Compressed Natural Gas

"It gets easier after the first billion miles"

Los Angeles Metro's Plans for Implementation of "Near Zero" Low NOx Engines and RCNG

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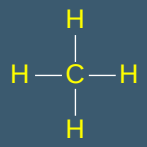
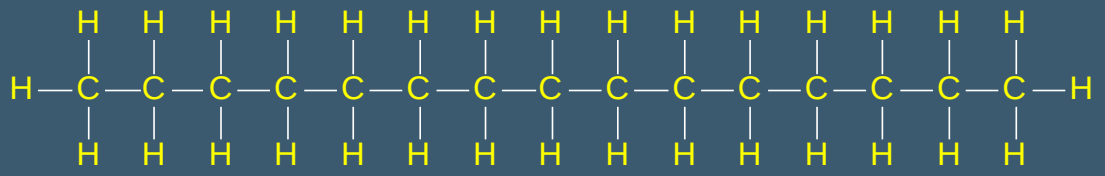
Alternative Fuel Basics – Hydrocarbon Fuels

Methane Gas
(CNG) CH_4



Diesel Fuel $C_{15}H_{32}$



More Carbon = More Energy + More Emissions

Hydrogen:	H_2	High Fuel Cost, lowest emissions
Methane (CNG):	CH_4	Lower Fuel Cost, lower emissions
Gasoline:	C_6H_{14}	Higher Fuel Cost, higher emissions
Diesel:	$C_{15}H_{32;}$	Higher Fuel Cost, higher emissions
Coal:	$C_{240}H_{90}O_4NS$	Lowest Fuel Cost, highest Emissions
Electricity:	NA	Note - Primarily sourced from hydrocarbons.
RCNG	CH_4	Methane from renewable/bio source

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History of Alternative Fuel and CNG Buses at Metro

Metro's Alternative Fuel Fleet

- First 10 CNG buses purchased in 1988
- Purchased fleet of 333 Methanol buses 1989-1992
- AFI Policy Adopted - Purchased only CNG buses since 1992
- First fleet purchase of 294 CNG buses in 1995
- CNG Fueling Public/Private Partnerships in 1998
- 100% CNG Operation since 2011
- ~ 2500 CNG buses; 85m+ miles/year.
- ~ 1.5 billion miles on CNG buses

1973 "Steam Bus"

- GMC New Look bus with custom built Leer Co. steam engine
- Unreliable, inefficient, very high emissions
- "Yes, there are bad ideas…"

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Current Outlook for CNG at Metro

- We foresee continued refinement of CNG engines, exhaust systems. We also anticipate migrating to 100% RCNG within next 12 months, and Low NOx engines starting in 2018.

- CNG engines do require more maintenance than diesel (e.g. spark plugs, CNG tank inspections). Less of an issue with current engines.

- Recent Fuel Price History
  - Diesel currently $2.05/gallon (~$0.70/mile)
  - CNG cost $0.599/therm (~$0.40/mile)
  - Since 2002, average diesel fuel price for Metro is $2.80/gallon ($0.85 per mile)
  - Since 2002, average CNG fuel price for Metro is $0.51/therm ($0.38/mile).

