Los Angeles Metro Technology Assessment

ZERO AND NEAR ZERO BUS OPTIONS

APTA Webinar

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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

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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

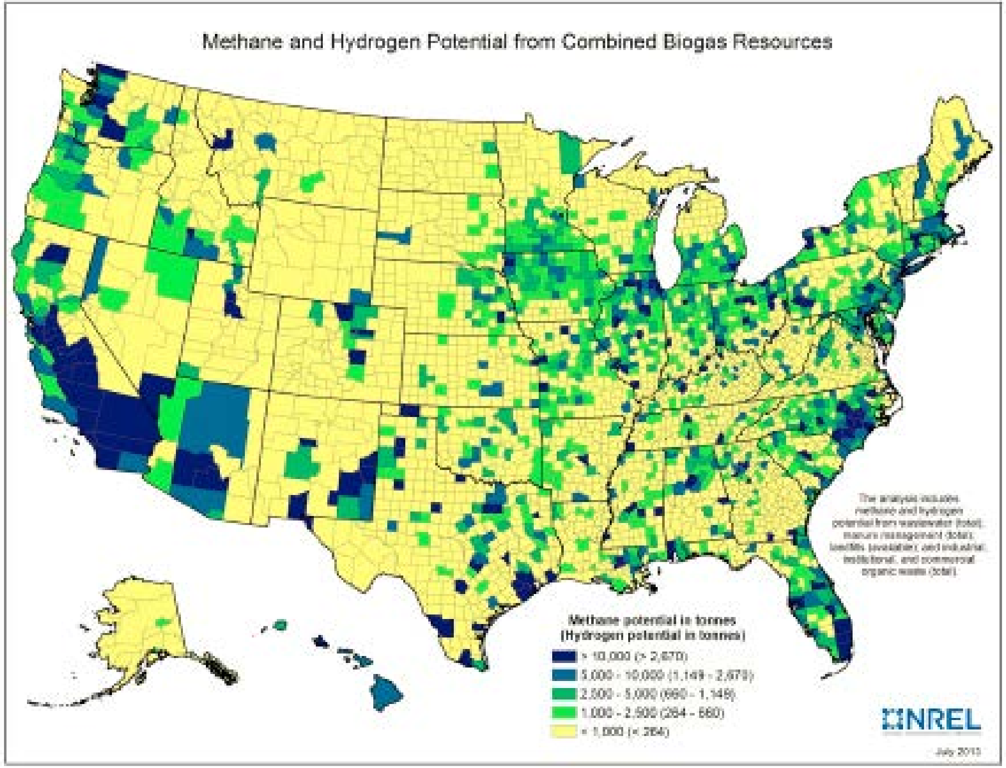
RENEWABLE NATURAL GAS (RNG)

- Produced by landfills, wastewater treatment plants, animal manure – anaerobic digestion
- Processed to remove water, sulfur, CO_2 - can be injected into pipelines, used in NG engines

LOW NOx NATURAL GAS ENGINE

- Commercially available from Cummins; based on ISLG platform used in transit
- 90% lower tailpipe NOx than required by EPA/CARB; 70% lower tailpipe CH_4

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

BUS TECHNOLOGY / FUEL SCENARIOS

	LNOx + RNG	ELECTRIC	FUEL CELL
FLEET REPLACE-MENT	Purchase 178 new buses/yr with LNO_x engines beginning in 2019 Repower 178 old buses/yr with LNO_x engines beginning in 2018	Purchase 178 – 240 [1] new electric buses/yr beginning in 2025.	Purchase 178 new fuel cell buses/yr beginning in 2025
FUELING	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)
NEW INFRA-STRUCTURE	None required	Depot and In-route chargers. Depot expansion for expanded fleet, and for depot chargers	Hydrogen production and fueling stations Upgraded ventilation, H_2 sensors at depots

[1] 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
BUS PURCHASE	2015	$490,000	$500,000	$760,000	$920,000
	2045	$490,000	$495,000	$692,000	$506,000
MID-LIFE OVERHAUL	2015	$35,000	$38,000	$281,000	$335,000
	2045	$35,000	$38,000	$237,000	$135,000
DAILY RANGE	2015	NA	NA	125 mi	NA
	2045	NA	NA	175 mi	NA
FUEL USE	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
FUEL COST		$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_2$ production and fuel station)
DEPOT MODS		NONE	NONE	$36,000/bus (depot expansion)	$28,000/bus ($H_2$ sensors & ventilation)

