

# Los Angeles Metro Technology Assessment

## ZERO AND NEAR ZERO BUS OPTIONS

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Dana Lowell  
M.J. Bradley & Associates, LLC

# BACKGROUND



- ❑ California Air Resources Board has proposed a “Zero Emission Bus” (ZEB) rule
  - Applicable to all California Transit Agencies
  - All buses must be “zero emission” by 2040
  - Only electric & fuel cell buses qualify as ZEB
- ❑ LACMTA commissioned this study to:
  - Evaluate cost of compliance with the ZEB rule
  - Evaluate the costs and benefits of “near zero” emission options that are based on the continued use of natural gas

# ZERO EMISSION BUS OPTIONS



## BATTERY ELECTRIC BUS

- ☐ Depot-only charging, or
- ☐ Depot and in-route charging



## HYDROGEN FUEL CELL BUS

- ☐ Hydrogen fuel produced from electricity (electrolysis), or
- ☐ Hydrogen fuel produced from natural gas (steam methane reforming)

# "NEAR ZERO" BUS OPTION



## RENEWABLE NATURAL GAS (RNG)

- ❑ Produced by landfills, wastewater treatment plants, animal manure – anaerobic digestion
- ❑ Processed to remove water, sulfur, CO<sub>2</sub> - can be injected into pipelines, used in NG engines

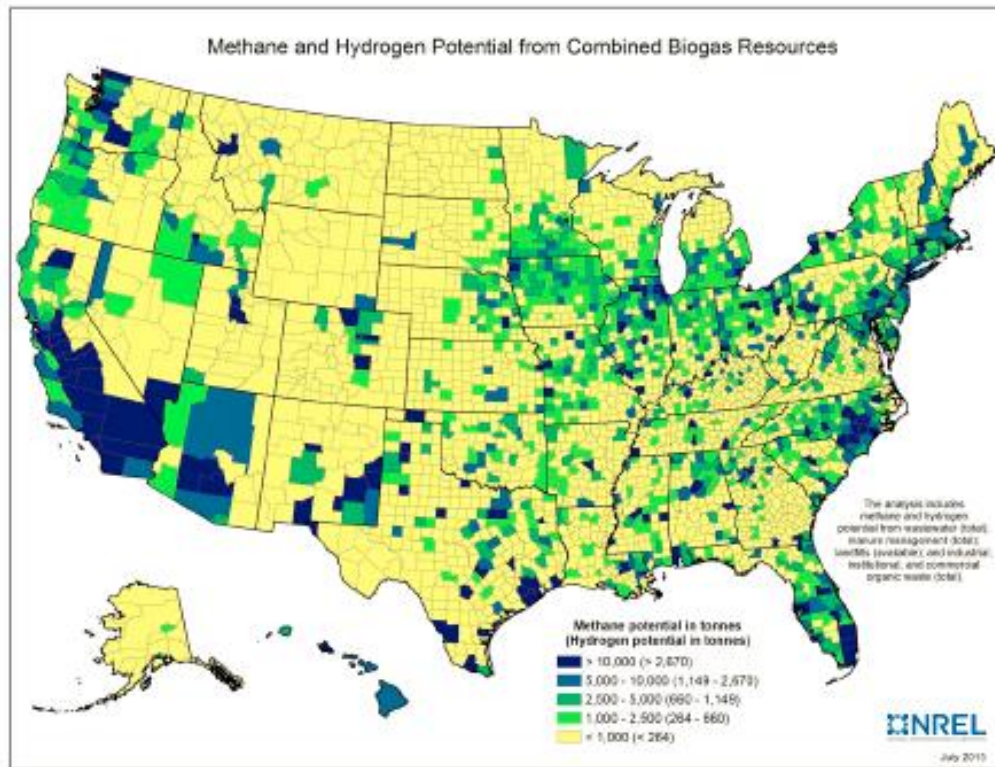


## LOW NO<sub>x</sub> NATURAL GAS ENGINE

- ❑ Commercially available from Cummins; based on ISLG platform used in transit
- ❑ 90% lower tailpipe NO<sub>x</sub> than required by EPA/CARB; 70% lower tailpipe CH<sub>4</sub>



# RENEWABLE NATURAL GAS



*RNG captures  
& uses a  
resource that is  
normally  
wasted*

*This results in  
significant life  
cycle GHG  
reductions  
compared to  
petroleum NG*

# WHAT DID WE DO?

- ❑ Estimated total fleet costs and “wells-to-wheels” fleet emissions from 2015 – 2055 under three bus technology/fuel options, compared to baseline business as usual:
  - **BASELINE:** continue to buy “standard” CNG buses and conventional natural gas
  - **LNOx Bus + RNG:** Starting in 2016 purchase Renewable Natural Gas and in 2018 start transitioning fleet to Low NO<sub>x</sub> CNG engines
  - **ELECTRIC BUSES:** In 2025 start transitioning fleet to electric buses
  - **FUEL CELL BUSES:** In 2025 start transitioning fleet to hydrogen fuel cell buses

# 2016 LACMTA FLEET

❑ All buses are CNG

1,212 40-ft transit

625 45-ft transit (composite)

356 60-ft articulated

**2,194 total**

❑ 75% of fleet has MY2007+ engines that meet most stringent EPA/CARB standards (0.2 g/bhp-hr NO<sub>x</sub>)