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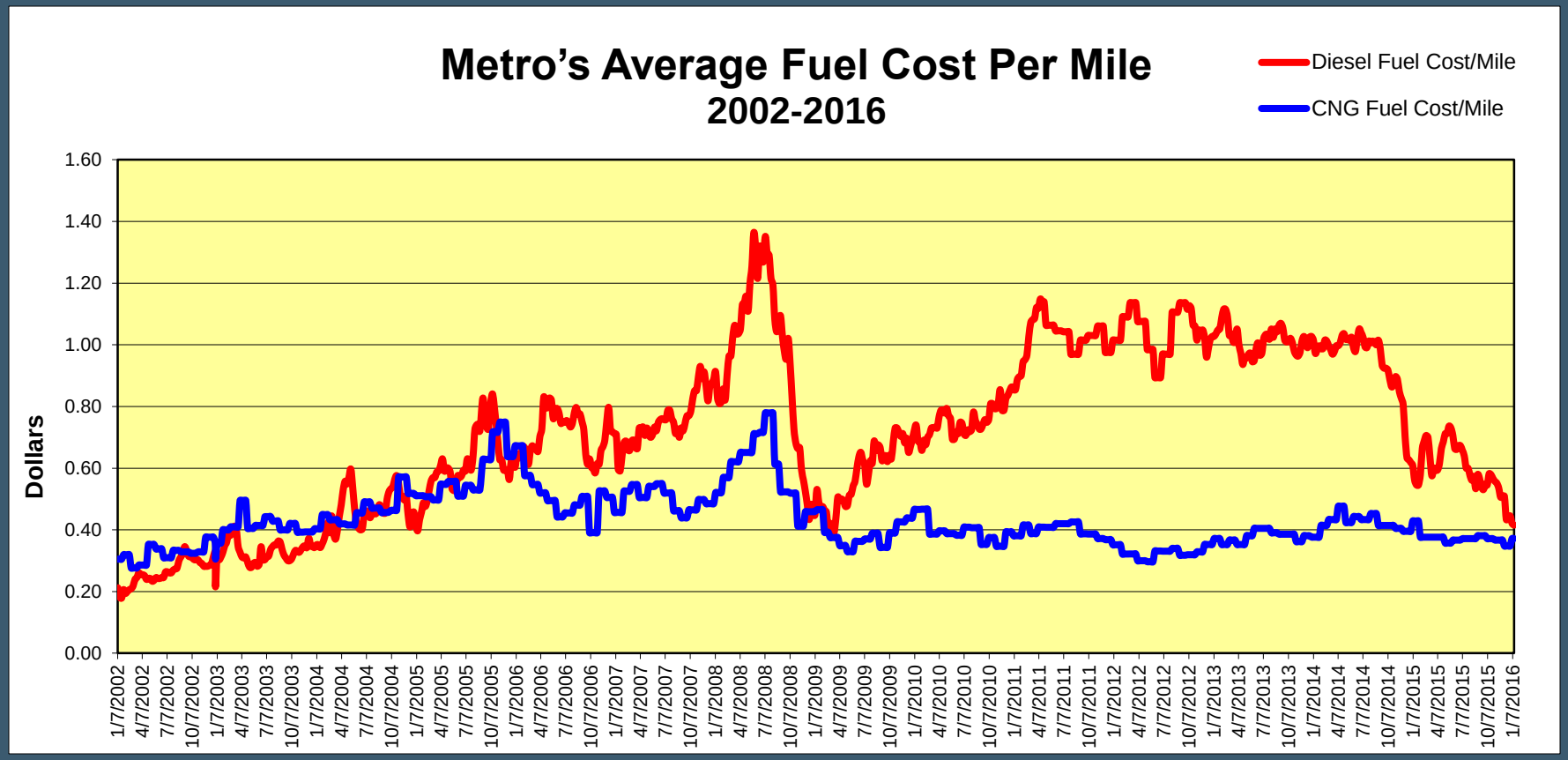
Comparison of CNG and Diesel Fuel Prices (cost/mile)



Metro has run 1.5 billion miles on CNG

Currently, CNG fuel is about $0.20/mile less than diesel

Over the last 15 years, Metro has saved an average of $0.45/mile on CNG fuel costs

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Next Generation CNG

Can “Near Zero” CNG engines reduce fleet emissions?

- Low NOx Engines with Renewable Natural Gas
  - New Low NOx engine were certified in 2016 at 0.02g/bhp
  - 90% NOx and PM reduction from 2010 EPA/CARB reg’s
  - 80% reduction in CO and GHG with RCNG
  - 0.02g/bhp NOx; PM <0.01g/bhp (nearing parity with electric bus?)
  - Low technology risk to RCNG/LoNOx engine
  - Nearly equivalent to battery electric ZE in Los Angeles
  - At LA Metro
    - One 2017 “Low NOx engine” now in daily operation
    - A second prototype 2018 engine also starting testing here