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

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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

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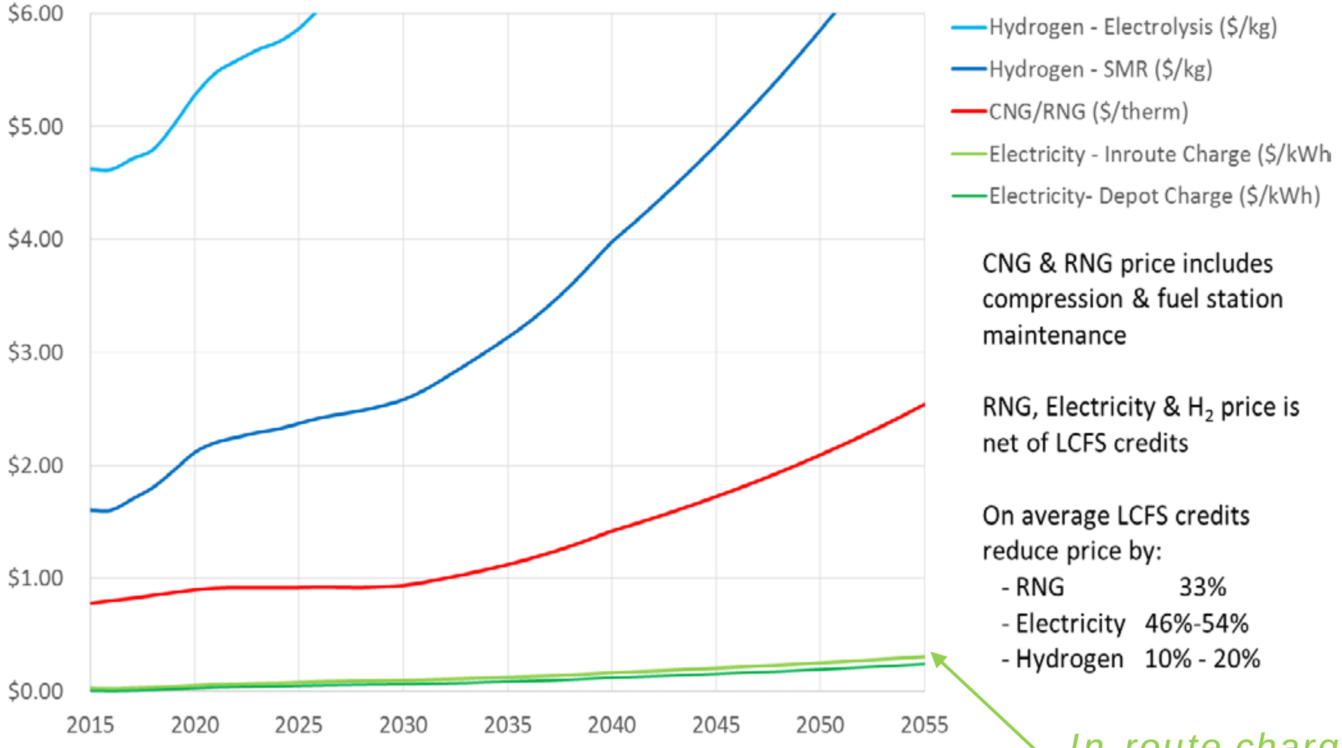
FUEL COSTS