❑ Approximately 7% of fleet (178 buses) are retired and replaced with new buses each year



# BUS TECHNOLOGY/FUEL SCENARIOS

	LNO <sub>x</sub> + RNG	ELECTRIC	FUEL CELL
<b>FLEET REPLACE- MENT</b>	Purchase 178 new buses/yr with LNO <sub>x</sub> engines beginning in 2019 Repower 178 old buses/yr with LNO <sub>x</sub> engines beginning in 2018	Purchase 178 – 240 <sup>1</sup> new electric buses/yr beginning in 2025.	Purchase 178 new fuel cell buses/yr beginning in 2025
<b>FUELING</b>	RNG provided through utility pipeline; fueling at existing CNG fuel stations	Depot based charging or Depot and In-route charging	Hydrogen fuel produced on-site by electrolysis of water or steam reforming of natural gas (SMR)
<b>NEW INFRA- STRUCTURE</b>	None required	Depot and In-route chargers.  Depot expansion for expanded fleet, and for depot chargers	Hydrogen production and fueling stations  Upgraded ventilation, H <sub>2</sub> sensors at depots

<sup>1</sup> Due to daily range restrictions 1.35 electric buses replace one existing CNG bus if charging is only at the depot



# MAJOR COST ASSUMPTIONS

		BASELINE	LNOx + RNG	ELECTRIC	FUEL CELL
<b>BUS PURCHASE</b>	2015	\$490,000	\$500,000	\$760,000	\$920,000
	2045	\$490,000	\$495,000	\$692,000	\$506,000
<b>MID-LIFE OVERHAUL</b>	2015	\$35,000	\$38,000	\$281,000	\$335,000
	2045	\$35,000	\$38,000	\$237,000	\$135,000
<b>DAILY RANGE</b>	2015	NA	NA	125 mi	NA
	2045	NA	NA	175 mi	NA
<b>FUEL USE</b>	2015	0.48 therm/mi	0.49 therm/mi	2.1 kWh/mi	0.16 kg/mi
	2045	0.48 therm/mi	0.49 therm/mi	1.9 kWh/mi	0.14 kg/mi
<b>FUEL COST</b>		\$0.78/therm	\$0.78/therm	\$0.006/kWh \$0.028/kWh	\$1.60/kg \$4.62/kg

All costs in 2015 \$, and do not include inflation. Inflation assumed to be ~2%/year

Fuel Costs: Higher electricity cost (\$/kWh) for in-route charging, lower for depot charging. Higher hydrogen cost (\$/kg) for electrolysis, lower for SMR

Costs for CNG, RNG, Electricity, and Hydrogen are net of Low Carbon Fuel Standard (LCFS) Credits

# MAJOR COST ASSUMPTIONS (CONT)

		BASELINE	LNOx + RNG	ELECTRIC	FUEL CELL
MAINT COST	2015	\$0.850/mi	\$0.865/mi	\$0.808/mi	\$0.867/mi
	2045	\$0.850/mi	\$0.850/mi	\$0.808/mi	\$0.859/mi
FUEL INFRA-STRUCTURE		Future upgrade costs included in \$/therm NG cost	Future upgrade costs included in \$/therm NG cost	\$41,000/bus (depot chargers) \$14,000/bus (in-route chargers)	\$105,000 /bus (H <sub>2</sub> production and fuel station)
DEPOT MODS		NONE	NONE	\$36,000/bus (depot expansion)	\$28,000/bus (H <sub>2</sub> sensors & ventilation)

All costs in 2015 \$, and do not include inflation. Inflation assumed to be ~2%/year

# DEPOT VS IN-ROUTE CHARGING

- ❑ LACMTA buses average 130 miles/day
  - To be reliably used on ALL routes, need to have ~170 mile range per charge (30% operational reserve)
- ❑ Current 40-ft electric buses have 325 kWh battery pack
  - Can achieve ~125 mi/charge in Metro service (80% depth of discharge)
  - With depot-only charging would need 1.35 electric buses for every CNG bus replaced, and dead-head mileage would increase due to in-service bus swaps
- Alternative: Depot and In-route charging
  - CNG buses can be replaced one-for one, no increase in dead-head mileage
  - One or more chargers required at every bus lay-over (310 system-wide); assume 10 minutes charge time for every hour of driving

# INFRASTRUCTURE



Electric Bus  
In-route Chargers  
30 kW x 310  
"no plug"



