Total Cost of Ownership to Advance Clean Transit

4th ACT Workgroup Meeting

October 4, 2016

California Environmental Protection Agency

Air Resources Board

Fleet Cost Modeling Overview

- Evaluate total cost of ownership for individual fleets
  - 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
- Compare annual costs of baseline to scenario
- Individual fleet costs key to financial impact
- Sum of individual fleet costs for statewide total
- Analysis in 2016 constant dollars

Cost Inputs

- Bus prices
- Infrastructure
  - Fueling and maintenance facility upgrades
  - Operation and maintenance
- Bus annual maintenance and major mid-life
- Annual fuel costs vary by fleet
  - Fuel consumption
  - Long term fuel price
  - LCFS credit value
- Detailed latest assumptions for all bus and fuel types in handout www.arb.ca.gov/msprog/bus/actmeetings.htm

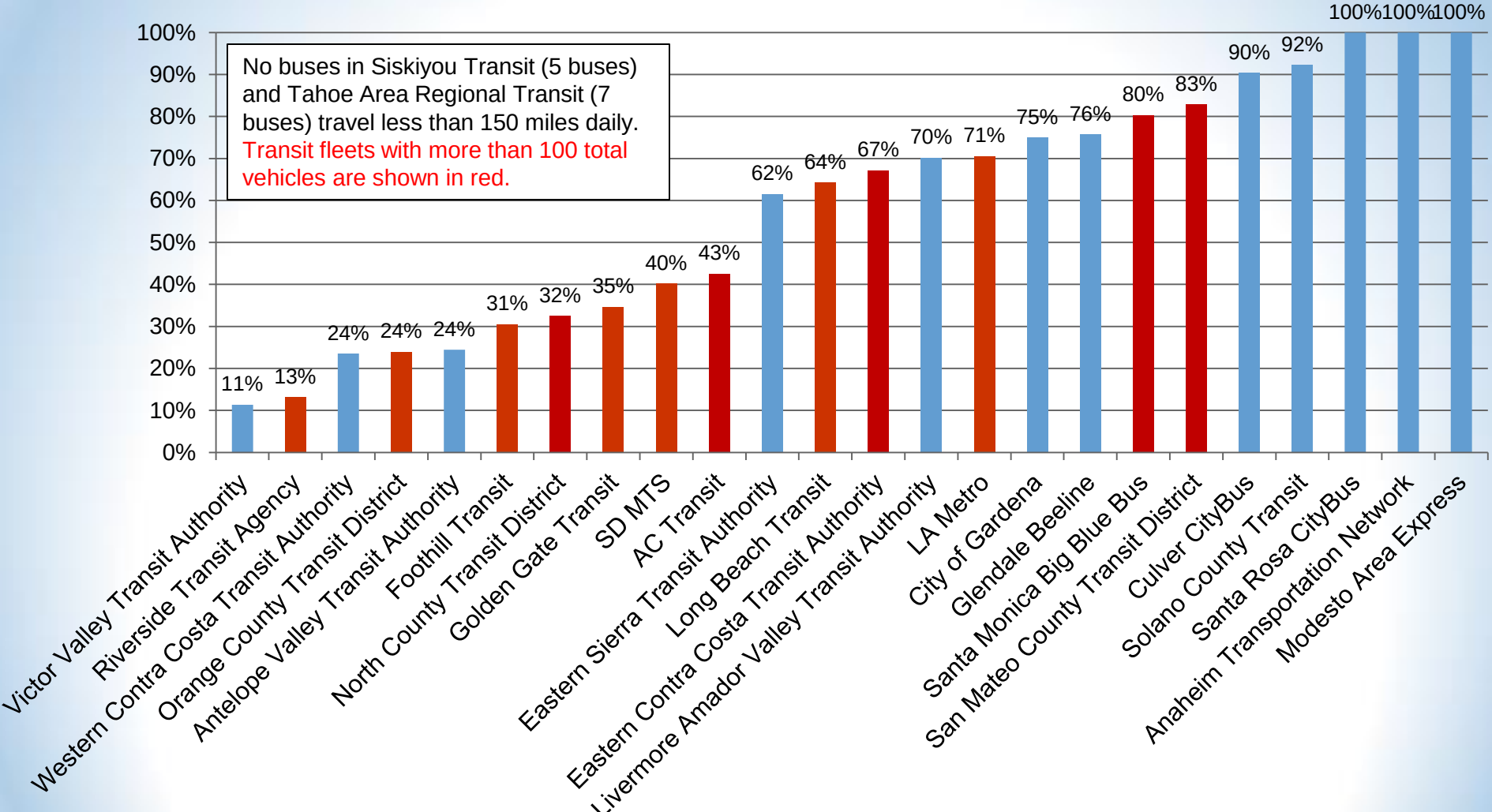
Where are Lower Risk Opportunities for ZEBs

