Draft
Cost Model Discussion with ACT Cost Subgroup

Mobile Source Control Division
Air Resources Board

August 23, 2016

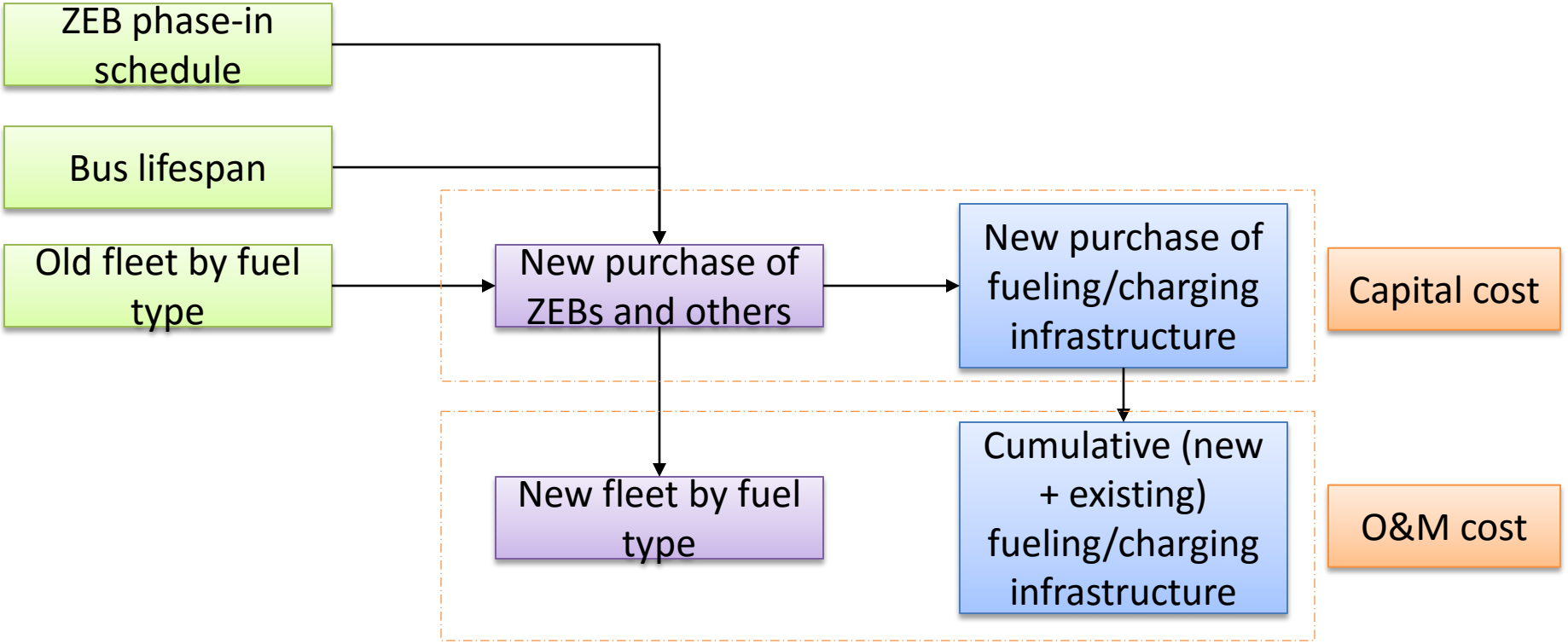
Agenda

- Overview of ARB's cost model:
- Comparison to Steve's model
- Continued data needs
- Cost assumptions
- LA Metro's presentation
- August 29 workgroup meeting agenda

ARB Fleet Cost Model Overview

- Cost items
  - Capital cost: vehicle, fueling infrastructure, maintenance infrastructure
  - O&M cost: vehicle maintenance, vehicle mid-life overhaul, vehicle fuel costs & LCFS credits, fueling infrastructure O& M
- Procurement schedule
  - Vehicle
  - Infrastructure
- Flexibility for different needs

ARB Fleet Cost Model Methodology



ARB Cost Model Features

- Timeframe: 2016 and 2040
- Constant dollars or nominal dollars (with inflation)
- Uses NTD data selection for specific agency or user defined fleet
- Bus replacements cycle capabilities
  - Regular cycles and ZEB phase-in (% of purchase) or
  - Custom irregular cycle with user input
- Costs for capital, mid-life, and O&M
  - Buses and infrastructure
- LCFS credits can vary by year

Comparison to Steve's Model

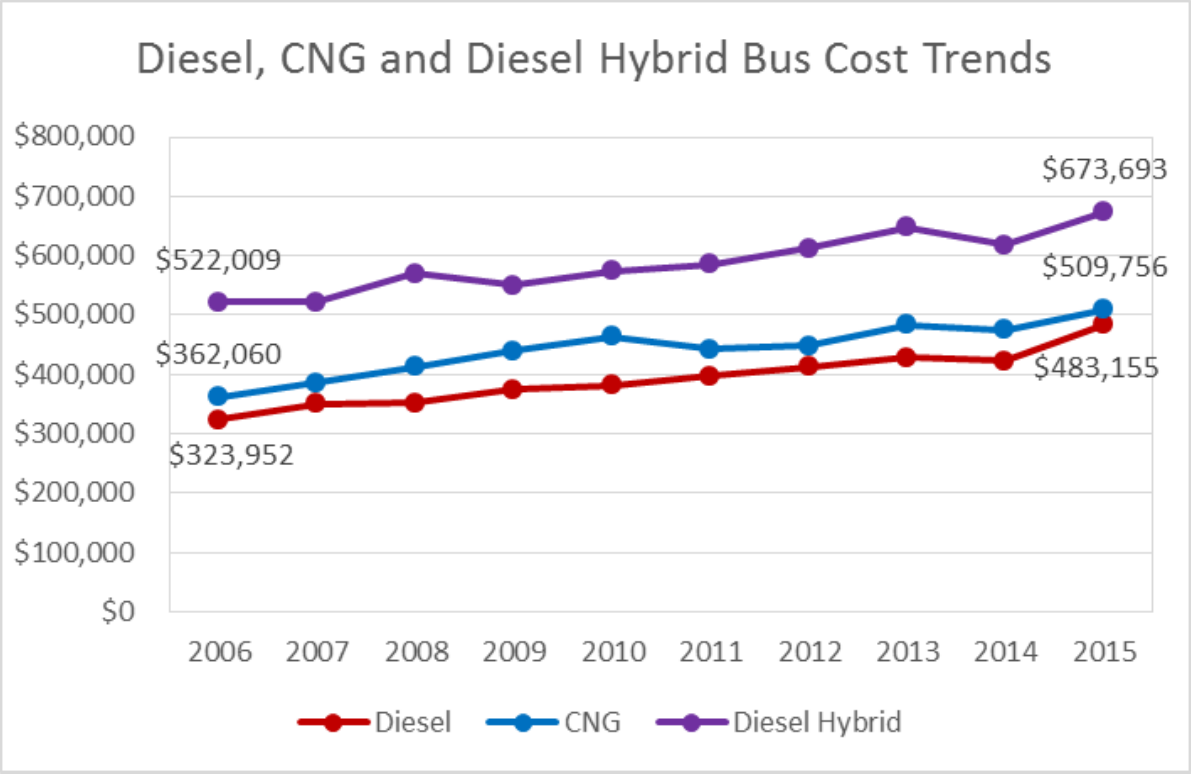
- Match inputs for capital and O&M costs
- Same bus/charger purchase schedule (triennial)
- Cash flow results essentially the same
  - Difference occurs in years where Steve's model does not retire ZEBs after end of useful life
- Questions about contract spare vehicles

