buses is a major part of the agency's operations. As such, fleet operations will be an important target in Metro's strategy to improve the sustainability of our operations. Although Metro already operates the largest fleet of alternative fuel buses in the United States, we continue to seek opportunities to reduce our GHG emissions. Metro staff have conservatively estimated that a transition to 10% biomethane consumption in our fleet of transit buses will reduce our GHG emissions by 12,000 MT CO_2e annually.[1]

In Fall 2012, Metro staff initiated research into the feasibility of transitioning Metro's fleet of buses to lower emitting alternatives, with a focus on biomethane. This report outlines the initial findings of Metro's research and outlines the next steps regarding the possibility of biomethane as a fuel for Metro's transit buses.

Metro staff have identified two likely pathways for Metro to transition to biomethane. These pathways, intended to position Metro at the forefront of innovative GHG reduction strategies amongst transit agencies, also provide flexibility and adaptability amidst a somewhat uncertain clean fuels market. These pathways are summarized as:

- Pathway 1: Metro purchases and conditions biogas
- Pathway 2: Pipeline injection of biomethane on Metro's behalf

These pathways are introduced in more detail in the following sections. For each pathway, Metro staff has outlined the following information:

  - Overview
  - Potential Sources / Partnerships
  - Impacts on Operations
  - Potential Costs

Following the discussion of the two main pathways considered for biomethane use in our transit fleet, Metro staff have outlined some of the potential ways to offset the costs associated with a transition to biomethane.

Overview of Metro's Demand for Natural Gas

Prior to the in-depth discussion of the likely pathways for Metro to introduce biogas, we provide a brief overview of Metro's demand for compressed natural gas (CNG). Metro currently consumes about 50 million therms of CNG annually to fuel its fleet of more than 2,200 buses.

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[1] Metro staff assumed 10% of conventional natural gas consumption in transit buses would be displaced by biomethane. Metro staff also accounted for the electricity that would be required to operate the biogas conditioning and upgrading equipment. GHG emissions factors for electricity and natural gas were taken from climate registry data reported online at http://www.climateregistry.org/tools/carrot/carrot-public-reports.html.

Metro has 11 divisions around Los Angeles County that have fueling infrastructure; however, only 10 of these divisions use significant quantities of CNG. The consumption of each division is about 10% of the total fleet consumption, which is equivalent to about 420,000 therms monthly.

For the sake of reference, landfill gas collected from waste facilities has a lower content of methane (CH_4) than what is required for operating buses. The landfill gas needs to be upgraded and conditioned. For the purposes of this report, we assume that biogas has a methane content of 60% and that a facility has a methane capture rate after conditioning and upgrading of 87%. In other words, if a landfill is capturing 1,000 therms, then it can produce 522 therms of natural gas for compression and use in a transit bus.

3.2. Pathway 1: Metro Purchases and Conditions Biogas

Overview

In this pathway, Metro would purchase biogas from a local or regional facility that captures methane (e.g., a landfill or wastewater treatment plant). Moreover, Metro would assume responsibility to condition and to upgrade the biogas for pipeline injection or delivery and use as a transportation fuel. Metro staff identified several sub-pathways, as described here:

- **Pathway 1a: Biogas delivery to Metro / Biogas conditioned at Metro facility.** Metro builds pipeline and conditioning facility at a Metro-owned site (e.g., Division) to dispense biomethane. Additional considerations: Other equipment needed on-site such as storage tanks, alignment/interface with bus operations (e.g., compression facilities, fueling demands).
- **Pathway 1b: Biogas conditioned at collection site / Biomethane delivered to Metro.** In this scenario, Metro would build a conditioning facility at the biogas collection site to enable pipeline injection and delivery to Metro facilities. Additional considerations: By injecting into a pipeline, Metro becomes an Energy Service Provider (ESP) or must use broker who will sell biomethane at a premium and has agreements with SoCalGas to provide energy into pipeline (storage, contracts, etc).
- **Pathway 1c: Metro procures biogas / SoCalGas conditions biogas on Metro's behalf.** This pathway is similar to Pathway 1a; however, rather than Metro assuming responsibility for conditioning and upgrading the biogas, Metro opts into a special tariff. As part of the service, SoCalGas will design, install, own, operate, and maintain a biogas conditioning/upgrading facility on or adjacent to the tariff service customer's premises and charge the tariff service customer the fully allocated cost of providing the service under a long term (10 to 15 year) agreement. SoCalGas will not own the biogas entering the facility or the processed renewable natural gas leaving the facility.