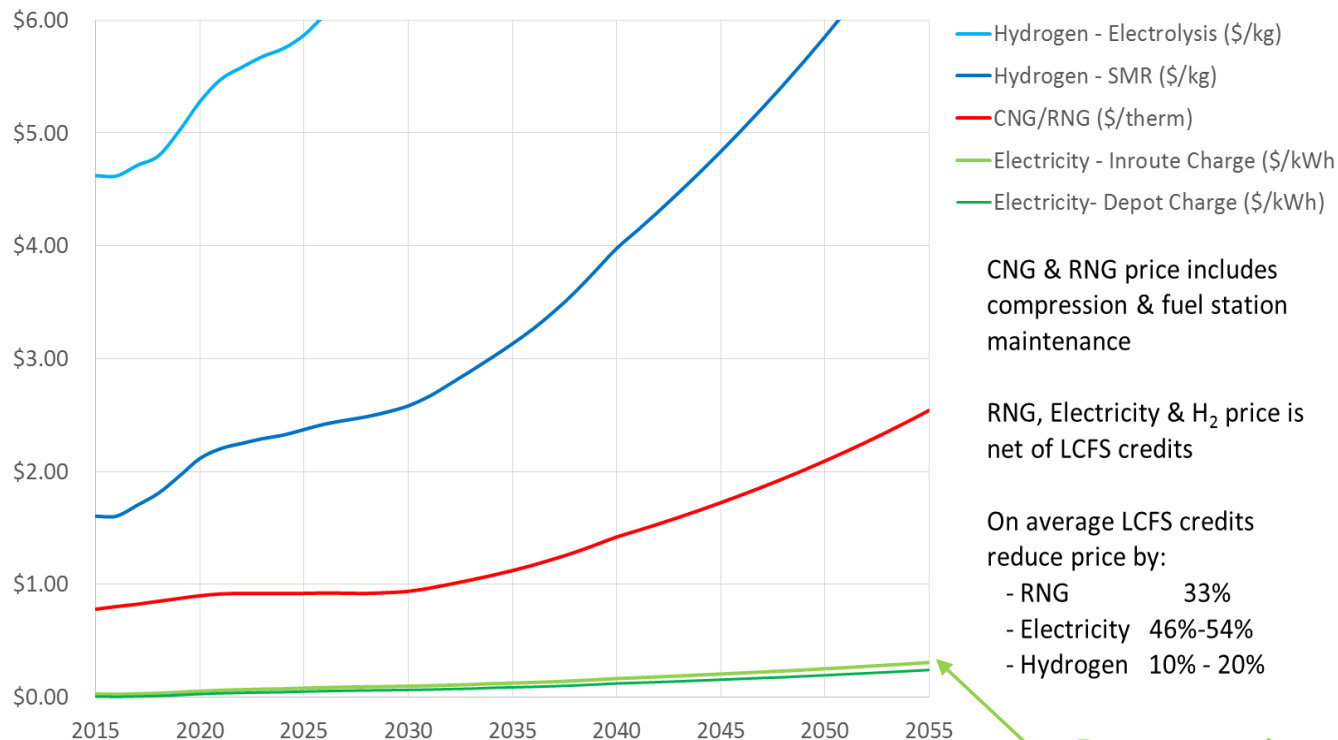
Electric Bus  
Depot Chargers  
23 kW x 2000  
"plug-in"

*Sized based on daily  
energy use and  
available charging time*



Fuel Cell Bus  
On-site  $H_2$  production via  
electrolysis or SMR  
*Sized based on  $H_2$   
throughput*

# FUEL COSTS



CNG & RNG price includes compression & fuel station maintenance

RNG, Electricity & H<sub>2</sub> price is net of LCFS credits

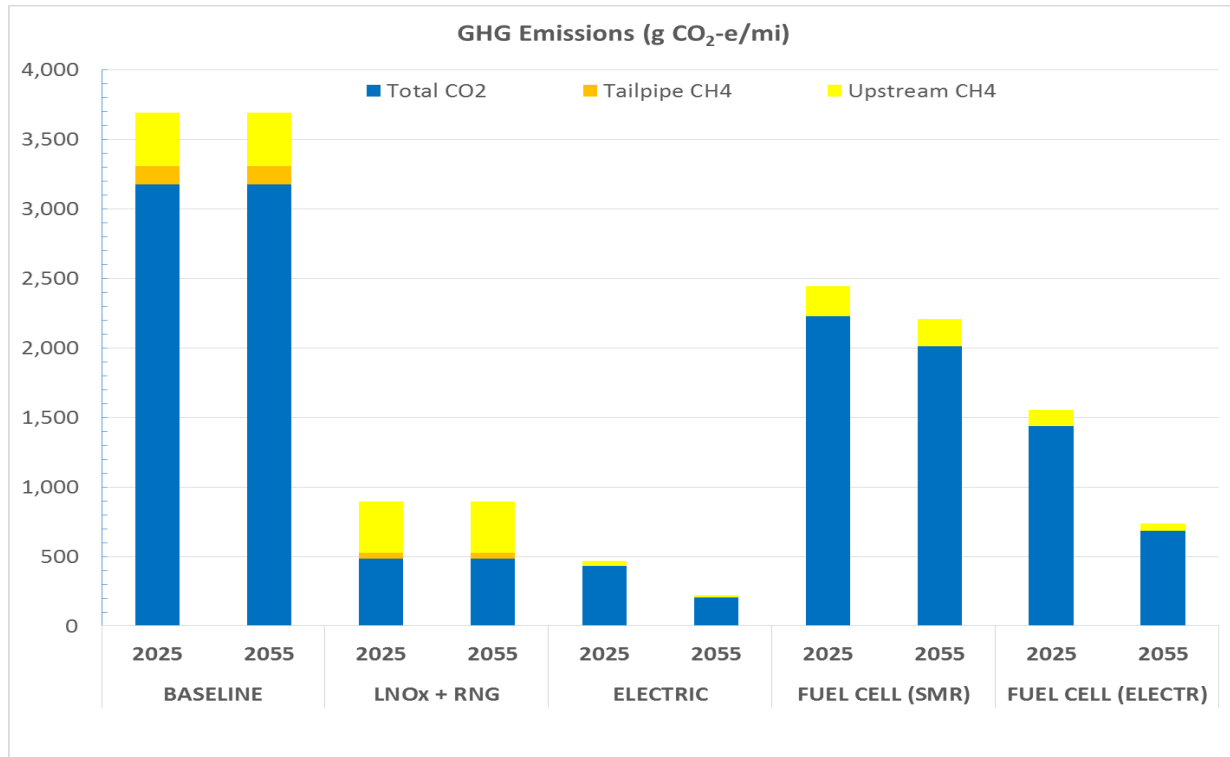
On average LCFS credits reduce price by:

- RNG 33%
- Electricity 46%-54%
- Hydrogen 10% - 20%

*In-route charging higher cost because more during peak periods*



# GHG EMISSIONS (G CO<sub>2</sub>-E/MI)



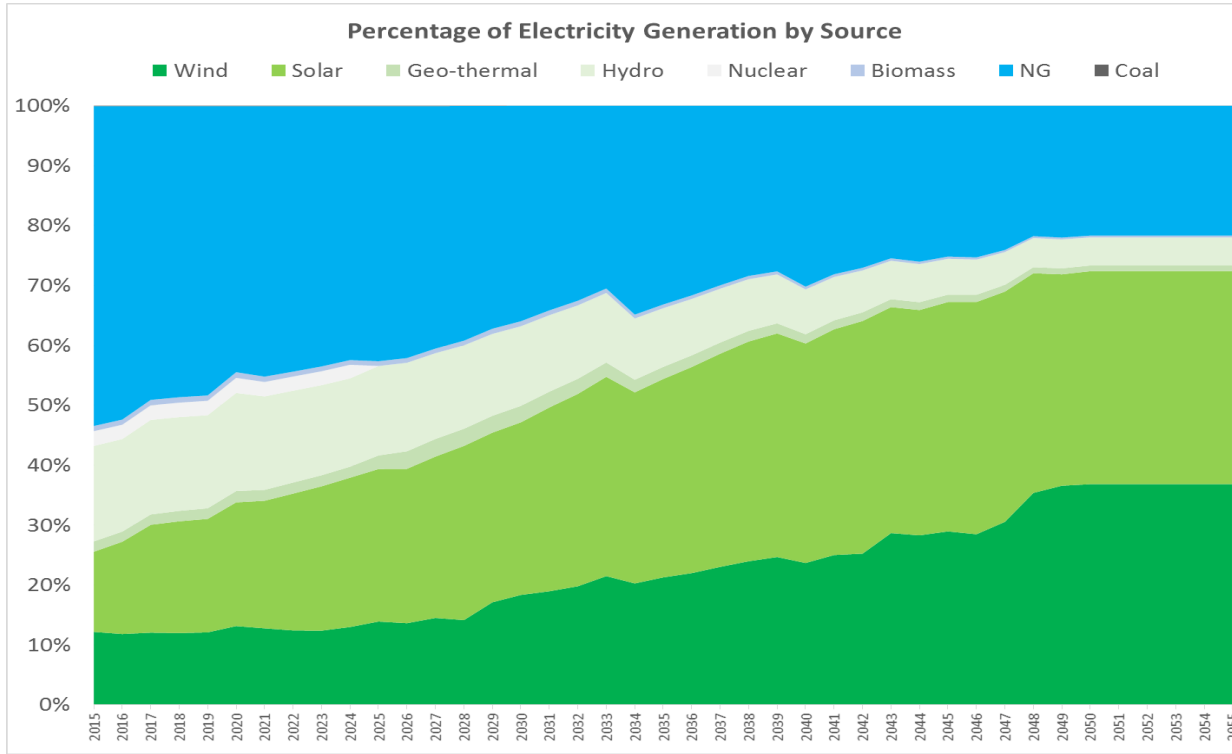
Tailpipe emissions per EMFAC2014 emissions model.

Upstream emissions per CA GREET.

CO<sub>2</sub> shown in chart is total tailpipe plus upstream

RNG assumed to be 100% landfill gas.