CNG & RNG price includes compression & fuel station maintenance

RNG, Electricity & H_2 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

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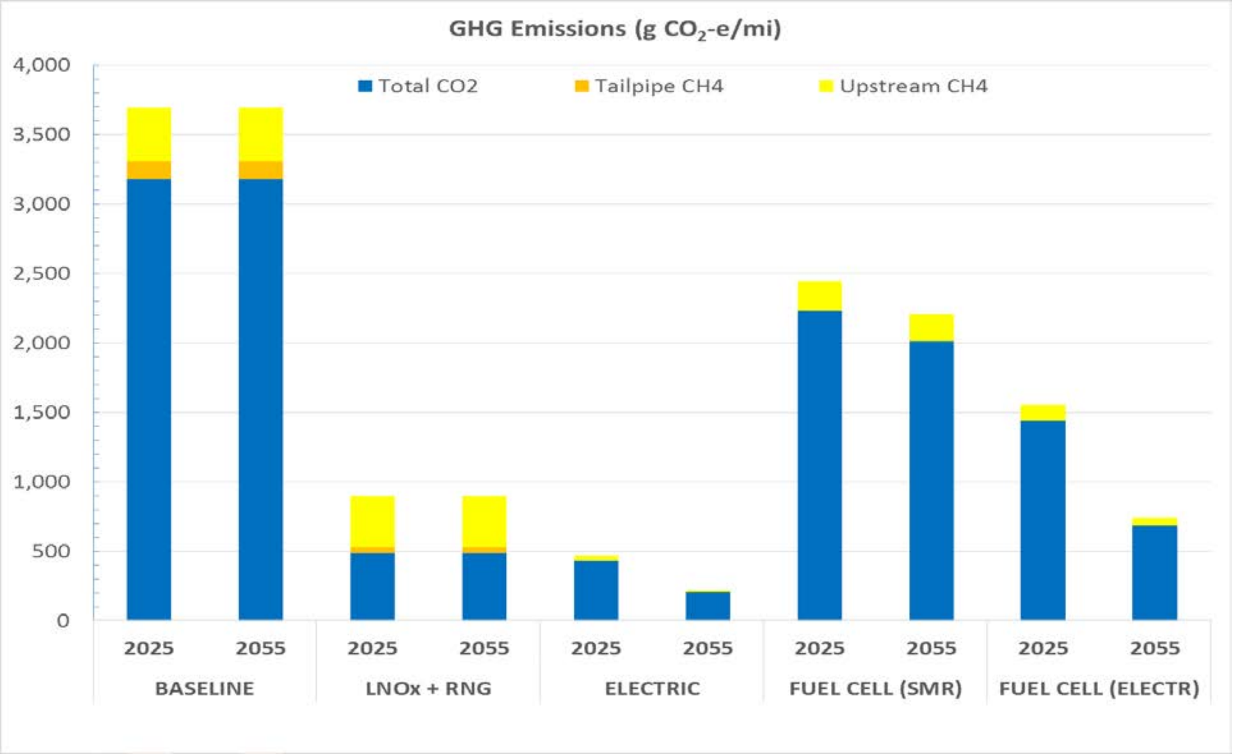
GHG EMISSIONS (G CO_2-E/MI)



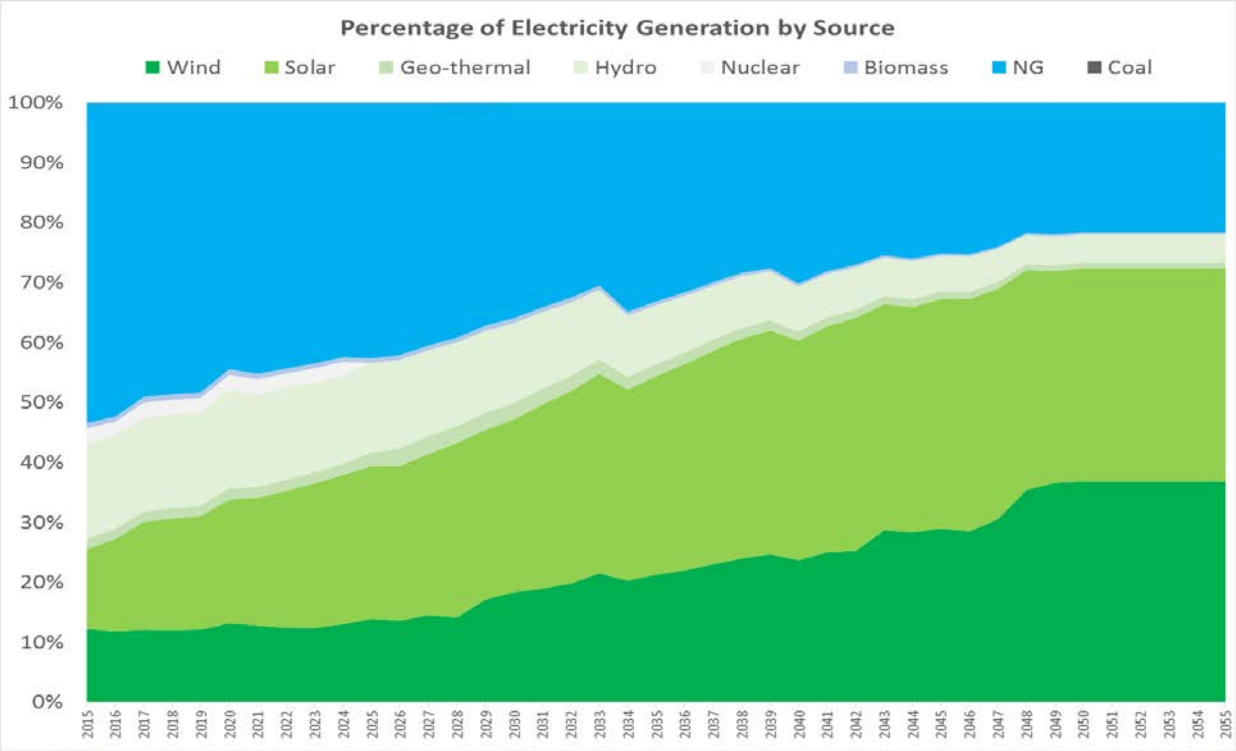
Tailpipe emissions per EMFAC2014 emissions model.