Cost Inputs

- Bus prices
- Maintenance and brake costs
- Annual fuel costs
  - Fuel consumption
  - Long term fuel price
  - LCFS credit value
- Infrastructure

Bus Price History from APTA

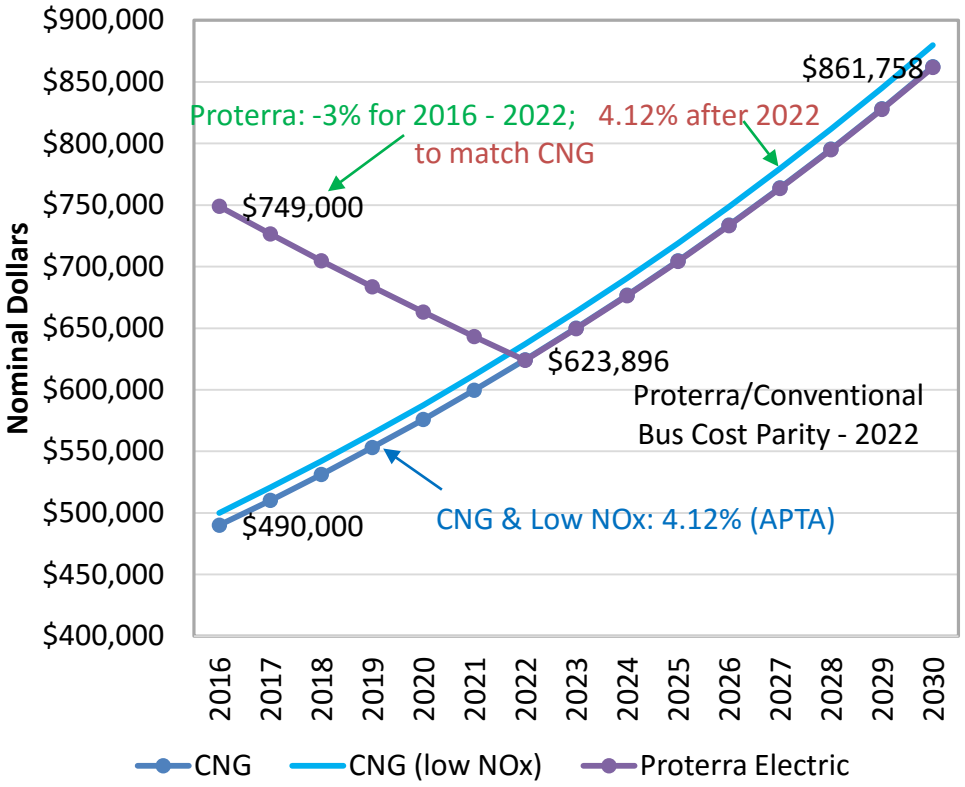
- 4.12% annual increase (nominal dollars)

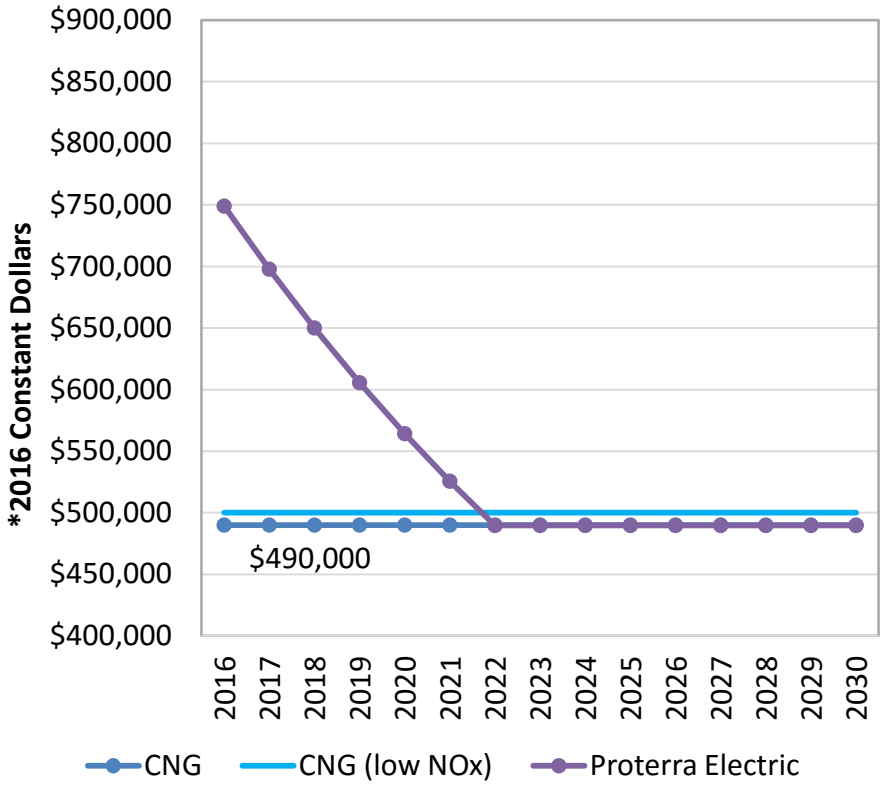


* Bus costs converted to constant dollars by using the historical price growth rate of 4.12%

Proterra Bus Price Projection

- Proterra (08/10/2016-08/19/2016, discussions with Alan Westenskow, Director of Business Development)