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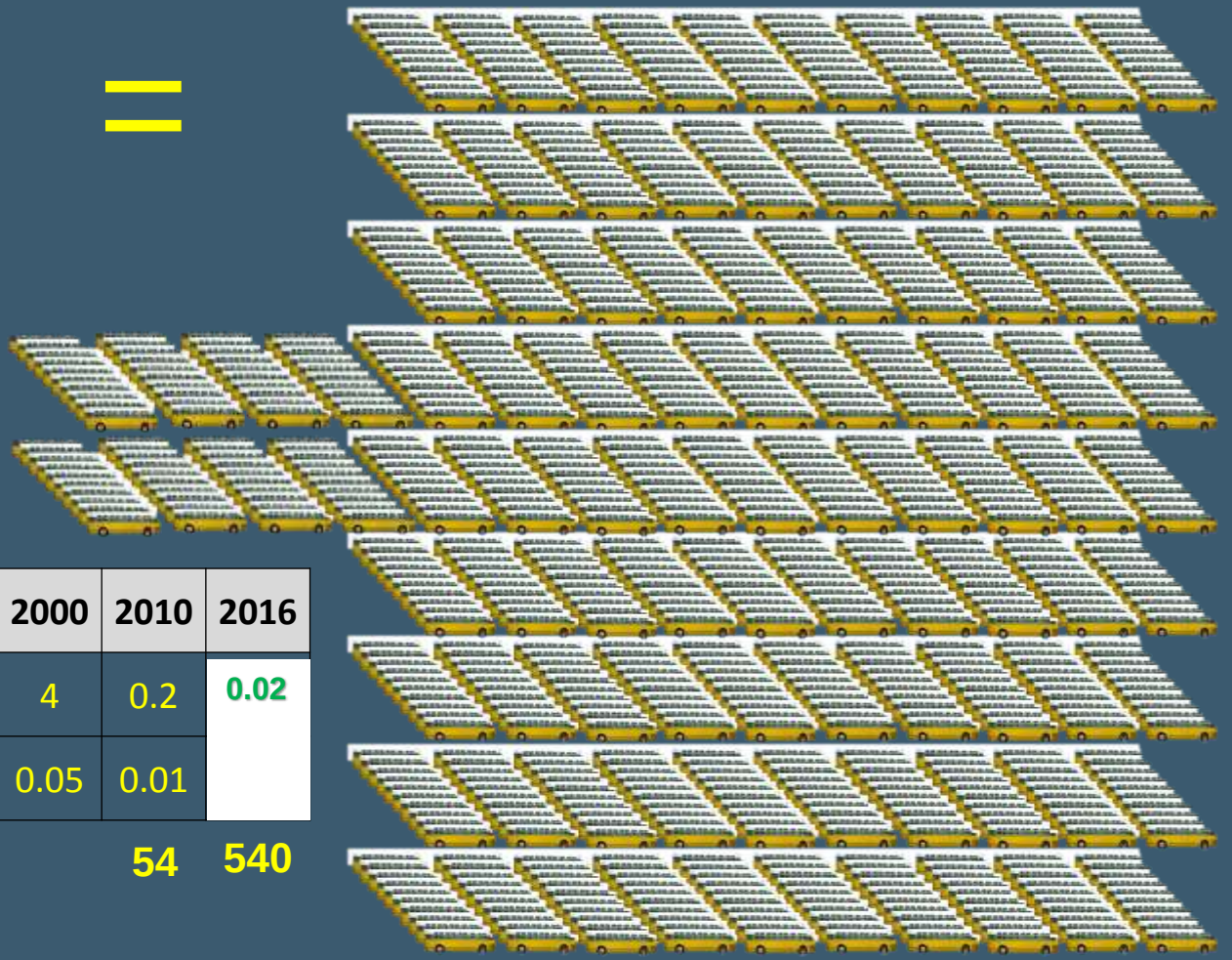
Emission Reductions Compared to 1990's Diesel Buses

One 1980 RTS-II

=

500+ Low NOx CNG Engines



	1985	1990	1991	2000	2010	2016
NOx (g/hp-hr)	10.8	6	5	4	0.2	0.02
PM (g/hp-hr)	0.59	0.59	0.25	0.05	0.01	
					54	**540**

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Analysis of Low Emission Options for Metro Bus

- Ramboll/Environ (Technical Consultant)
- Commissioned to review technologies and recommended options in June 2015
- Study conducted in 2015-2016
- Preliminary Draft in Feb 2016
- Follow-up Interviews with key stake-holders in spring/summer 2016
- Next update being prepared for release in October 2016