Upstream emissions per CA GREET.

CO_2 shown in chart is total tailpipe plus upstream

RNG assumed to be 100% landfill gas.

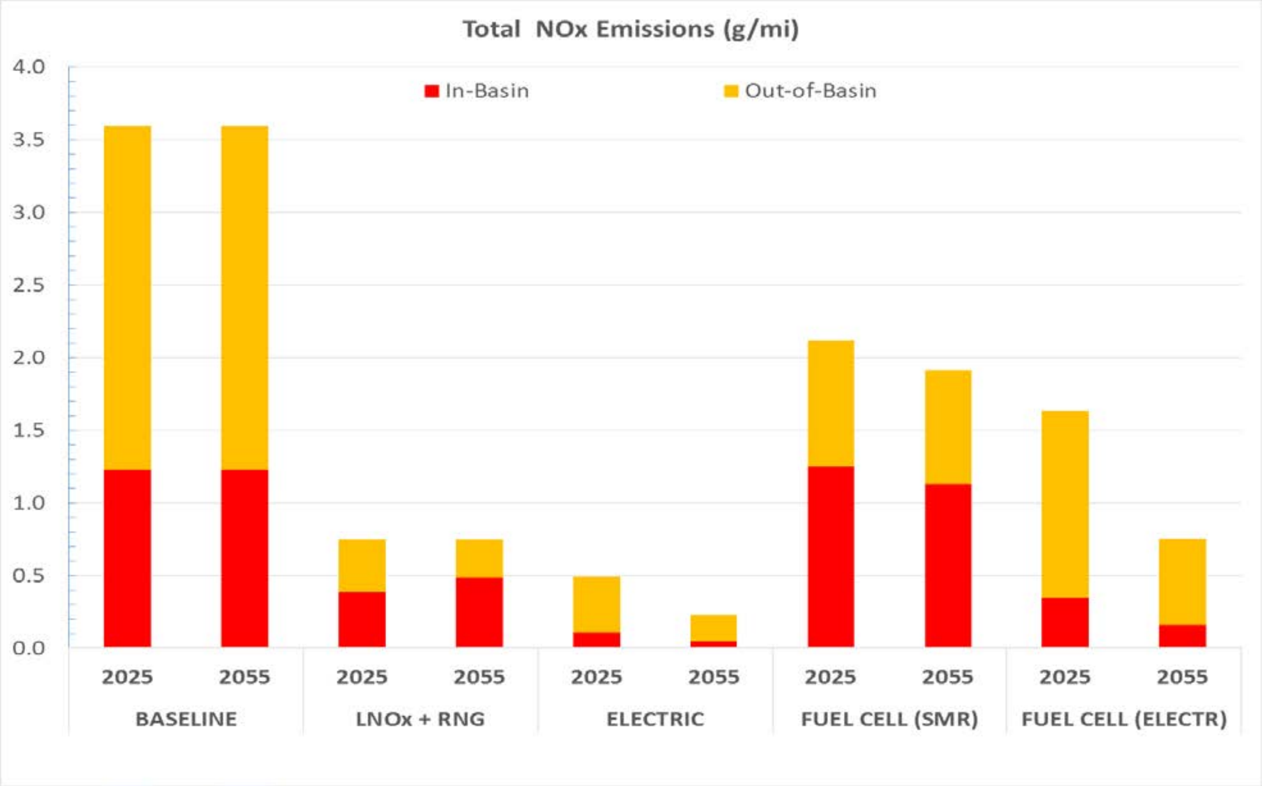
ELECTRICITY GRID MIX



ARB targets for future generation

78% zero emission generation by 2050

NO_X EMISSIONS (G/MI)