- Focus on first 15% of fleet
  - Where suitable for one for one replacements
  - Meet existing shorter daily range needs first
- Depot charging example to simplify discussion
- Bus replacements at a normal schedule (14 year life)
- Existing diesel and CNG infrastructure costs remain
- Fuel costs net of LCFS credit value at $100/credit
- Comparison made without including funding

Fleet Specific Cost Analysis

- Analysis assumes no operational barriers for first 15%
  - Plan to follow-up with individual fleets
- Selected fleet examples with key fuel cost differences
  - Golden Gate Transit – Diesel fleet in PG&E area
  - LA Metro – CNG fleet in SCE/LADWP area
  - San Diego MTS – CNG fleet in SDG&E area
- Highlight key differences among fleet categories

Percent of Standard Buses Driven Less than 150 miles/day



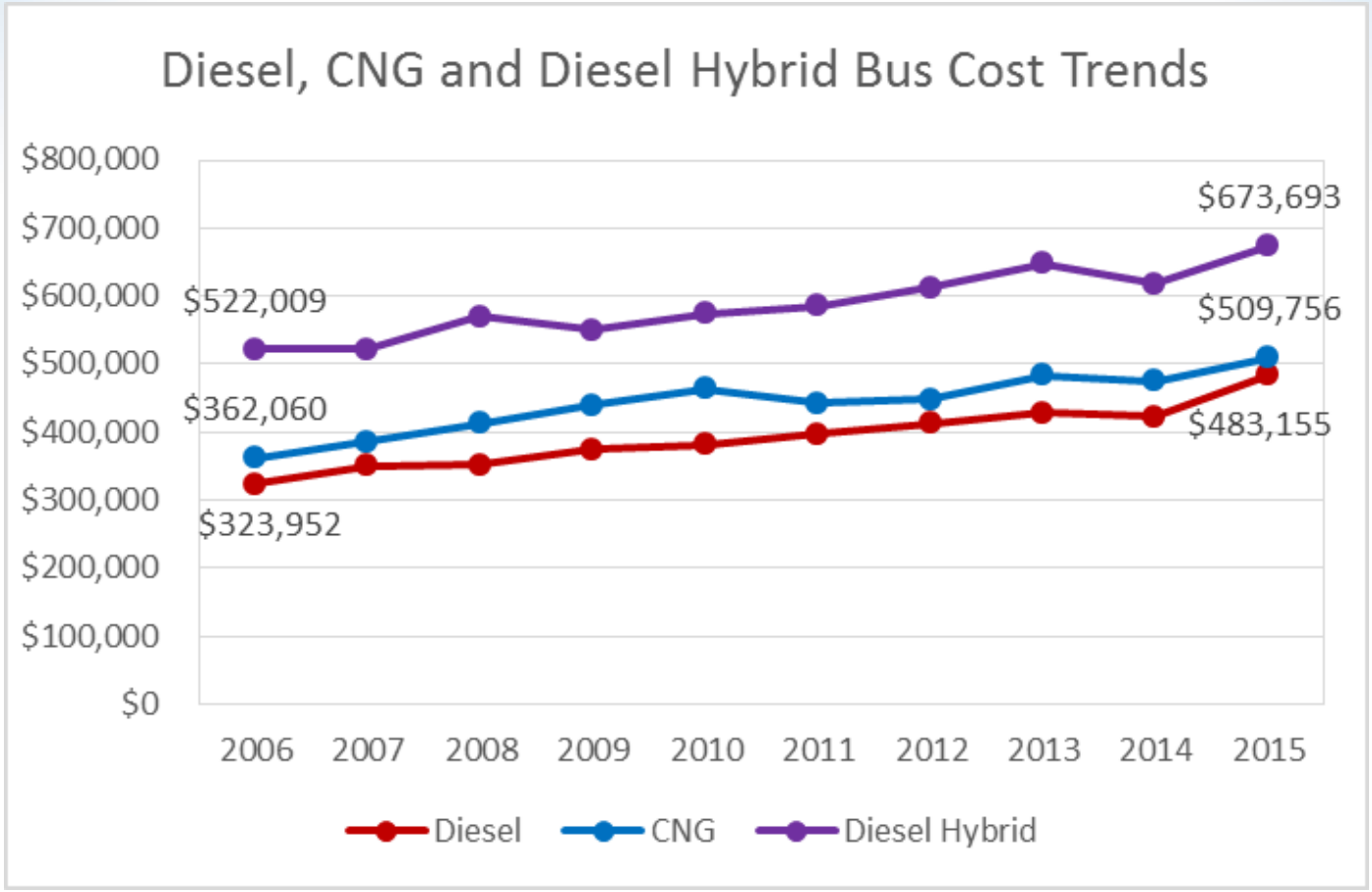
- Antelope Valley has committed to become all electric in 2018 with a depot charging strategy.
- Foothill Transit committed to become all electric by 2030