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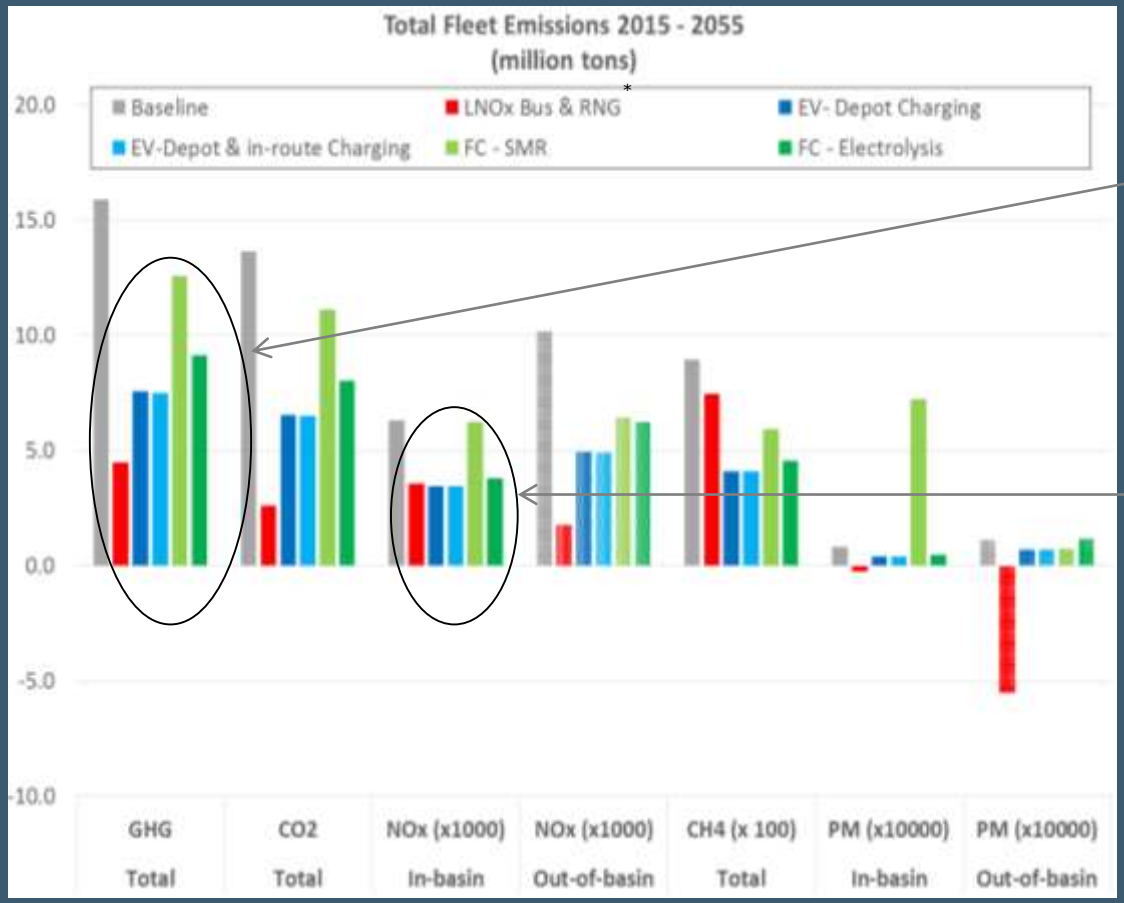
Projected Fleet Emissions 2015 - 2055



Of relevance to ARB:

- LNOx & RNG scenario has lower overall total GHG emissions than either EV or FC scenarios

Of relevance to SCAQMD:

- LNOx & RNG scenario has similar total in-basin NOx emissions to EV scenario
- LNOx & RNG has lower total in-basin NOx emissions to FC scenario

Notes:
* RNG assumed to be 100% landfill gas. If RNG included gas from wastewater treatment plants and/or food waste total NOx, CO_2, GHG, emissions from LNOx+RNG would be lower.