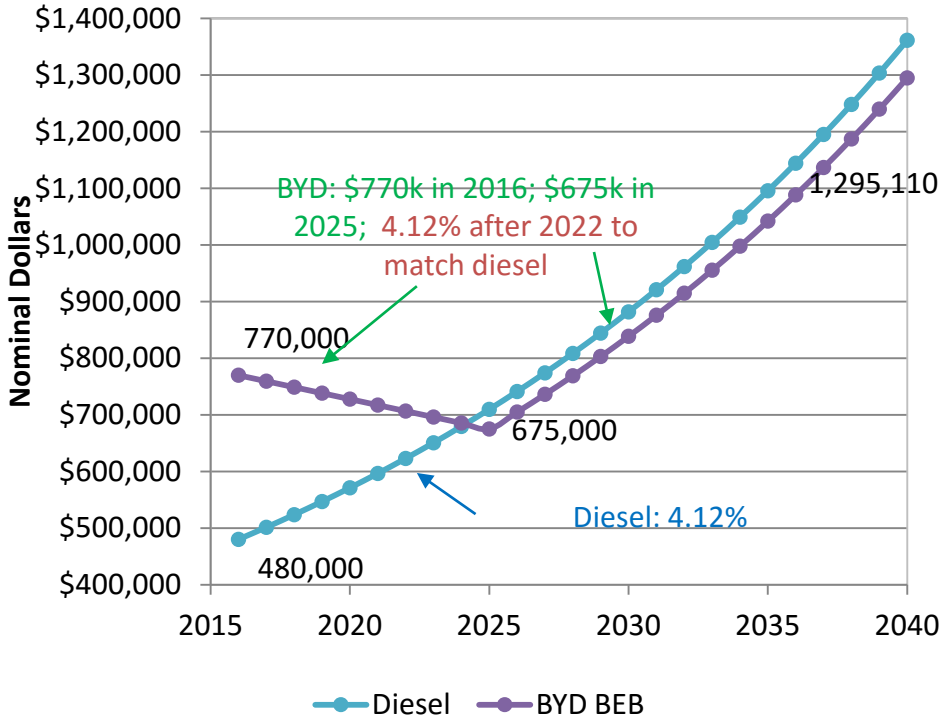


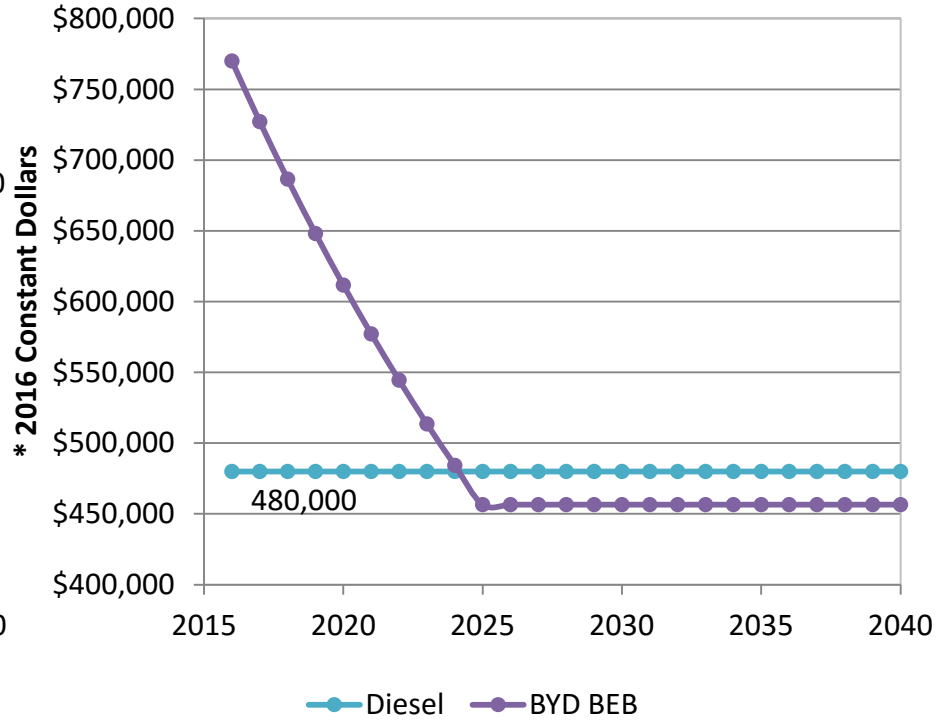


* Bus costs converted to constant dollars by using the historical price growth rate of 4.12%

BYD Bus Prices

- 08/22/2016, discussion with Vincent Wiraatmadja



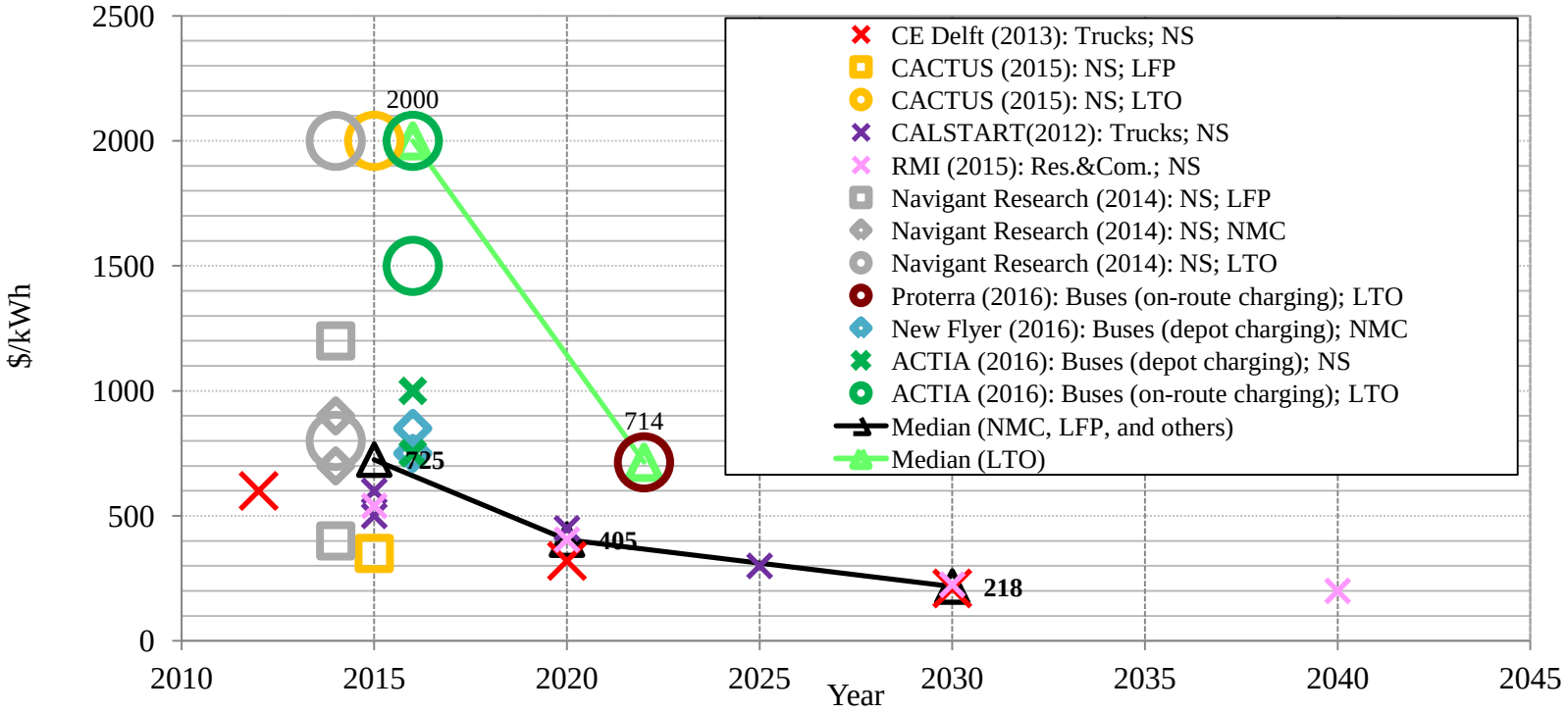


* Bus costs converted to constant dollars by using the historical price growth rate of 4.12%