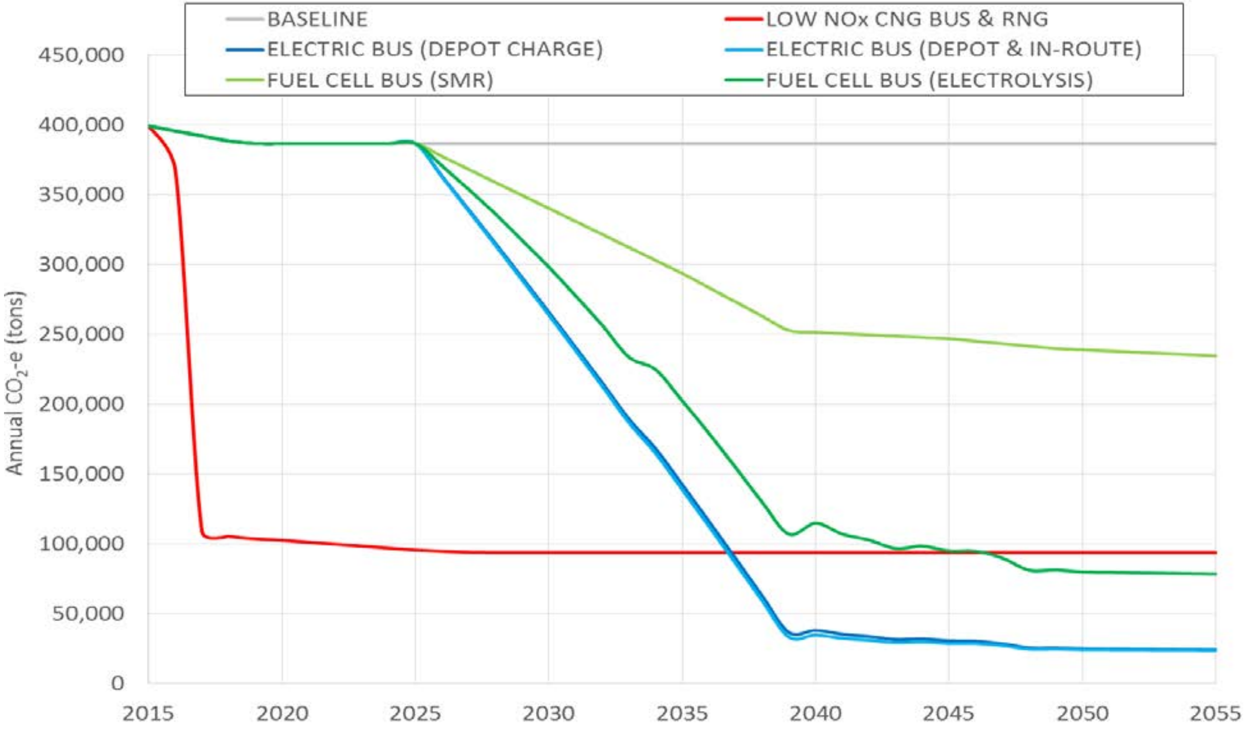


Tailpipe emissions per EMFAC2014 emissions model.

Upstream emissions per CA GREET.

RNG assumed to be 100% landfill gas.