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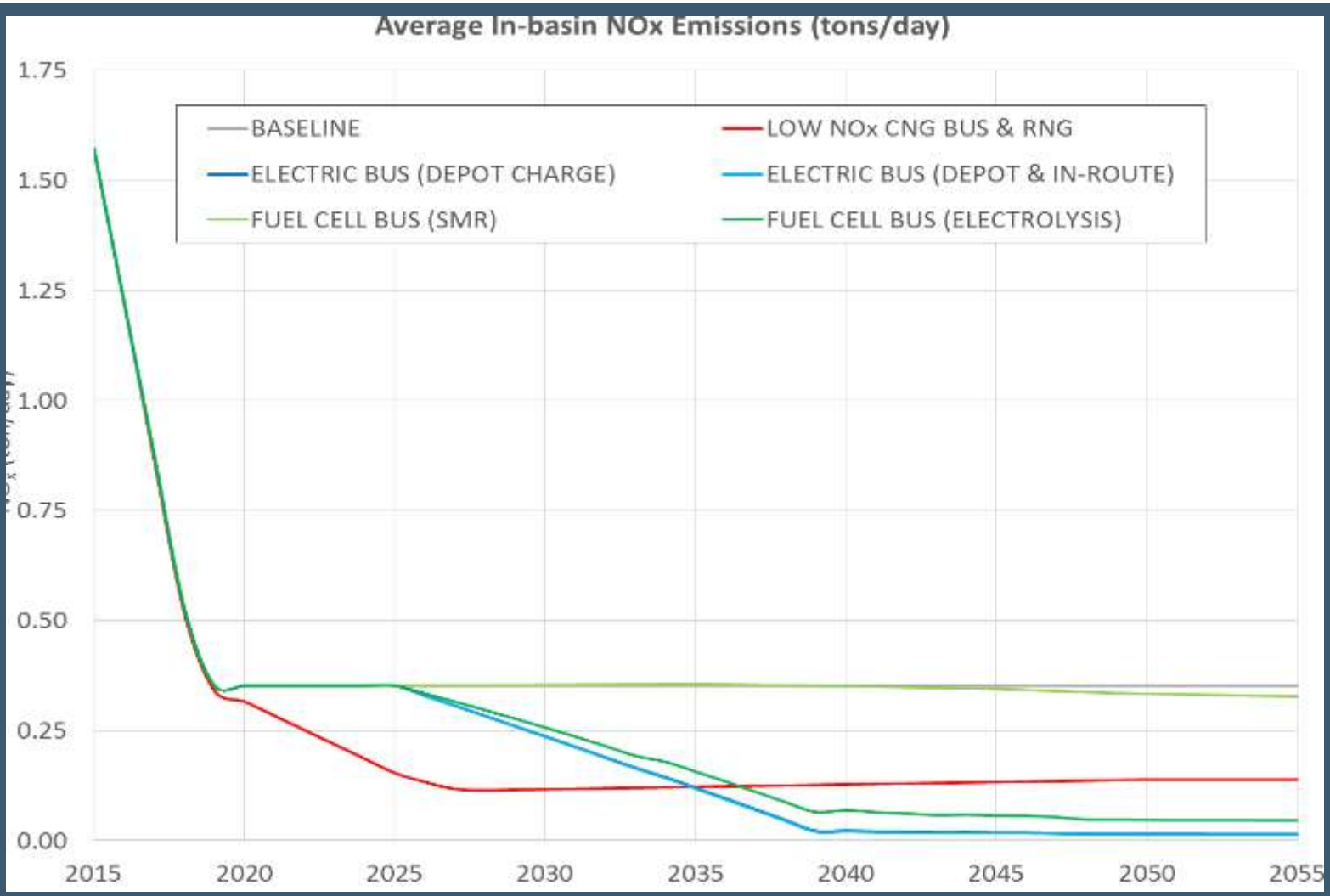
Potential NOX Reductions