Potential Sources and Partnerships

The focus of this pathway is identifying local or regional sources of biogas which could displace Metro's current consumption of fossil-based natural gas in our fleet of transit buses. Due to cost concerns (as discussed in more detail later), Metro staff focused research on identifying potential biogas sources in close proximity to Metro's divisions that use CNG. To help filter the potential local sources of biomethane, we assumed that a landfill would need a potential of at least 1,390 standard cubic feet per minute (scfm).[2] We identified the landfill gas facilities that met this threshold using the Waste to Biogas Mapping Tool available through the US Environmental Protection Agency's website.[3] The mapping tool provides the operating company, address, and estimated biogas capacity of landfills in a given area.

The map below shows Metro divisions that have CNG refueling infrastructure (blue markers) and the location of the landfills that met the aforementioned threshold of 1,390 scfm (red markers).

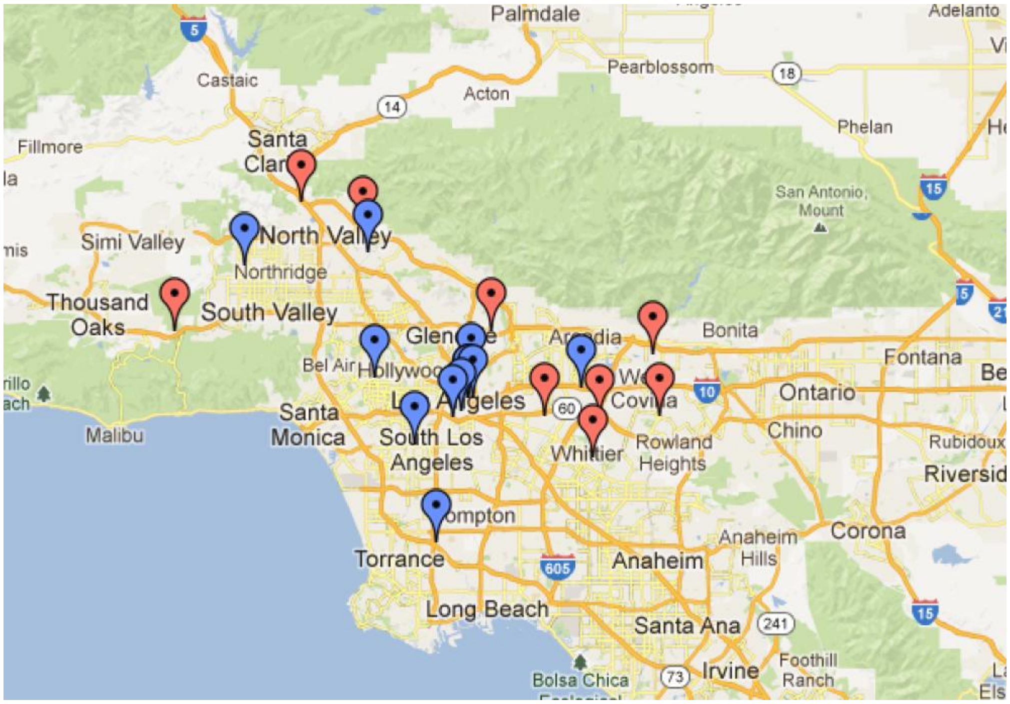


Figure 1. Metro Divisions (blue markers) and Nearby Landfills (red markers)

[2] Generally, biogas capture is measured in units of standard cubic feet per minute (scfm); this is more common than therms or other metrics.