Bus Capital Costs

Bus Price Issues

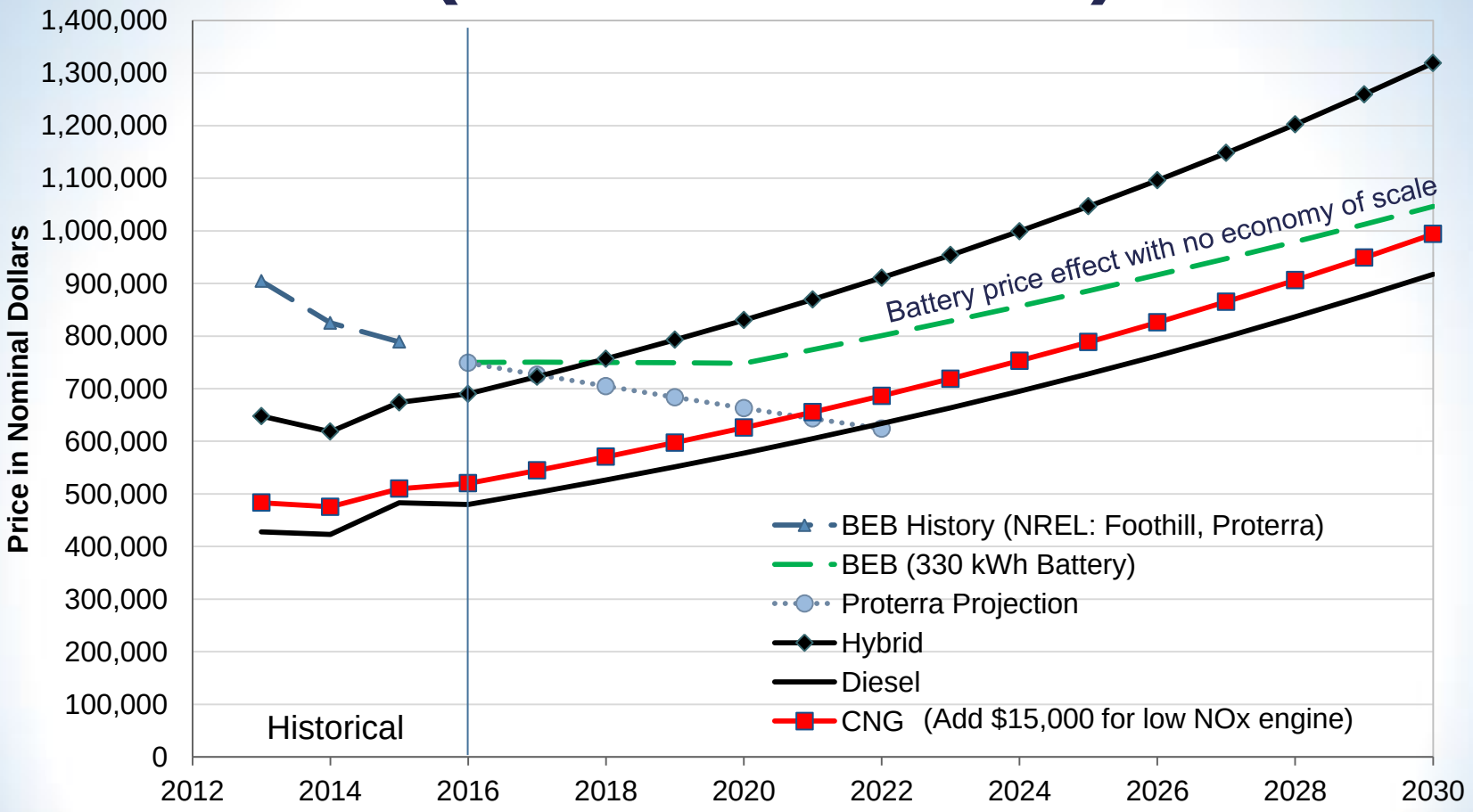
- Conventional bus prices increasing faster than inflation
- Battery electric bus prices currently declining
  - Battery cost reductions (2016 $725/kWh; 2020 $405 kWh)
  - Economy of scale
- Future battery electric bus prices depend on battery size and economy of scale
- Transits can use shorter range and lower cost buses now for substantial part of the fleet
- Longer daily range buses eventually needed with larger deployments