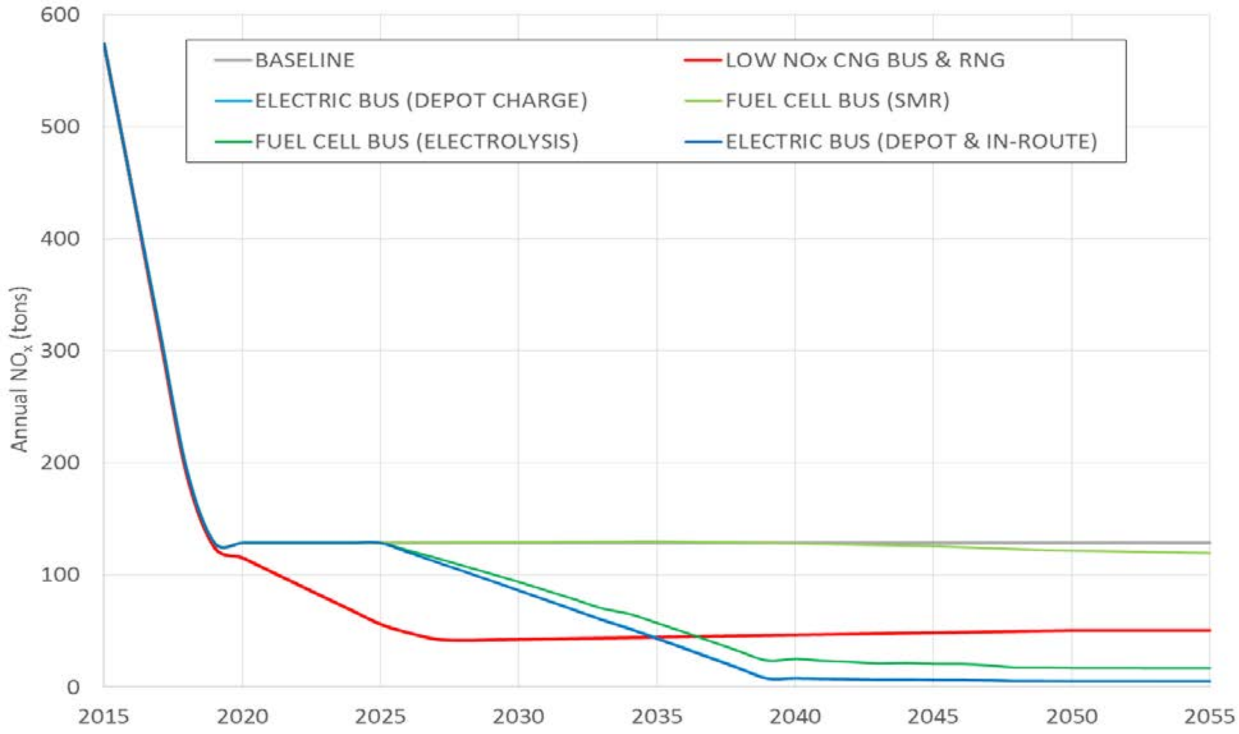
PROJECTED ANNUAL FLEET GHG (TONS CO_2-E)



Significant early reductions from RNG use. Low NOx engine gives minor reduction due to lower tailpipe CH_4

Emissions from H_2 produced by SMR significantly higher than other options

PROJECTED ANNUAL FLEET NO_X (IN-BASIN TONS)