[3] Available online at: http://epamap21.epa.gov/biogas/index.html. Accessed April 2013.

Company	Address	City	Biogas potential scfm/yr	Notes
Operating Industries Inc.	900 Potrero Grande Dr	Monterey Park	4,000	
Scholl Canyon Sanitary Landfill	3001 Scholl Canyon Rd	Glendale	6,242	
Azusa Land Reclamation Co. Landfill	1211 West Gladstone St	Azusa	2,270	
Lopez Canyon Sanitary Landfill	11950 Lopez Canyon Rd	San Fernando	2,150	Being used in microturbines; generation 6 MW
Sunshine Canyon City/County Landfill	14747 San Fernando Road	Sylmar	7,679	Partnering with DTE Energy to produce 20 MW energy (five turbines on-site planned)
Savage Canyon Landfill	13919 East Penn Street	Whittier	1,145	
Puente Hills Landfill	13130 Crossroads Pkwy South	Industry	28,220	Gas-to-energy project, produce 50 MW; biogas conditioning closed in 2007
BKK Sanitary Landfill	2210 South Azusa Avenue	West Covina	11,986	Closed; still have landfill gas collection in place
Calabasas Sanitary Landfill	5300 Lost Hills Road	Agoura	5,693	

Impacts on Operations

Transitioning Metro's bus fleet to biomethane under this pathway may require facility modifications. Although neither fueling stations nor buses will require any modifications, a biogas conditioning and upgrading facility may need to be sited on Metro property. Siting factors include size of the facility, hookups to existing utility connections and/or compression facilities, and associated storage tanks and other equipment. If for some reason the flow of biomethane or biogas is interrupted or cannot meet the demand of the bus fleet at that division, natural gas will still be available through existing utility hookups and Metro will be subsequently billed by the utility as occurs today.

Metro will likely have to incorporate on-site storage of biogas to accommodate a consistent flow of biogas. Under current conditions, when demand for natural gas ceases at a Metro facility, the flow from the pipeline ceases as well. This is optimal considering the non-linear nature of bus fueling operations. However, under the proposed pathway, the flow of biogas from the source and biomethane from the conditioning facility is constant. There is no off switch, although some landfills may have mechanisms for diverting captured biogas (note: generally, wastewater treatment plants do not). Therefore, the excess biomethane would need to be used or stored. Other options for this excess gas are co-generation plants and storage tanks. Currently, some biogas conditioning facilities have microturbines or fuel cell plants built in to utilize excess biogas. There will be additional costs and operational considerations such as heat and electrical output as part of these scenarios, but benefits include electrical generation and useful heat output.

Potential Costs

The cost elements that we must consider for Pathways 1a, 1b, and 1c are generally similar, but have some differences.[4] Metro staff have identified the following cost elements:

- Biogas procurement
- Costs of biogas conditioning facility
- Potential pipeline costs
- SoCalGas tariff (applies only to Pathway 1c)

Biogas Procurement

For the sake of reference, natural gas spot prices are currently around $4/MMBtu today. Metro staff anticipate that we should be able to enter into a contract to procure biogas for less than the SoCal Border Wholesale Market price. The commodity cost of biogas (i.e., excluding any clean-up costs or delivery charges) from a landfill operation should be lower than the commodity cost of natural gas spot prices for several reasons.:

- Biogas has a lower methane content, thereby lowering the value of the fuel. Generally, landfill biogas has around 60% methane and requires conditioning and upgrading for consumption in a transit application or for pipeline injection. If Metro were to bear the costs of conditioning and upgrading the fuel (see next subsection), then Metro staff anticipate that we should be able to purchase the biogas at a significant discount.
- Metro is in a position to provide landfills with a revenue stream that are otherwise flaring captured gas. In California, landfills are required to capture biomethane. Landfills can use the captured gas or flare it. Today, the regulatory environment in Southern California makes it difficult for biogas collection facilities to use the gas in energy production. In the past, facilities have simply combusted the captured biogas in reciprocating engines; however, due to air quality regulations, it is increasingly expensive and often cost-prohibitive to install engines that meet emission requirements. Furthermore, landfills are prohibited from injecting biogas into the pipeline.[5] As a result, many landfills are simply flaring the captured product.
- Metro is also in a strong bargaining position because it has a large and consistent demand for natural gas to fuel our transit bus fleet. In other words, Metro can use a significant amount of biogas that landfills are producing, thereby limiting the administrative barriers of having multiple purchasers of biogas from a single source.
- Metro would also be in a position to work with the landfill producer to share the revenue associated with LCFS credits (discussed in more detail in the following section).

[4] It is important to note that we assume that any facility which Metro partners with will already have biogas recovery equipment installed.

[5] The CEC and CPUC are seeking to resolve the issue of biomethane quality for injection into the pipeline per Assembly Bill 1900.

- A landfill biogas to transit fuel project would be an appealing and innovative strategy to reduce transit-related *and* regional greenhouse gases while making use of the country's landfills.

Costs of Biogas Conditioning Facility

There are two main cost components for a biogas conditioning facility: 1) the initial capital costs of the facility and 2) the ongoing maintenance costs of a biogas conditioning facility.

- We estimate capital costs of about $3-5 million for a medium- to large-sized (i.e., about 1,400 scfm) biogas conditioning facility at a landfill or on-site at one of Metro's divisions.
- We estimate ongoing operational costs for the biogas conditioning facility of about $1-1.5 million annually

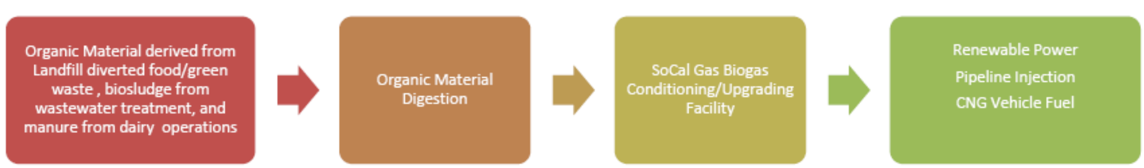
As noted previously, it is likely that Metro – in coordination with its biogas supplier – will have to install a storage facility because of the constant production of biogas from landfills. Conditioned biomethane can be stored in tanks designed for pressurized gas at an additional cost. For example, a 5,000 PSIG 3-pak storage tank costs about $75,000 and holds 36,000 scfm of gas.

Potential Pipeline Costs

The costs of building a pipeline can vary significantly depending on where the pipeline being installed. We use a general estimate of pipeline construction of $1 million per mile. Assuming that the delivery of biogas to Metro requires a pipeline, that there are no major configuration changes required at Metro Division facilities, and based on the proximity of landfills to Metro's facilities, we estimate potential costs of $2 million to $10 million.

Tariff through SoCalGas

SoCalGas has requested approval from the California Public Utilities Commission to establish a new tariff to offer Biogas Conditioning/Upgrading Services. Under this service, SoCalGas, will design, install, own, operate, and maintain a biogas conditioning/upgrading facility on or adjacent to the tariff service customer's premises and charge the tariff service customer the fully allocated cost of providing the service under a long term (10 to 15 year) agreement (as shown in the diagram below). SoCalGas will not own the biogas entering the facility or the processed renewable natural gas leaving the facility. SoCalGas' role will be to process the tariff service customer's biogas and condition/upgrade it to the gas quality level(s) contractually specified by the tariff service customer. SoCalGas will conduct an initial technical and economic feasibility analysis of the design, installation, operation and maintenance of the gas conditioning equipment. A site assessment and detailed information about the quality and quantity of biogas are included in this analysis as well. The potential tariff service customer will pay for this initial feasibility analysis. Approval for this tariff is expected by August 2013.