Battery Price Reduction

(August Discussion Paper)

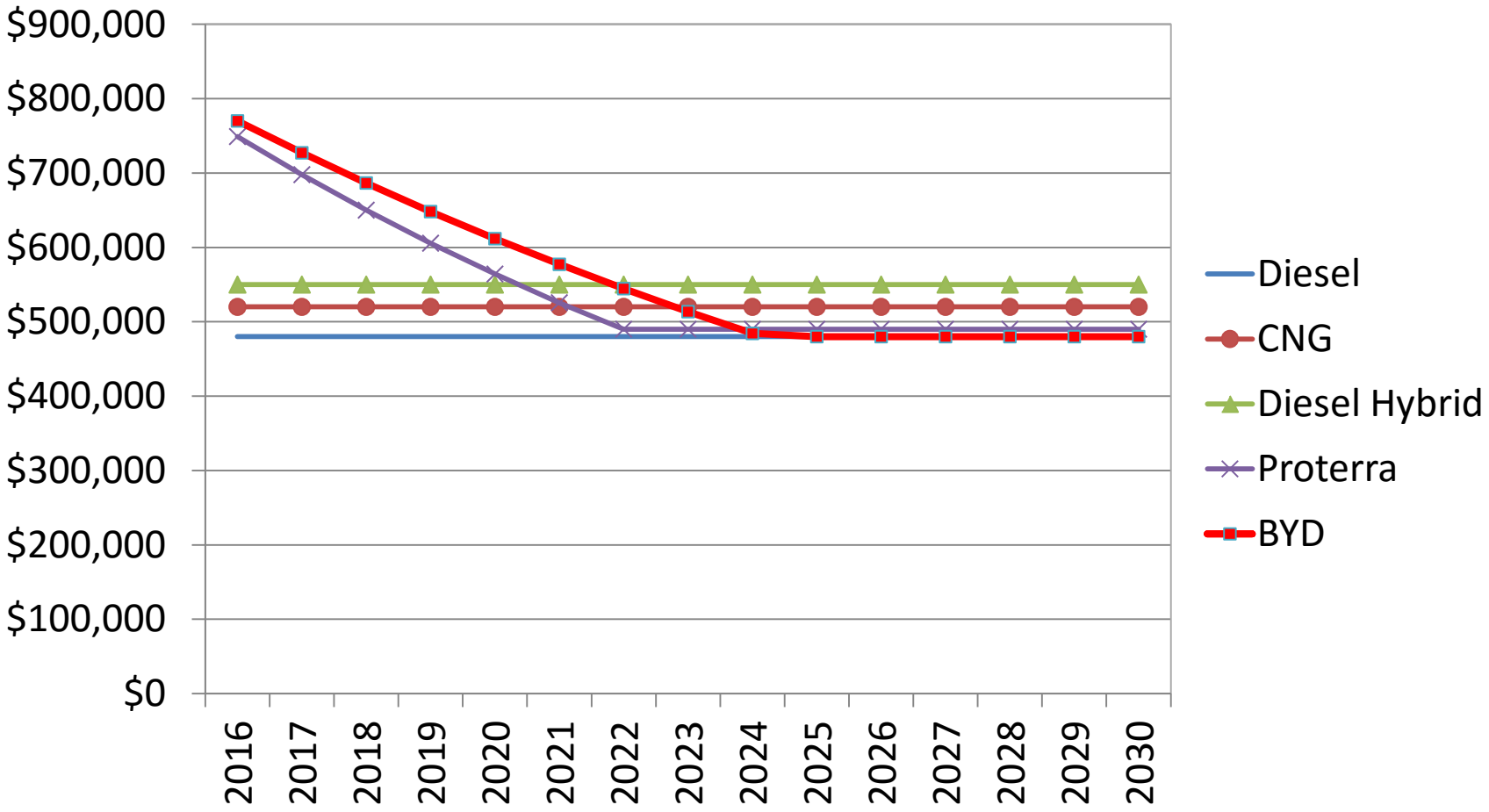
- Battery cost reduction literature review supports bus cost reduction estimates