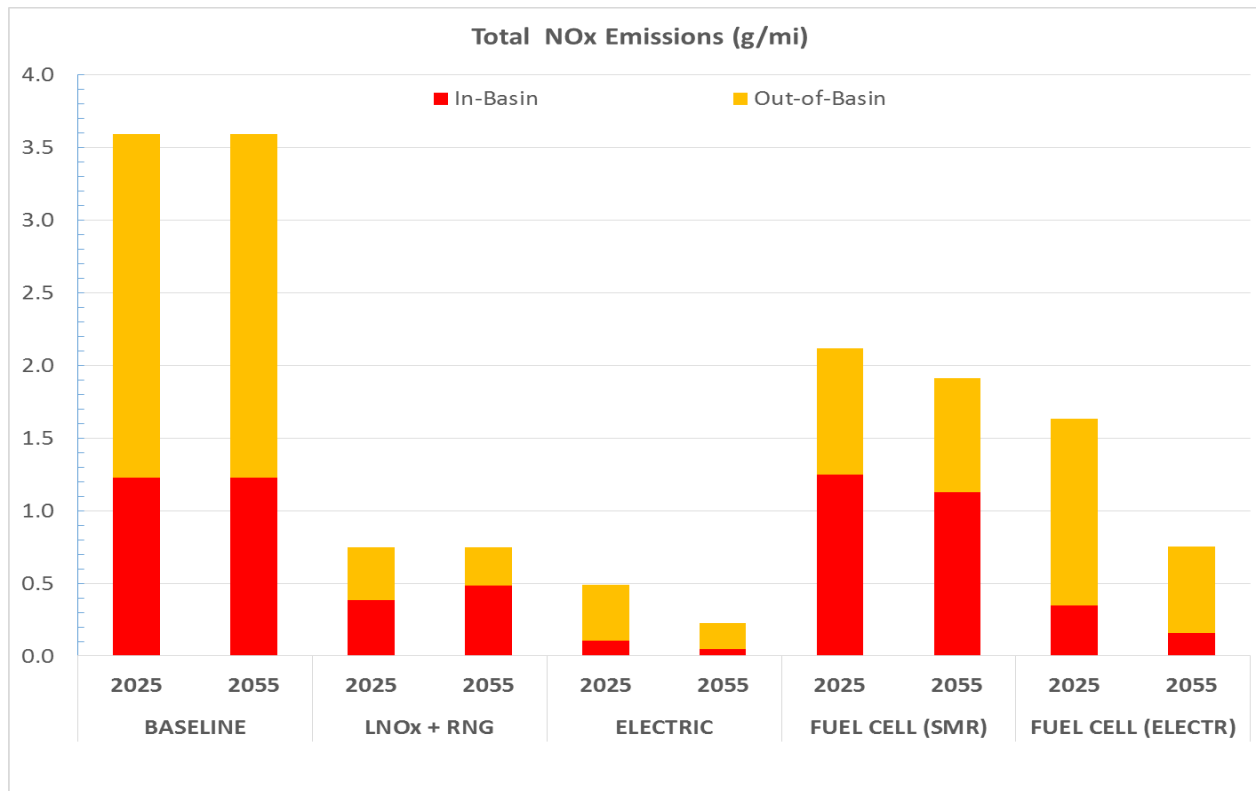
# ELECTRICITY GRID MIX



ARB targets for  
future  
generation

78% zero  
emission  
generation by  
2050

# NO<sub>x</sub> EMISSIONS (G/MI)

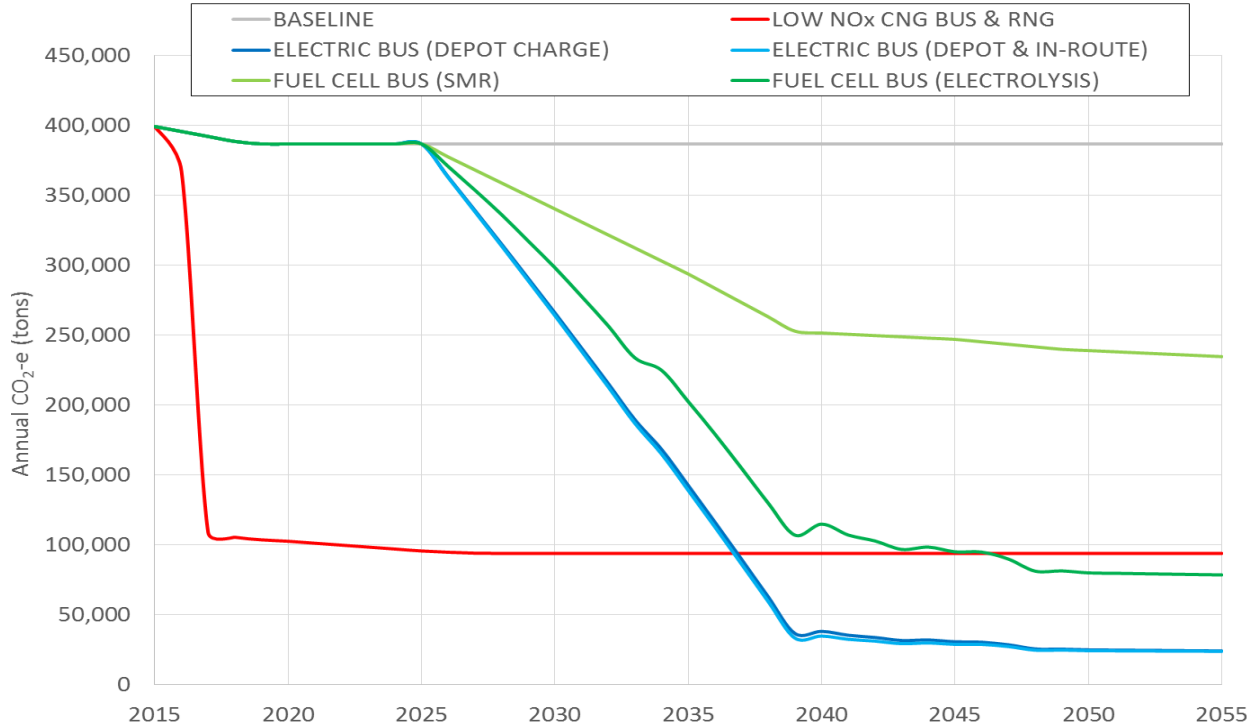


Tailpipe emissions per EMFAC2014 emissions model.

Upstream emissions per CA GREET.

RNG assumed to be 100% landfill gas.