The deal is structured so that the tariff customer pays no capital costs upfront. The capital costs may include laying pipeline, building the facility, and projected operations and maintenance over the lifetime of the project. The tariff customer pays a monthly bill for the life of the project, with a CPI escalator (2-3%). The tariff customer also must pay for electricity to run the facility. In previous scenarios, the cost of electricity is about 2/3 of the entire cost to the tariff customer.

SoCalGas staff has provided Metro with rough estimates of the costs of these services. In order to take 1,400 scfm of raw biogas (estimated demand in previous section) and upgrade it to natural gas quality for expected biomethane output of about 375,000 MMBtu/Year costs about $165,000 per month over 15 years ($29.7 million). In addition, the parasitic load for the biogas conditioning facility is about 5.5 million kWh per year or an additional $660,000 annually in electricity costs. Therefore, the total monthly cost of dispensing biomethane is approximately $220,000 plus the cost of purchasing the raw biogas and associated pipeline extension costs. As a reference, the average monthly cost of dispensing CNG at a given bus division ranged from about $150,000 to $240,000.

3.3. Pathway 2: Biomethane Injected into Pipeline on Metro's Behalf

Overview

In this pathway, rather than dealing with a local provider of biogas, Metro would contract with a 3rd party Energy Service Provider (ESP) because SoCalGas does not offer biomethane. In this case, the biomethane would still be delivered to Metro via the natural gas transmission and delivery system of SoCalGas. As part of its contract with an ESP, Metro would stipulate a percentage of biomethane as part of the pro forma. This biomethane, like the natural gas, would be injected into the pipeline on Metro's behalf. Elements of this pathway include contracts terms with an ESP and administrative agreements with utility.

Potential Partnerships

SoCalGas maintains a list of participating ESPs pre-approved to supply "Core" customers such as Metro.[6] If Metro were to form an agreement with a non-listed ESP, that entity would have to go through an approval and agreement process with SoCalGas which can take several months.

In this scenario, Metro enters into an agreement with an ESP which can provide biomethane for injection directly into the pipeline. One of the primary differences between this pathway and the previously discussed pathway is the source of biogas. There are currently restrictions on injecting landfill-derived biogas into pipelines in California; however, these restrictions do not exist in other states. In other words, a biogas producer in another state (e.g., Texas or Washington) can capture landfill gas, condition it and inject it into the pipeline locally and have this gas delivered to California for use by a customer such as Metro.

[6] The list is available at http://www.socalgas.com/for-your-business/natural-gas-services/energy-service-providers/customer-core-list-of-esps.shtml.

This would require an agreement between the biomethane injector (Metro) and SoCalGas in order for this to occur, as well as an interconnection fee which can cost up to $2 million depending on where a local connection capable of receiving pipeline quality gas exists in relation to the site. At many sites, this local connection already exists due to previous installations of biogas conditioning and injection programs.

If Metro contracts with an ESP to inject biomethane into the pipeline on its behalf, there are protocols that must be followed, as outlined by SoCalGas. Generally, these include a number of contracts including a Master Services Agreement, ESP Agreement, Storage Contract, and others.

As part of the pro forma, Metro should insist on a minimum percentage of biomethane (equal to or greater than fuel demand of one bus division) to be injected into pipeline on our behalf. It is also recommended that Metro stipulate a percentage of ownership of RINs and LCFS credits as part of this deal.

Additionally, under Pathway 1, if Metro is injecting the biomethane into the pipeline rather than dispensing it at its bus divisions, it is recommended that Metro go through an experienced broker with contracts with SoCalGas already in place to buy, sell, and inject pipeline quality gas on the behalf of its customers.