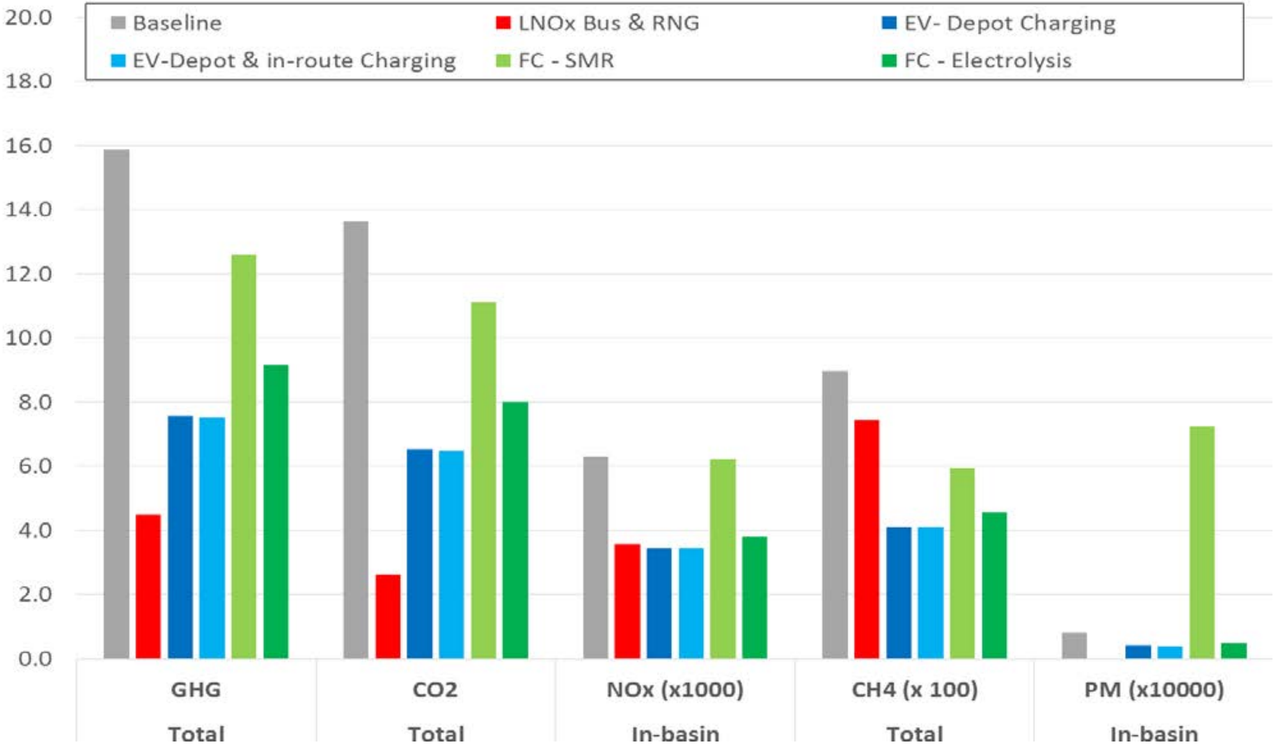


Significant reductions under baseline as fleet turns over to 2010+ engines.

Low NOx engine further reduces emissions

Emissions from H_2 produced by SMR similar to baseline

PROJECTED TOTAL FLEET EMISSIONS 2015 – 2055 (MILLION TONS)



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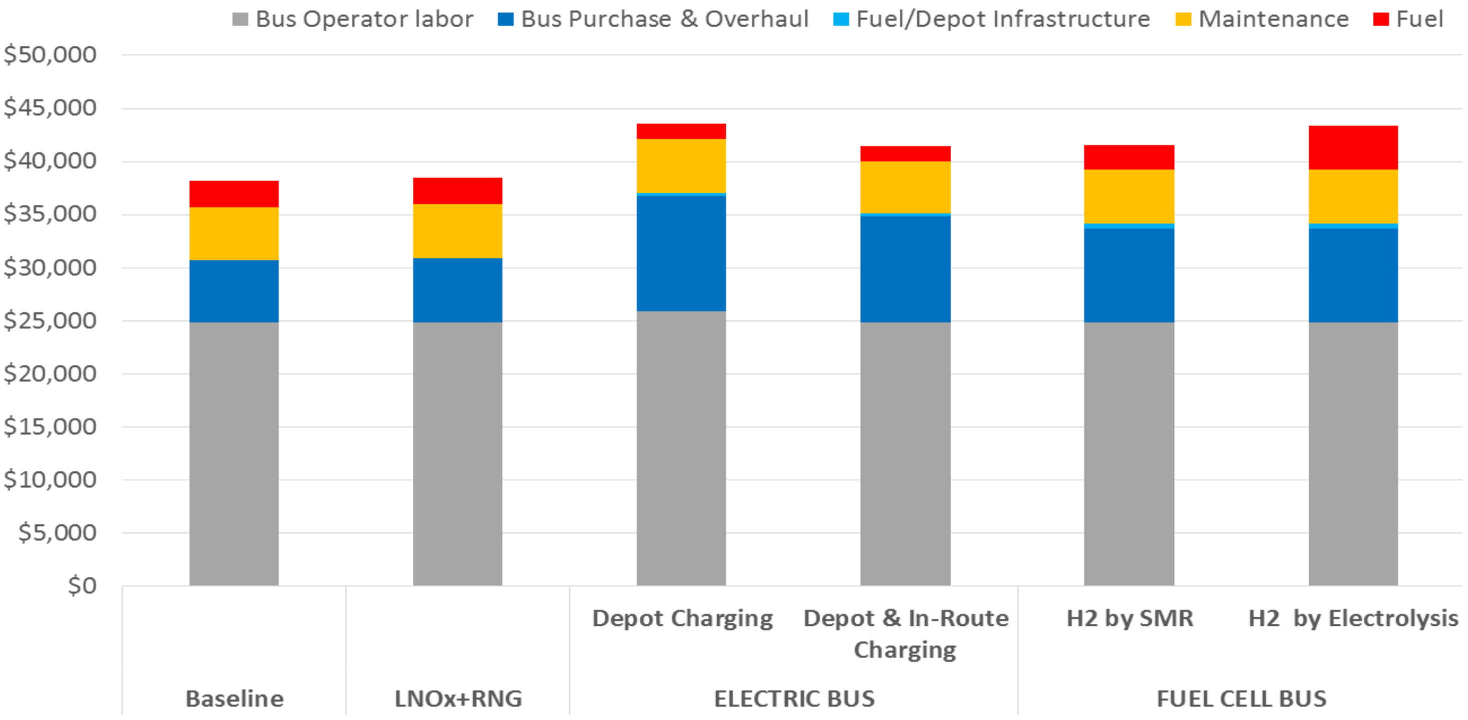
PROJECTED TOTAL FLEET COSTS
2015 – 2055 ($ MILLIONS)