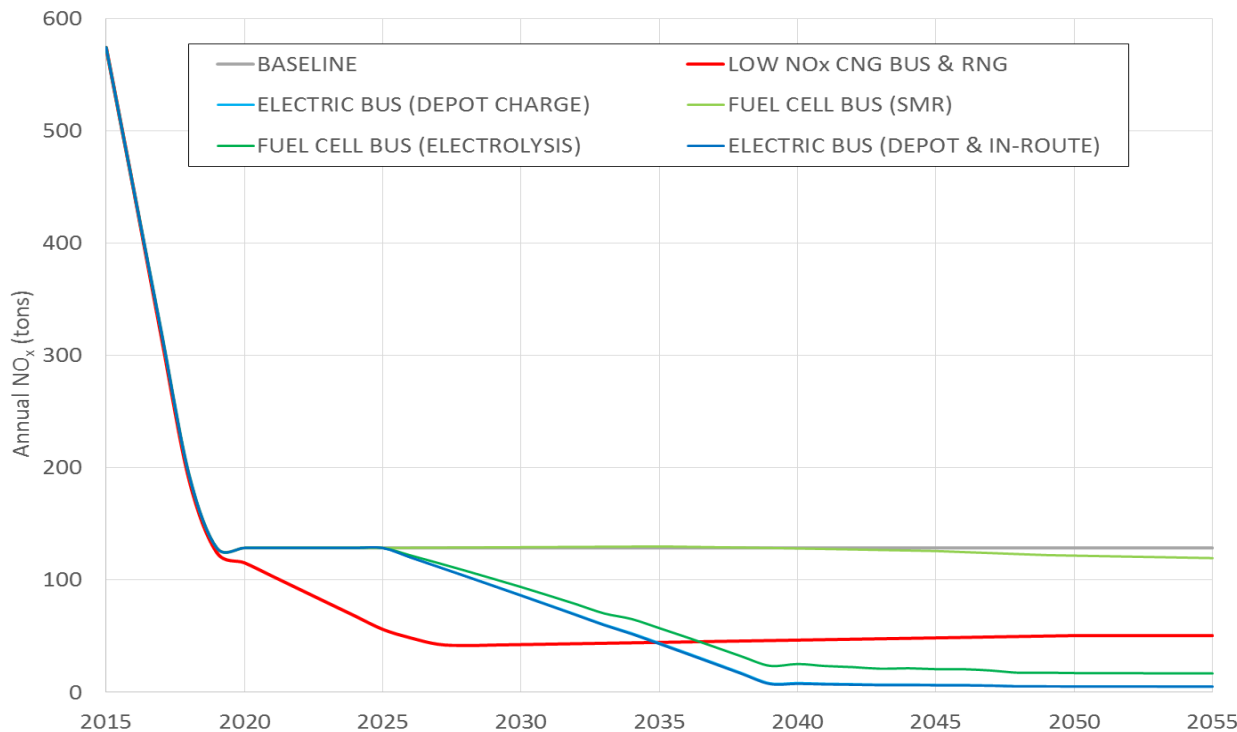
# PROJECTED ANNUAL FLEET GHG (TONS CO<sub>2</sub>-E)



Significant early reductions from RNG use. Low NOx engine gives minor reduction due to lower tailpipe CH<sub>4</sub>

Emissions from H<sub>2</sub> produced by SMR significantly higher than other options

# PROJECTED ANNUAL FLEET NO<sub>x</sub> (IN-BASIN TONS)



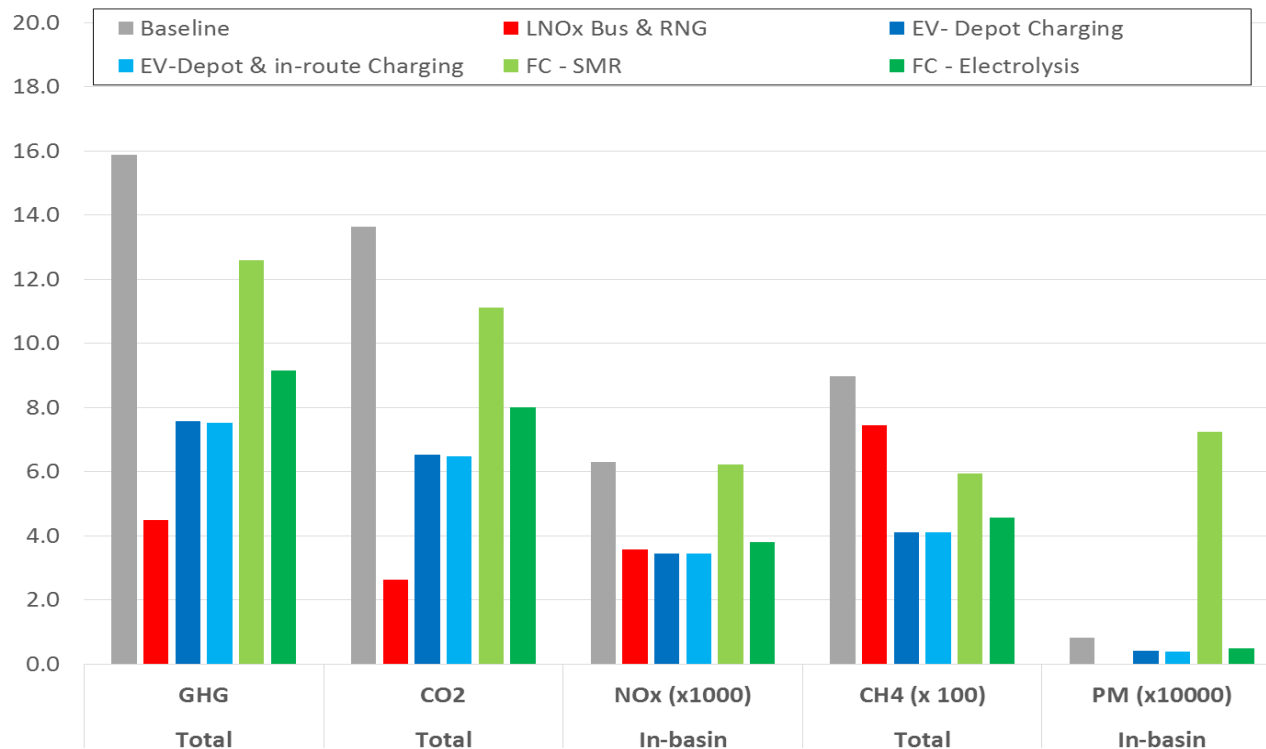
Significant reductions under baseline as fleet turns over to 2010+ engines.