Impacts on Operations

In Pathway 2, there are no impacts on operations or modifications to existing facilities. Further, there would be no discernible difference between the natural gas that would be delivered to Metro's facilities.

Potential Costs

If Metro were to contract with an ESP to inject biomethane on its behalf, Metro staff are operating under the assumption that the long-term contract with the ESP would link to the SoCal Border Wholesale Market price for natural gas. Apart from this, Metro does not anticipate any additional costs to procure biomethane.

3.4. Revenue/Cost Offsetting Potential

There are two fundamental strategies that Metro can employ to help offset the potential costs of transitioning to biomethane, particularly as they apply to Pathway 1 (and each subpathway):

- Revenue from regulatory markets i.e., LCFS market and the RFS2 market
- Grants from funding agencies e.g., CEC or SCAQMD

Revenue from Regulatory Markets

Low Carbon Fuel Standard

Metro currently has a LCFS credit balance of about 150,000 credits. At this point in time, Metro has not taken the steps to monetize these credits. However, credits are currently trading for about $35-40/credit. Based on Metro's initial conversations with brokers and other market participants, it may be challenging to sell the entire balance of Metro's credits in the near-term future as a financing mechanism. In other words, the potential value of Metro's current account balance is upwards of $6 million; however, that is dependent on Metro's ability to move a large volume of credits.

The carbon intensity of biomethane is considerably lower than conventional fossil-based CNG. As a result, the consumption of biomethane as a transportation fuel has the potential to earn a significant number of LCFS credits.

As noted previously, Metro already has a credit balance of 150,000 LCFS credits based on its use of CNG in its fleet of transit buses. Biomethane in the transportation sector has significant potential to generate credits. Today, Metro earns credit as the owner of the fueling station that dispenses CNG. However, the entity that generates the credit for biomethane is the producer. In order for Metro to earn additional credits, we would have to enter an agreement with the biogas provider indicating what is called an obligation with transfer.

The table below highlights the potential LCFS credit generating opportunities under various scenarios:

- Under the business-as-usual (BAU) scenario, Metro continues to earn credits by dispensing natural gas.
- For Pathway 1, Metro staff assumed a 100% transition to biomethane by 2015 from a local in-state landfill. We assumed a carbon intensity of about 11 g/MJ.
- For Pathway 2, Metro staff assumed a 100% transition to biomethane by 2015 from an out-of-state landfill. We assumed a carbon intensity of about 29 g/MJ.

Year	CNG (BAU)	Pathway 1: Biogas (in California)	Pathway 2: Biogas (out-of-state)
2013	90,000		
2014	88,000		
2015	83,000	348,000	264,000
2016	79,000	343,000	260,000
2017	73,000	337,000	254,000
2018	67,000	331,000	248,000
2019	61,000	325,000	242,000
2020	53,000	317,000	233,000
Total (2015-2020)	**416,000**	**2,001,000**	**1,501,000**

Federal RFS2 Market: RIN Generation

Biogas also has the potential to generate Renewable Identification Numbers (RINs), the currency that the US Environmental Protection Agency (EPA) uses to administer the Federal Renewable Fuel Standard (RFS2). In order to generate RINs, the facility producing biogas needs to register as a RIN-generating entity with the US EPA. Biomethane is categorized as an Advanced Biofuel under the EPA's RFS2 program and can generate RINS in this category. Today, biodiesel and sugarcane ethanol are the most common fuels used to comply with the RFS2 requirements of the Advanced Biofuel category.