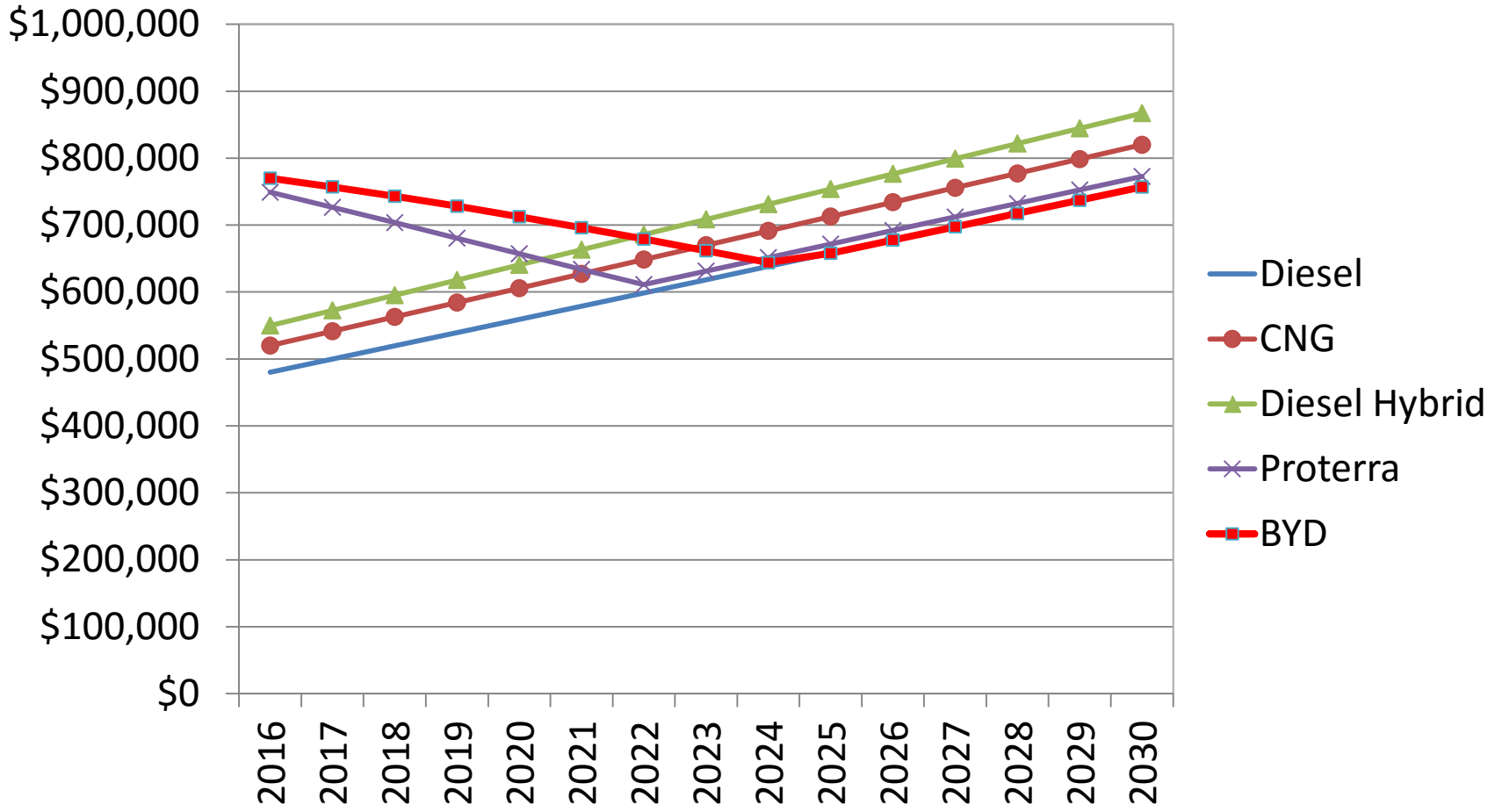
Fuel Cell Electric Buses

- $1.2 million for single bus purchase 2016
- $900,000 for 40 bus purchase via New Flyer letter
- Additional cost reductions possible

Bus Prices (Constant Dollars)



Bus Prices (Nominal Dollars)



Maintenance Cost Literature Review

- Available data supports minimum of $0.19 cost savings per mile
  - Brake cost savings and avoided regular maintenance from Foothill study
  - No data to compare long term bus repairs
- Manufacturer lifecycle estimates reflect savings from avoided repairs at savings of about $0.25/mile

Maintenance Costs for Buses

Category	Mid-Life Cost ($2016)*	Average Lifetime Maintenance** ($/mile)
CNG Bus	$35,000	$0.85
Diesel Bus	$35,000	$0.85
Low NOx CNG Bus	$55,000	$0.85
Hybrid Bus	$35,000	$0.80
BYD Slow Chg	$0	$0.60
Proterra Fast Chg	$75,000	$0.60
Proterra Slow Chg	$75,000	$0.60
Fuel Cell	$200,000	$1.00

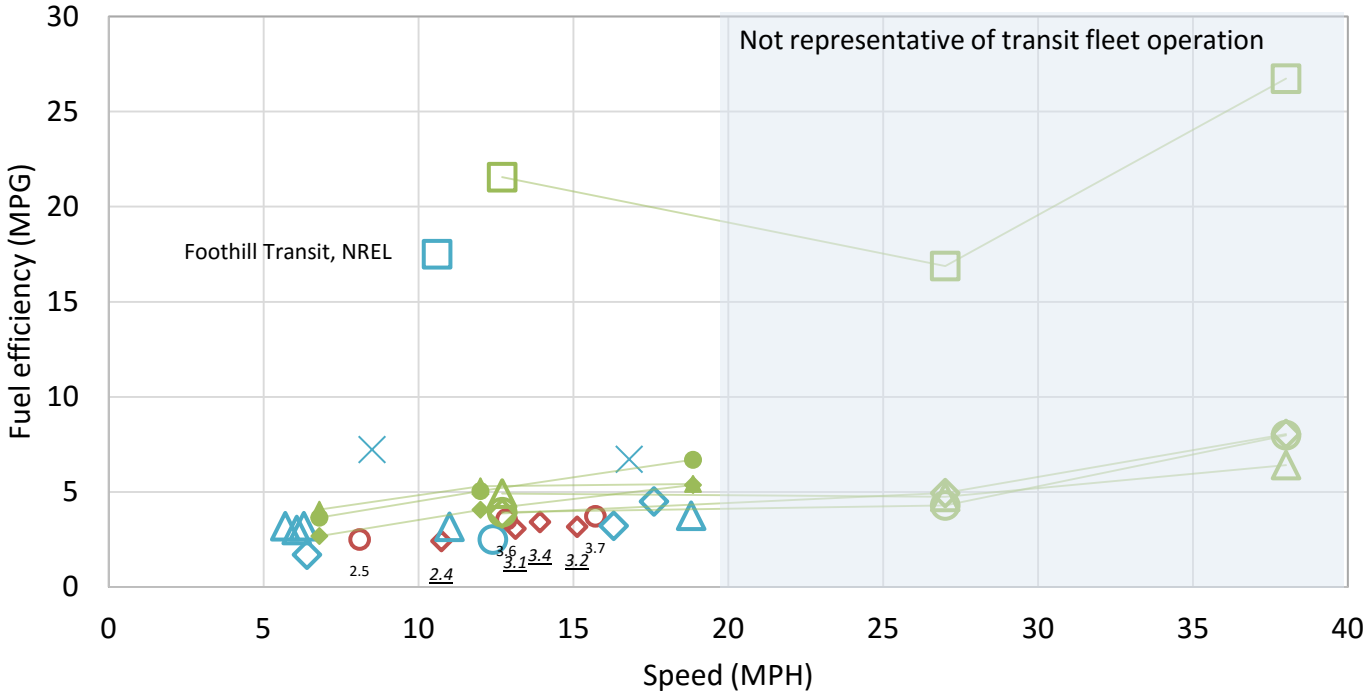
* Mid-life rebuild of engine, transmission, or replacement of traction battery after 7 years.
** Excludes mid-life costs.

- FTA bus lifecycle cost report in 2007 identified higher mid-life cost for conventional bus propulsion system (including engine and transmission) for internal combustion engines for a large operator at around $47,000.