Low NO<sub>x</sub> engine further reduces emissions

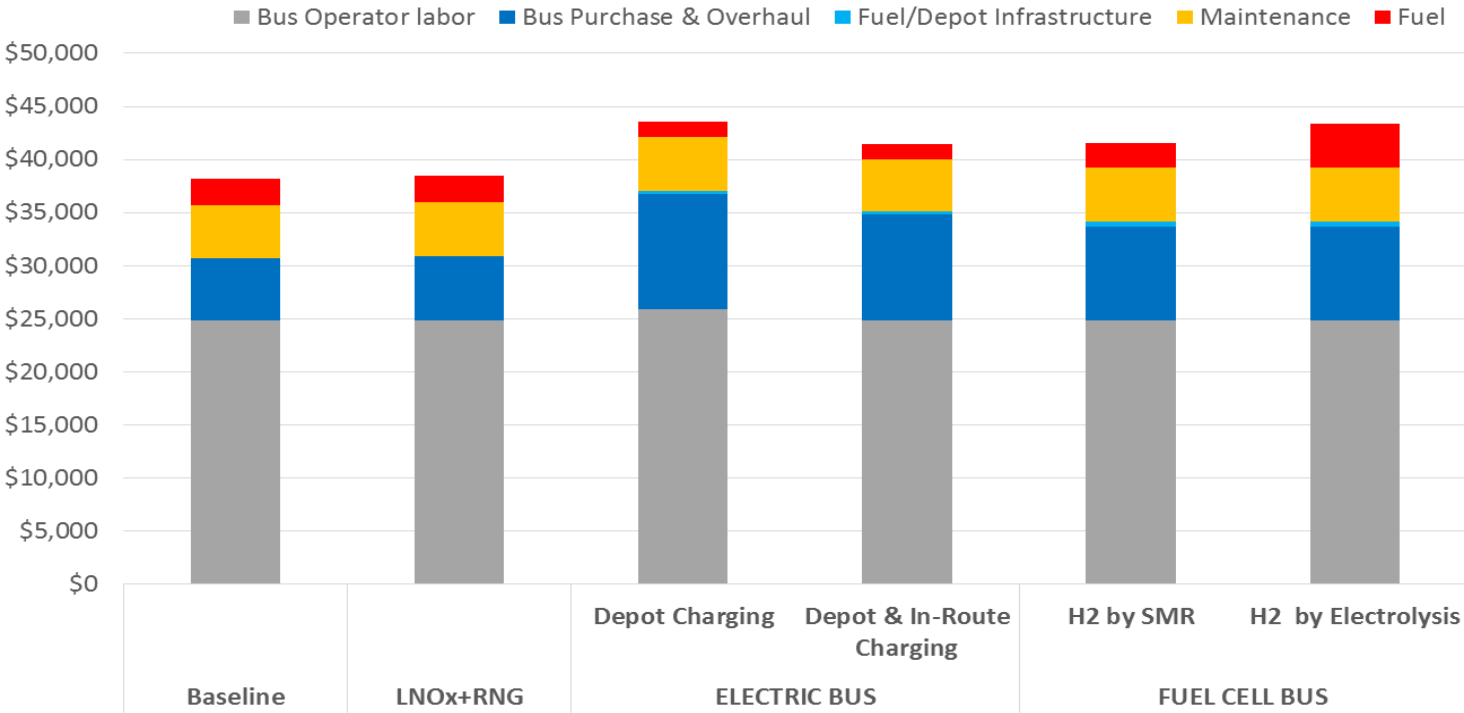
Emissions from H<sub>2</sub> produced by SMR similar to baseline