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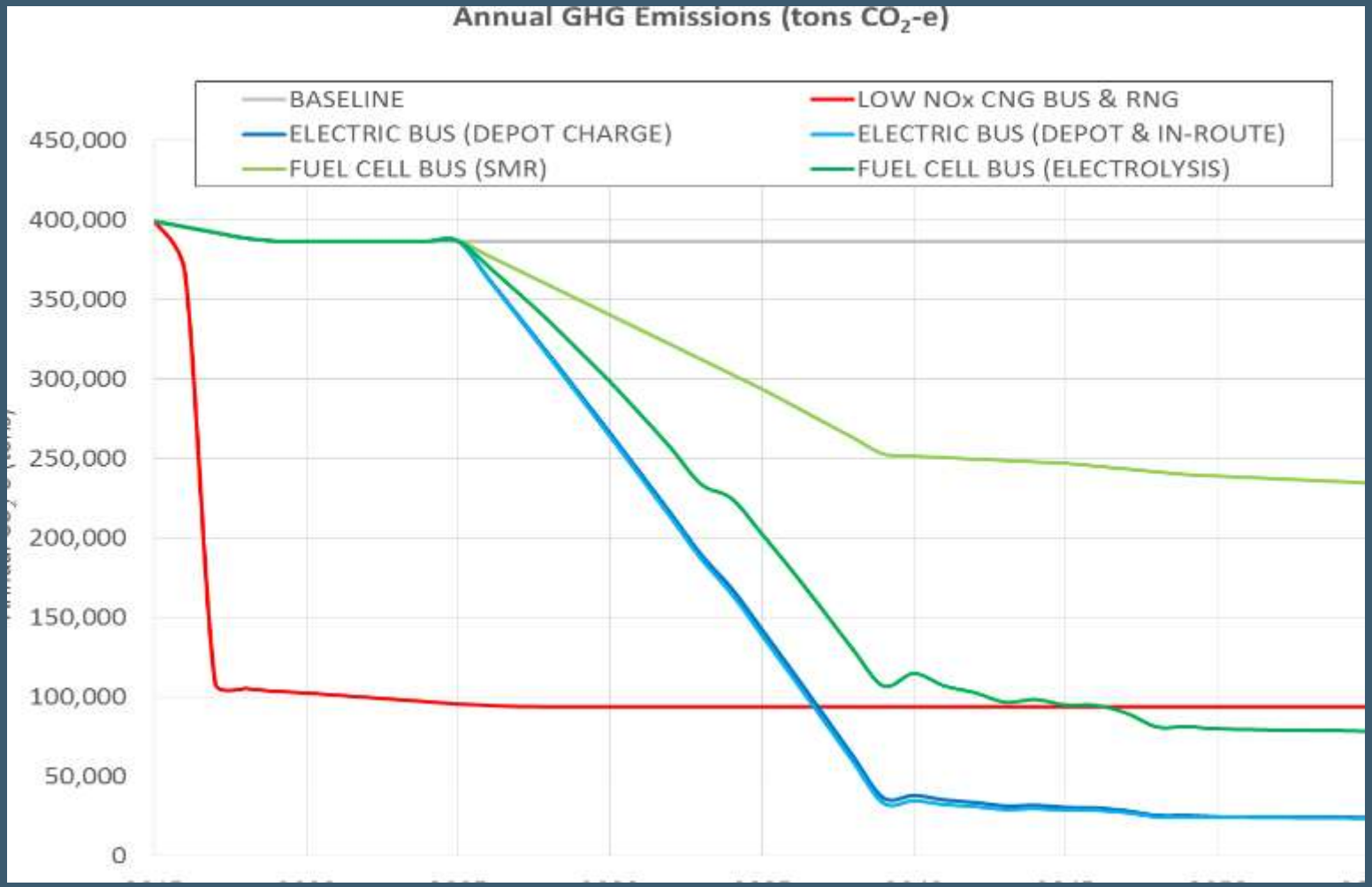
Potential GHG Reductions



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Emission Reduction Cost Effectiveness ($/ton)

		LNOx + RNG	ELECTRIC BUS		FUEL CELL BUS	
			Depot Charge	Depot & In-route	SMR	ELECTR
Compared to Baseline	Cost Increase (NPV $ million)	***$173***	$768	$376	$1,379	$1,680
	GHG Reduction (million tons)	***11.4***	8.2	8.2	3.3	6.7
	In-basin NO_x Reduction (tons x 1000)	2.72	2.83	***2.84***	0.07	2.50
Cost Effectiveness ($/ton) [1]	GHG	***$15***	$94	$46	$419	$250
	NO_x	***$64,000***	$272,000	$133,000	$20,200,000	$671,000

[1] Assumes that 100% of cost increase attributed to each pollutant

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Metro's Next Steps

- Immediate (FY18) adoption of RNG/LNOx buses for urgently needed AQMP NOx reductions and most expeditious GHG reductions for our region
- New Buses and Engine Repowers
  - Metro has a 1,000 bus RFP Underway – Contract awards in 1Q2017, deliveries thru 2022
  - Includes purchase of up to 800 new CNG buses with Low NOx engines.
  - Options for up to 200 ZEB battery electric buses.
  - We will also repower existing bus fleet with Low NOx engines starting in FY18 at 200 buses/year (goal of 100% CNG fleet should be low NOx by 2025).
- Transition to ZEBs when/where economically feasible for additional out-year reductions
  - Developing plans to electrify Orange Line and Silver Line BRT Services (85 buses)
- Near term ZEB efforts will focus on electric buses rather than fuel cell buses
- Preserve flexibility to adjust plans as ZE & low emission technologies evolve
  - Project total costs of a potential ZE fleet transition plan
  - Retain outside engineering/architecture firm(s) to start developing fleet electrification plans and cost estimates