Vehicle/Fuel Efficiency

- Fuel consumption dependent on bus technology and route speed
- Real world NTD data for different bus categories
  - Limit to fleets with single fuel type for standard buses
- NREL reports capture real world fuel consumption for part of fleet that is evaluated
- Altoona emissions test cycle and fuel economy in controlled tests
- Real world fuel economy best estimate of annual fuel costs and much lower than Altoona tests

Fuel Efficiency Data

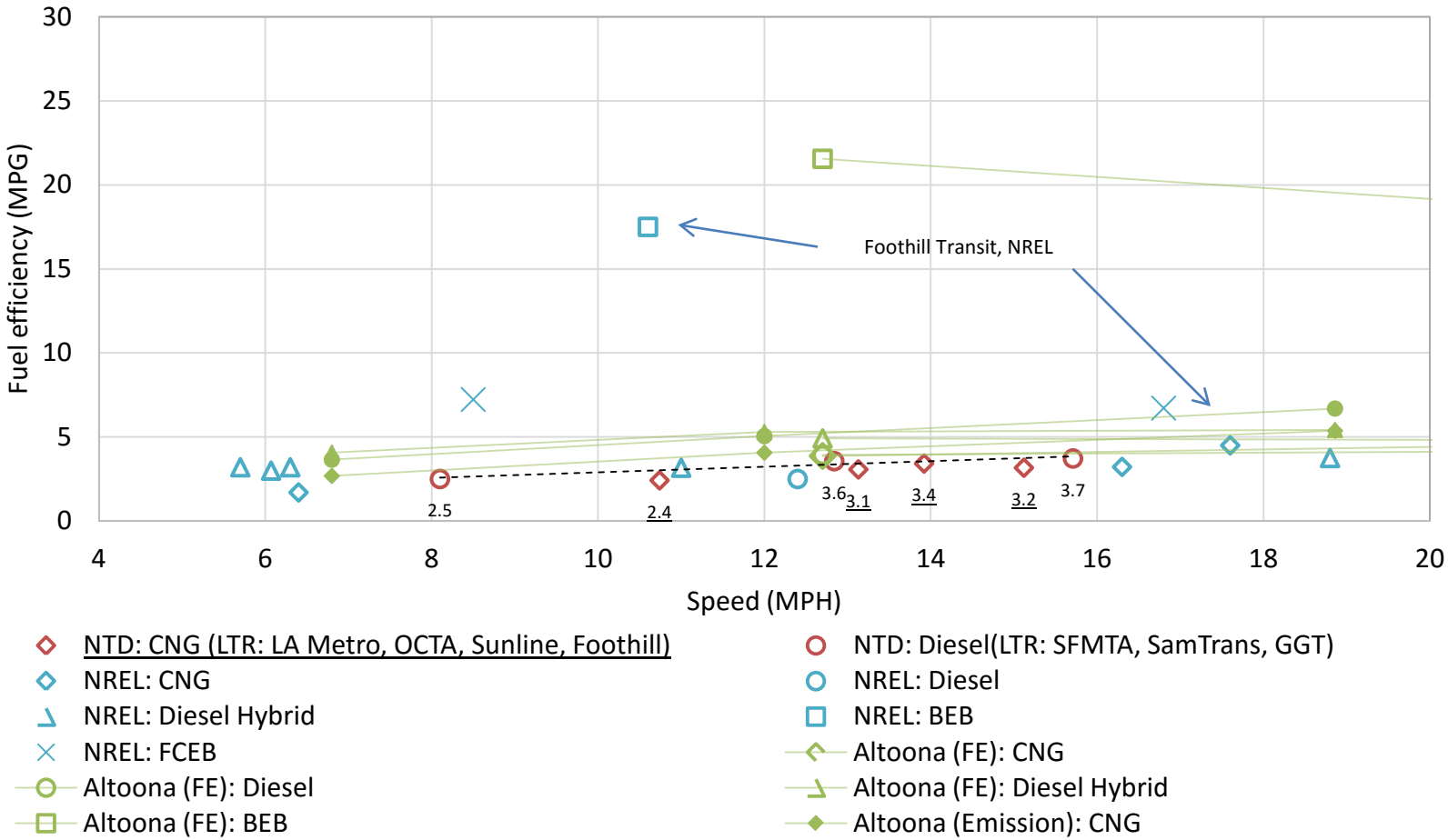


- NTD: CNG (LTR: LA Metro, OCTA, Sunline, Foothill)
- NREL: CNG
- NREL: Diesel Hybrid
- NREL: FCEB
- Altoona (FE): Diesel
- Altoona (FE): BEB
- Altoona (Emission): Diesel
- NTD: Diesel(LTR: SFMTA, SamTrans, GGT)
- NREL: Diesel
- NREL: BEB
- Altoona (FE): CNG
- Altoona (FE): Diesel Hybrid
- Altoona (Emission): CNG
- Altoona (Emission): Diesel Hybrid

Altoona test cycles	Manhattan (Emission)	Orange County (Emission)	UDDS (Emission)	CBD (FE)	Arterial (FE)	Commuter (FE)
Speed (MPH)	6.80	12.00	18.86	12.70	27.00	38.00

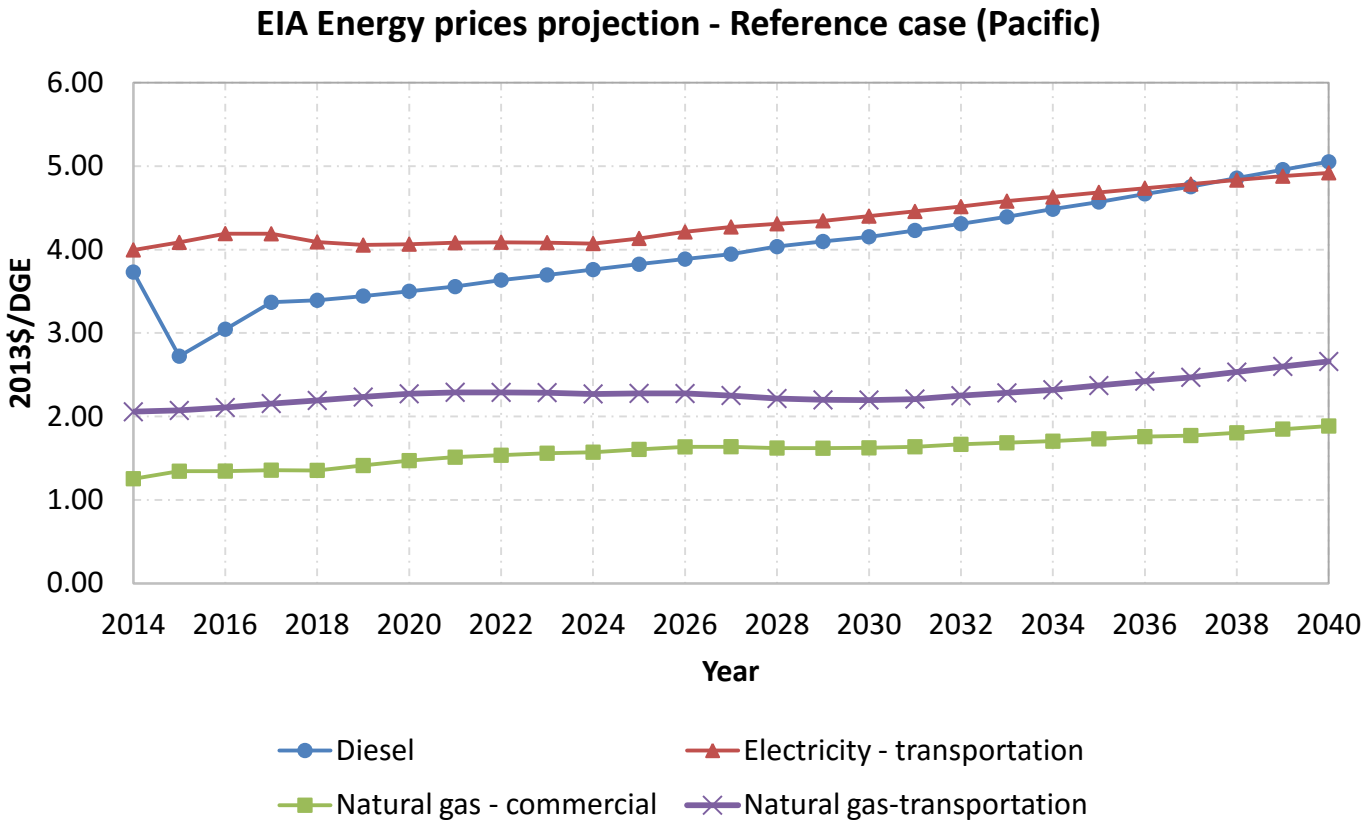
Data sources: NREL reports, Nation Transit Database, and Altoona tests for 2010 or newer models