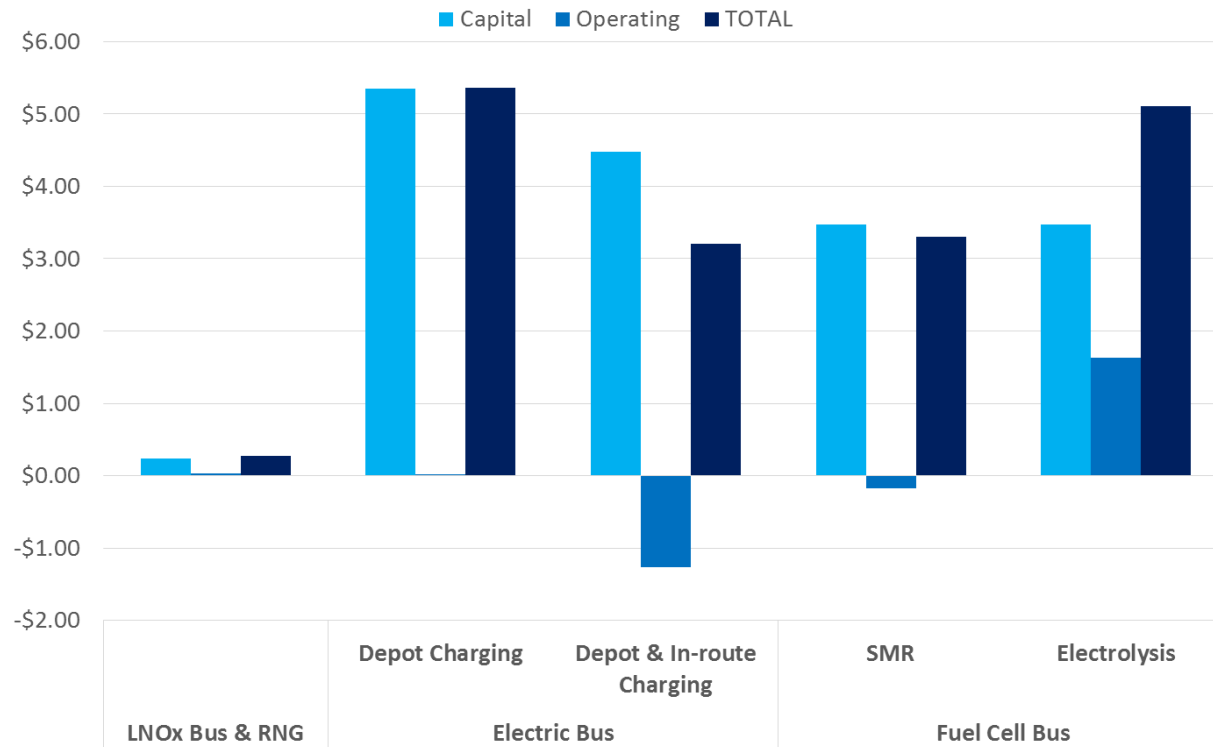
# PROJECTED TOTAL FLEET EMISSIONS 2015 – 2055 (MILLION TONS)



# PROJECTED TOTAL FLEET COSTS 2015 – 2055 (\$ MILLIONS)



# PROJECTED INCREMENTAL FLEET COSTS 2015 – 2055 (\$ BILLIONS)



Compared to baseline:

- LNOx+RNG +1%
- Electric Bus +8%-14%
- Fuel Cell Bus +9%-13%

# EMISSION REDUCTION COST EFFECTIVENESS 2015 – 2055 (\$/TON)

		LNOx + RNG	ELECTRIC BUS		FUEL CELL BUS		
			Depot Charge	Depot & In-route	SMR	ELECTR	
Compared to Baseline	Cost Increase (NPV \$ million)	\$161.3	\$2,154.9	\$1,224.5	\$1,420.7	\$1,992.4	
	GHG Reduction (million tons)	11.4	8.3	8.4	3.3	6.7	
	In-basin NO <sub>x</sub> Reduction (tons x 000)	2.7	2.9	2.9	0.1	2.5	
Cost Effectiveness (\$/ton) <sup>1</sup>		GHG	\$14	\$259	\$146	\$432	\$296
		IB NO <sub>x</sub>	\$59,000	\$755,000	\$427,000	\$20 mill	\$795,000

<sup>1</sup> Assumes that 100% of cost increase attributed to each pollutant

# SUMMARY

- ❑ Over the next 40 years the use of RNG and transition to Low NO<sub>x</sub> CNG engines will be:
  - More effective at reducing GHGs from the LACMTA fleet than transition to either Electric or Fuel Cell buses
  - More effective at reducing in-basin NO<sub>x</sub> emissions than transition to fuel cell buses, and almost as effective as transition to electric buses
  - Significantly less expensive than transition to either electric or fuel cell buses
- ❑ Emission reductions of both GHG and NO<sub>x</sub> from LNO<sub>x</sub> engines and RNG are an order of magnitude more cost effective than reductions from transition to electric or fuel cell buses



# THANK YOU

John Drayton  
Los Angeles Metro  
One Santa Fe Ave  
MS 63-1-1, Suite 100  
Los Angeles, CA 90013  
213-617-6285  
[Draytonj@metro.net](mailto:Draytonj@metro.net)

Dana Lowell  
M.J. Bradley & Assoc. LLC  
47 Junction Square Drive  
Concord, MA  
978-405-1275  
[dlowell@mjb Bradley.com](mailto:dlowell@mjb Bradley.com)

Julia Lester  
Ramboll/Environ  
707 Wilshire Boulevard  
Suite 4950  
Los Angeles, CA 90017  
213-943-6329  
[JLester@ramboll.com](mailto:JLester@ramboll.com)