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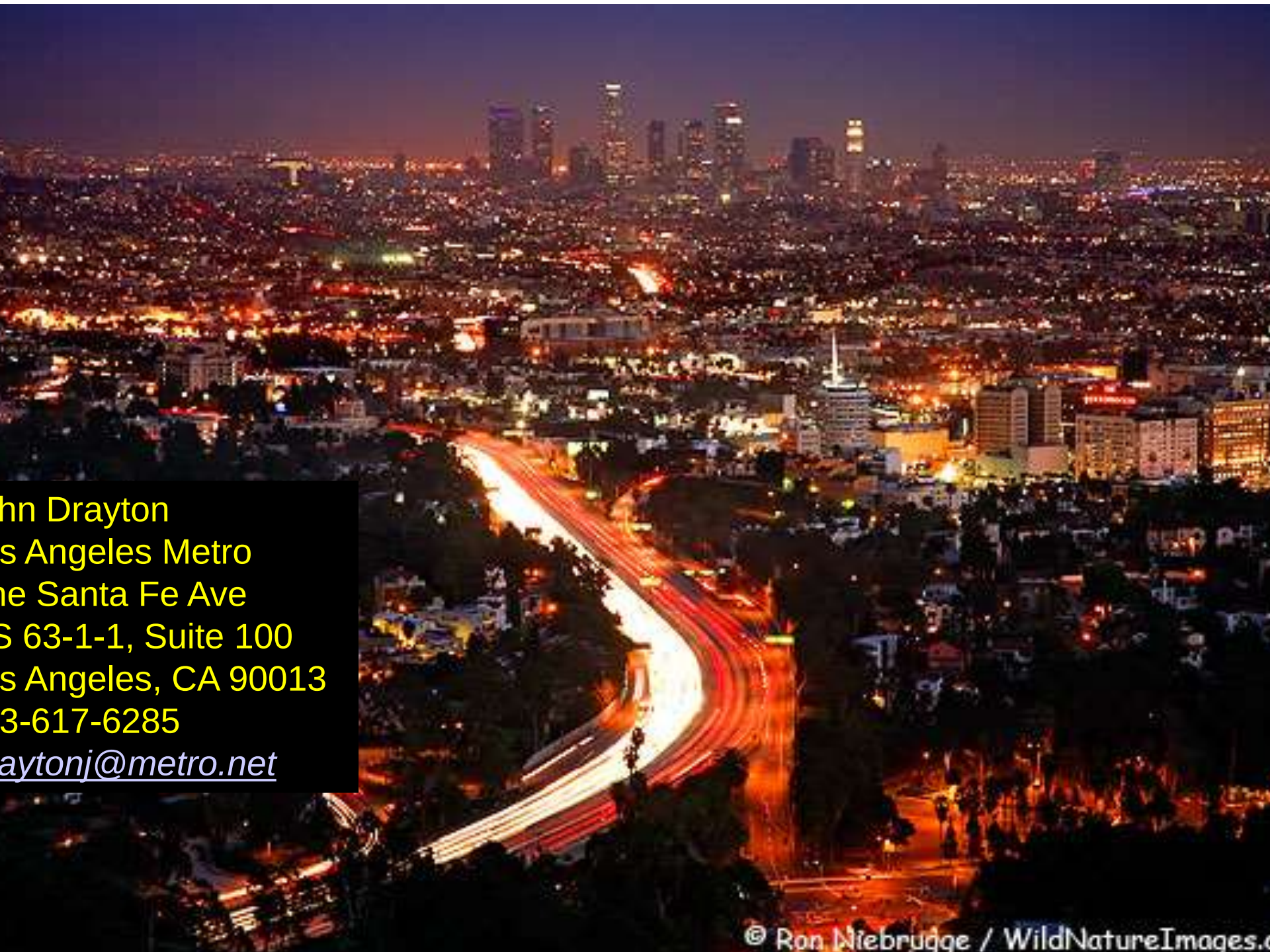
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