Transit Fleet Fuel Efficiency



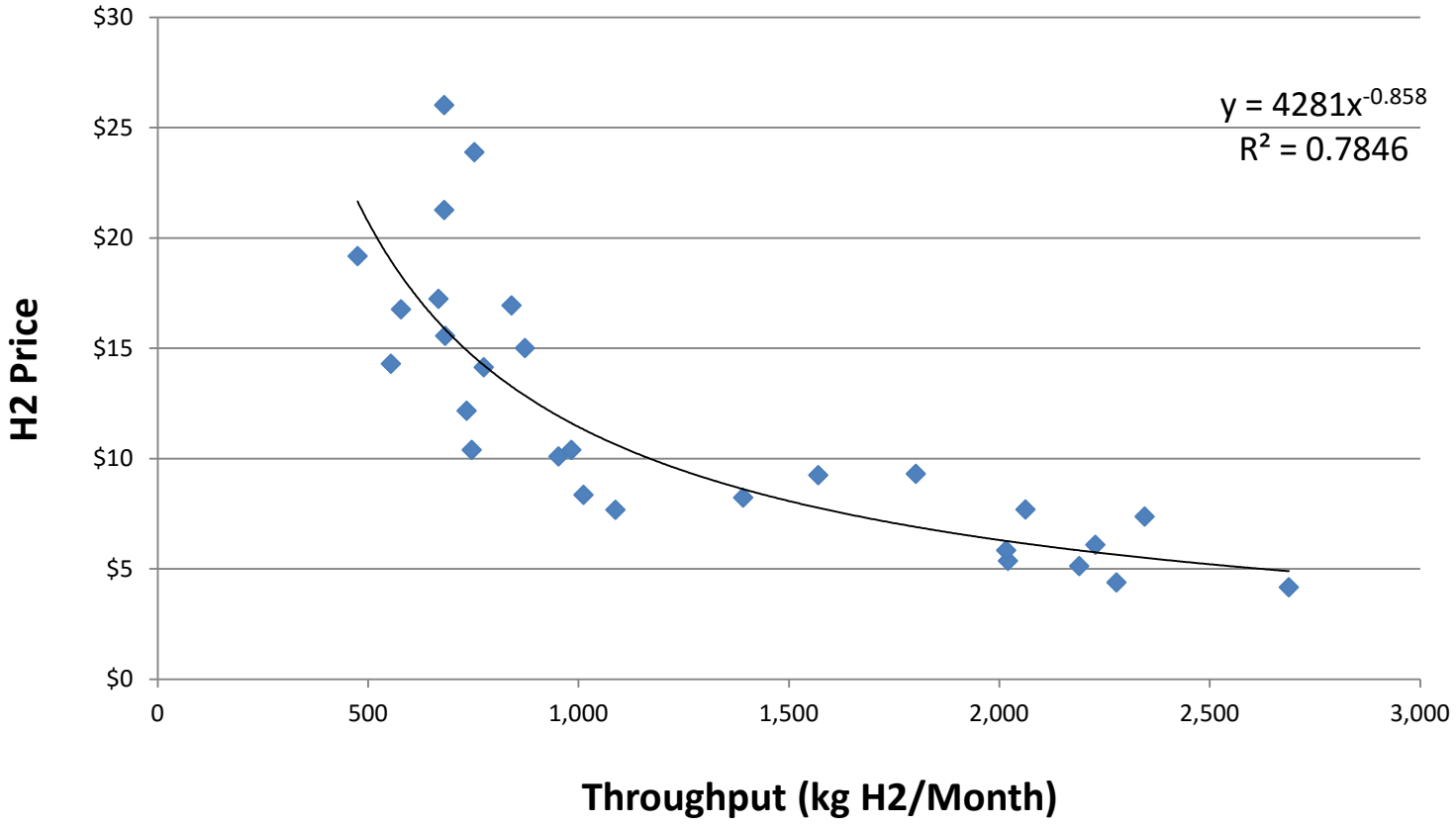
Long Term Fuel Prices

Fuel Type	Typical Transit Fuel Costs
Diesel (2016 $/DGE)	$2.00
CNG (2016 $/DGE)*	$1.00
Hydrogen (2016 $/kg)	$8.00



* CNG cost includes, commodity, transportation, compression (~$0.18/DGE), taxes and fees but excludes station capital costs.