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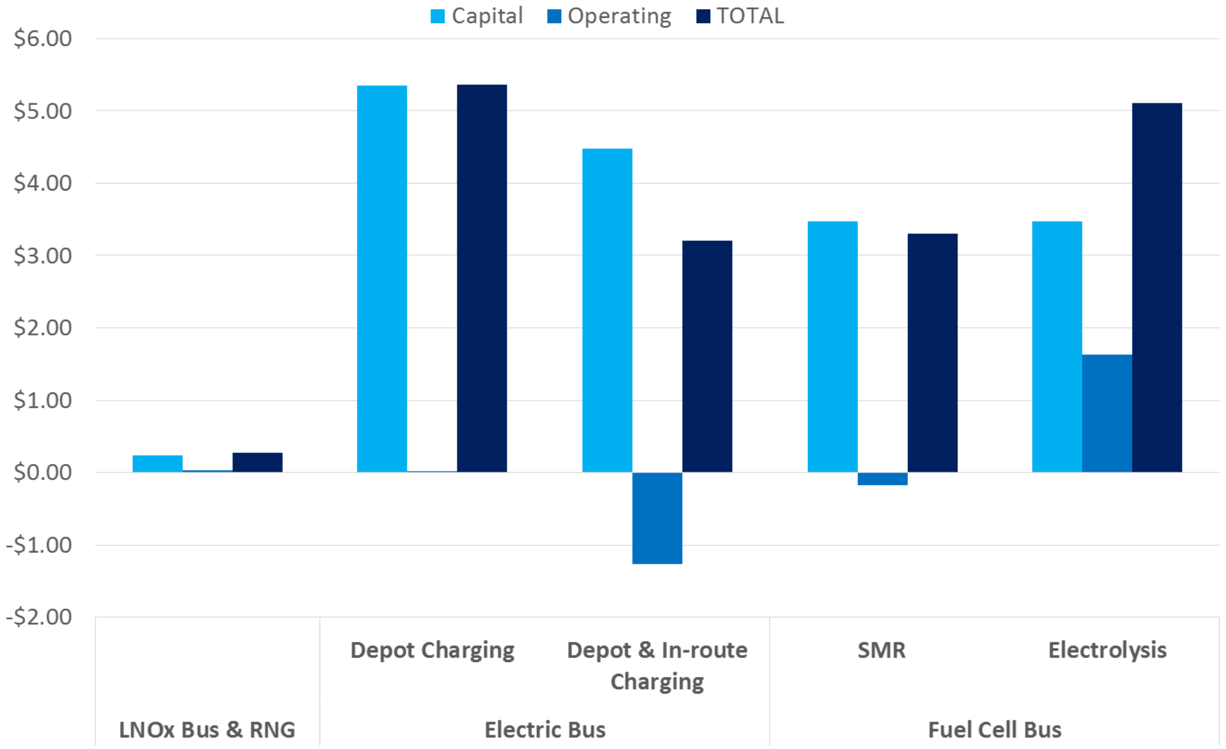
PROJECTED INCREMENTAL FLEET COSTS
2015 – 2055 ($ BILLIONS)



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	$1,992.4
	GHG Reduction (million tons)	11.4	8.3	8.4	3.3	6.7
	In-basin NO_x Reduction (tons x 000)	2.7	2.9	2.9	0.1	2.5
Cost Effectiveness ($/ton) [1]	GHG	$14	$259	$146	$432	$296
	IB NO_x	$59,000	$755,000	$427,000	$20 mill	$795,000

[1] 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_x 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_x 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_x from LNO_x engines and RNG are an order of magnitude more cost effective than reductions from transition to electric or fuel cell buses

THANK YOU

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