Potential Grant Funding

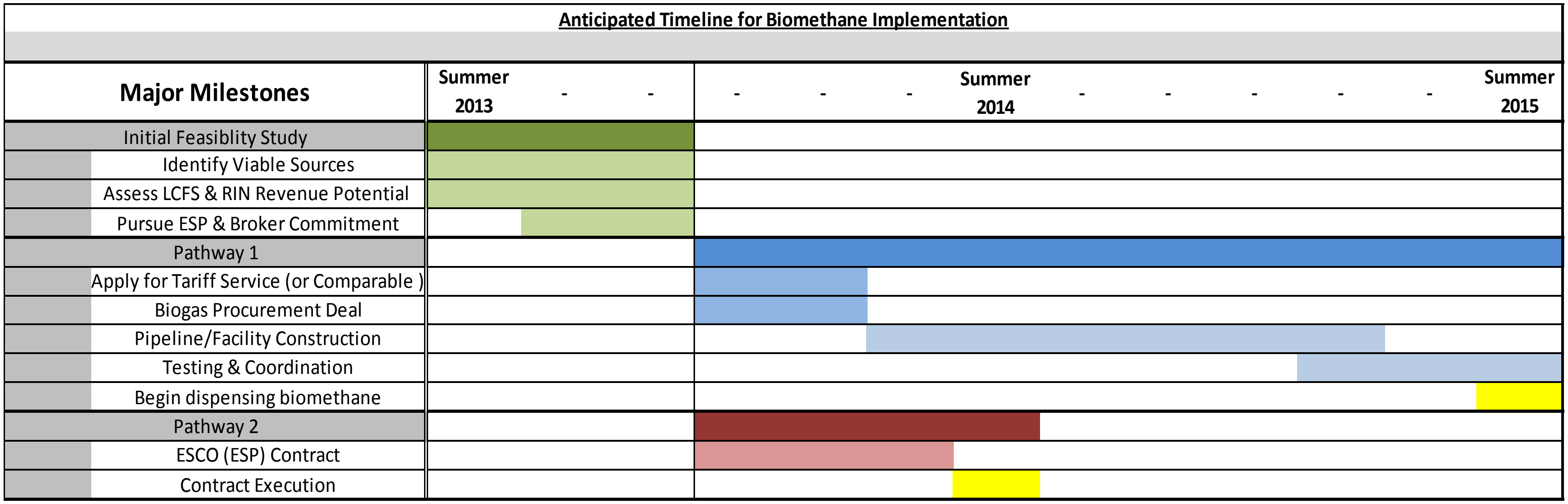
Metro staff have identified two potential sources of grant funding to help offset the additional costs of delivering and conditioning biogas that we would incur if we pursued Pathway 1:

- Metro could collaborate with a partner and apply for money under the CEC's Alternative and Renewable Fuel and Vehicle Technology Program (funded via AB 118). Biomethane as a transportation fuel has received a significant amount of funding to date, which is likely to continue in the coming years.
- Metro could also seek opportunities to fund a biomethane project through the Clean Fuels Program, administered by SCAQMD's Technology Advancement Office.

4. Next Steps

The near-term focus of Metro staff is to conduct the following outreach:

- Engage potential local suppliers in substantive discussions regarding the potential to provide biogas to Metro. These discussions need to address the following items:
  - What is the potential supply to Metro? And what is the length of contract that the landfill can guarantee delivery of the biogas? Furthermore, what price is the biogas supplier seeking?
  - Would biogas conditioning occur at the landfill for injection? Or on-site at one of Metro's facilities?
  - What is the arrangement regarding LCFS credits or RINs?
- Based on the outcome of conversations with local suppliers regarding the potential to supply biogas to Metro, determine feasibility of Pathway 1. If Pathway 1 (and its sub-pathways) are not viable, then Metro can immediately engaged with a short list of ESPs that would be willing to supply us with biomethane.


Anticipated Timeline for Biomethane Implementation
Major Milestones
Summer 2013
Summer 2014
Summer 2015
Initial Feasiblity Study
Identify Viable Sources
Assess LCFS & RIN Revenue Potential
Pursue ESP & Broker Commitment
Pathway 1
Apply for Tariff Service (or Comparable)
Biogas Procurement Deal
Pipeline/Facility Construction
Testing & Coordination
Begin dispensing biomethane
Pathway 2
ESCO (ESP) Contract
Contract Execution

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