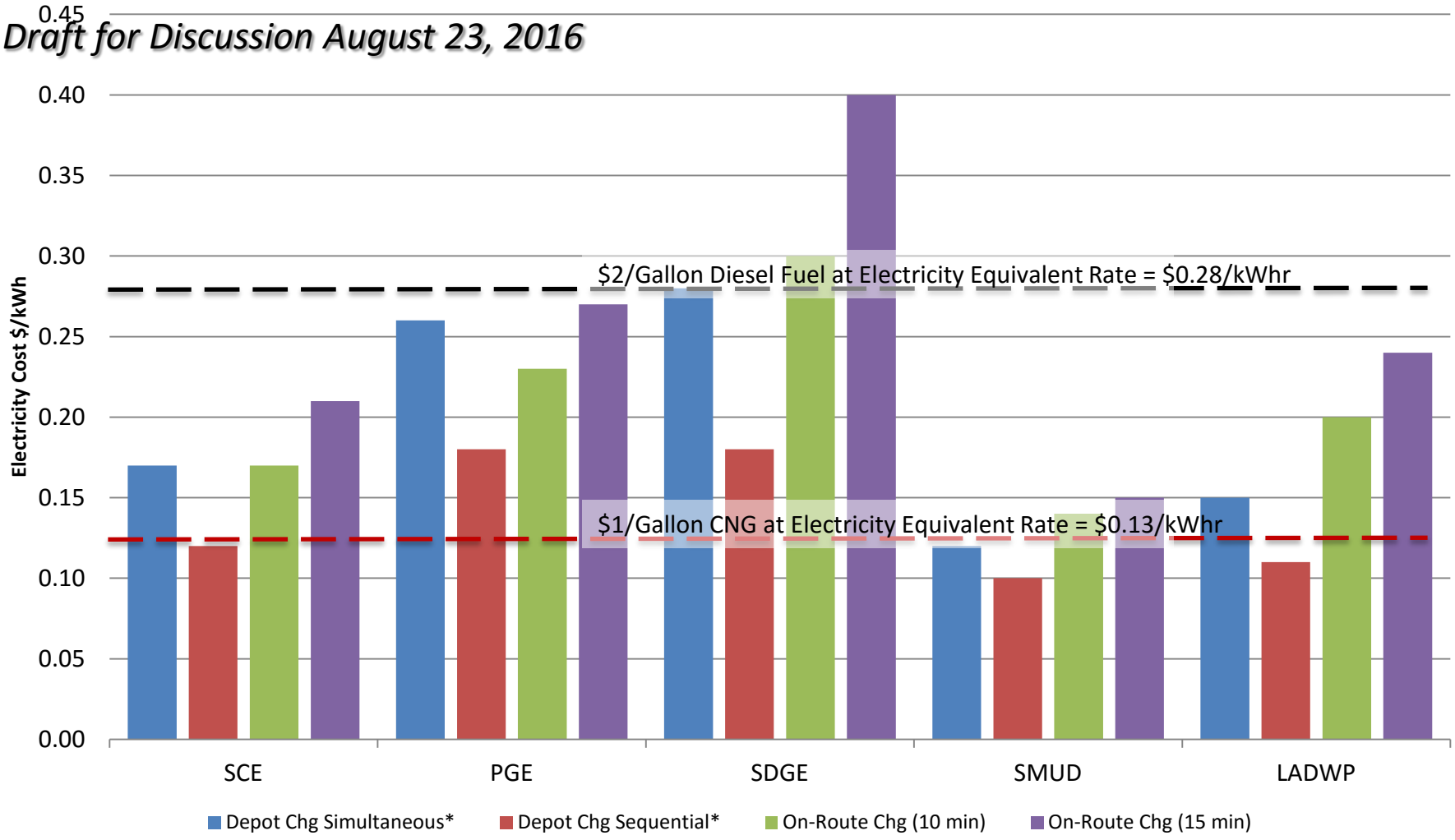
Hydrogen Price Change with Throughput Sunline Transit H_2 Station (11/2013 – 2/2016)



Source: Data provided by NREL

Electricity Costs Depend on Utility, Charging Time and Demand

Draft for Discussion August 23, 2016



*Simultaneous charging means charging the entire fleet at the same time while "sequential" means breaking the fleet into non-simultaneous charging groups (here, a 50/50 split).

LCFS Credit Value Base on Fuel Use

Discussion Draft 8/17/2016

Table 1. LCFS credit revenue for selected fuels in 2016 and in 2020[a] at credit price $100/MT

	Representative Carbon Intensity[b] (CI) (gCO2e/MJ)	EER for transit buses	LCFS Credit Revenue in 2016	LCFS Credit Revenue in 2020
Fossil diesel	102	1	- $0.02/DGE	- $0.12/DGE
Renewable diesel	50	1	$0.67/DGE	$0.56/DGE
Fossil CNG	78	0.9	$0.16/DGE	$0.06/DGE
Renewable CNG	25	0.9	$0.87/DGE	$0.77/DGE
Electricity (Grid)	105	4.2	$0.11/kWh	$0.10/kWh
Electricity (Solar)	0	4.2	$0.15/kWh	$0.14/kWh
33% Renewable Hydrogen[c]	88	1.9	$1.22/kg	$1.03/kg
100% Renewable Hydrogen[d]	0	1.9	$2.28/kg	$2.09/kg

a: The revenues shown for 2020 assume no improvement in carbon intensities.
b: Certified CI values can be found at http://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf (Table 6 on p. 66) and at http://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm
c: Hydrogen made by reforming a mixture of natural gas with 33% biomethane.
d: A certified pathway for hydrogen produced by electrolysis using solar PV power.

Infrastructure Costs

Technology Type	Capital Cost ($)	Throughput (buses)	MidLife $ and Years	Useful Life (Years)	O&M Costs
Diesel station		200		20	$0.02/dge
CNG station	$6,000,000	175		20	$0.27/dge
CNG maintenance bay	$1,000,000	200		NA	
BYD slow charger pedestal	$0	1-2	--	14	$0.02/dge
Slow charger installation	$15,000*	-	--	--	
Proterra slow charger	$50,000	2	--	14	$0.02/dge
Proterra Fast charger	$349,000	6	--	20	$0.05/kWh
Fast charger installation	$250,000	-	--	20	
Hydrogen station	$5,050,000	40		20	$5,000/bus/yr
Hydrogen maintenance bay	$750,000	13	--	--	
WAVE wireless charger	$286,000	-		20	
WAVE in ground installation	$220,000	-			
WAVE receiver (on bus)	$103,000	-			

CPUC Rule 15 and 16 - utilities to incur costs of grid expansion until 2019

* Based on BYD's comment on the presentation of LA Metro. This number represents the installation cost for a 80 kWh charger, but it does not include additional electrical costs. BYD chargers are included in purchase price, but if purchased separately, 40 kW charger costs $6,000 ($2,500 for power interface + $3,500 install) and 80 kW charger costs $15,000 ($8,000 for power interface + $7,000 install).

LA Metro's Analysis

- 170 miles sufficient for all buses, electricity cost is $0.13/mile
- Delay of ZEBs to 2025 creates bias in emissions analysis
- High mid-life overhaul cost for BEBs should be zero with 12 year battery warranty
  - Could replace bus after 12 years or extend useful life to 18 years
- 1.35 electric buses to replace one CNG bus not warranted
  - Conflicts with prior statements about route length
  - Does not reflect longer bus range by 2025
  - Ultra-conservative use of battery not needed with 12 year warranty
- Minimal maintenance cost savings inconsistent with manufacturer information and literature review
- Long-term CNG infrastructure costs not included
- Land expansion questionable

Additional Cost Data Needs

- Cost for maintenance infrastructure upgrades
  - Conventional to ZEB
  - Hybrid to ZEB
  - CNG or diesel to fuel cell electric
- Cost for CNG, hydrogen fueling infrastructure
- Other soft cost
  - Driver training
  - Repair and maintenance training