Bus Prices Have Increase Faster Than Inflation



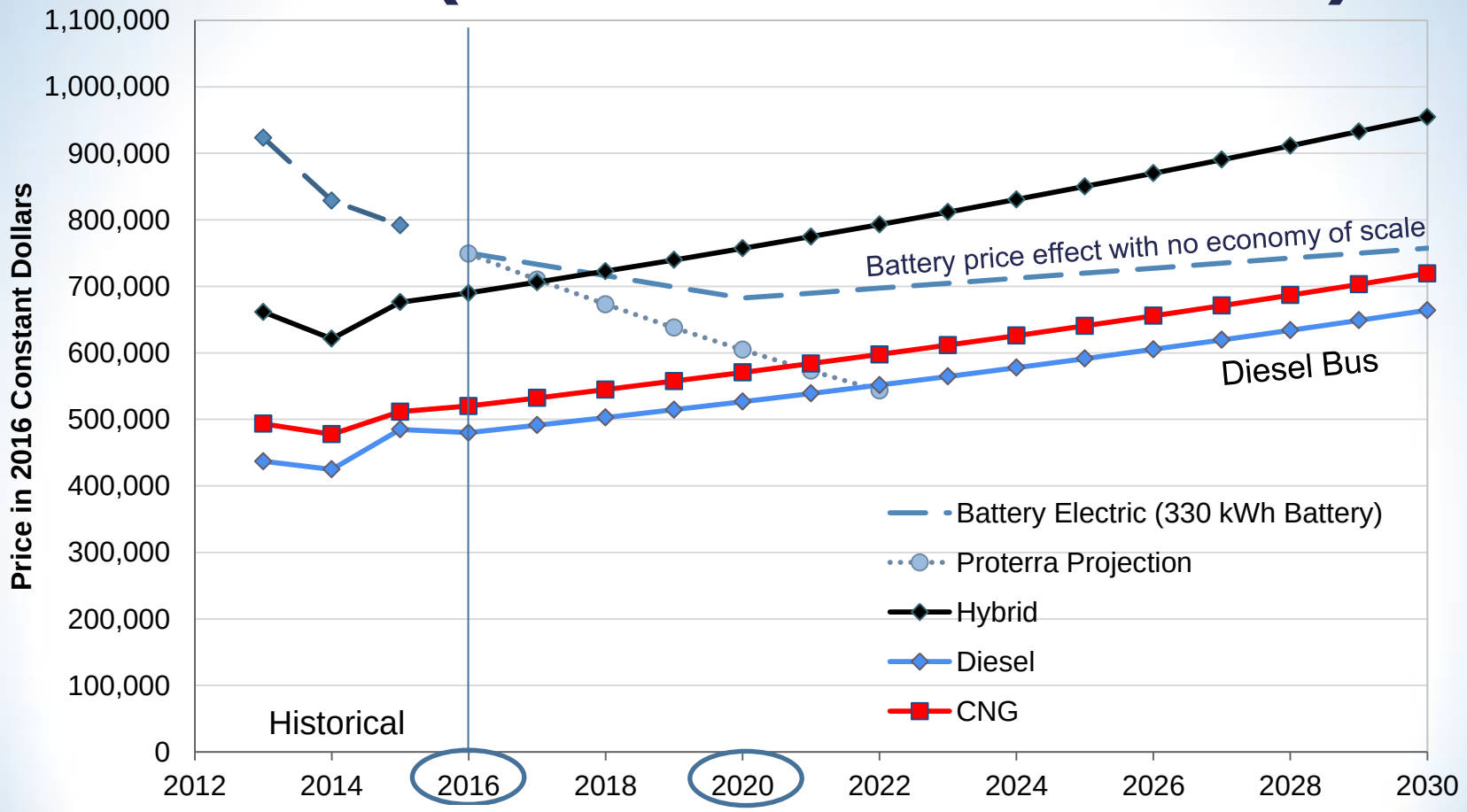
Source: APTA bus price data

Bus Price (nominal dollars)



Literature review of battery price curves available in Advanced Clean Transit Workgroup discussion paper, August 2016
www.arb.ca.gov/msprog/bus/battery_cost.pdf

Bus Price (2016 constant dollars)

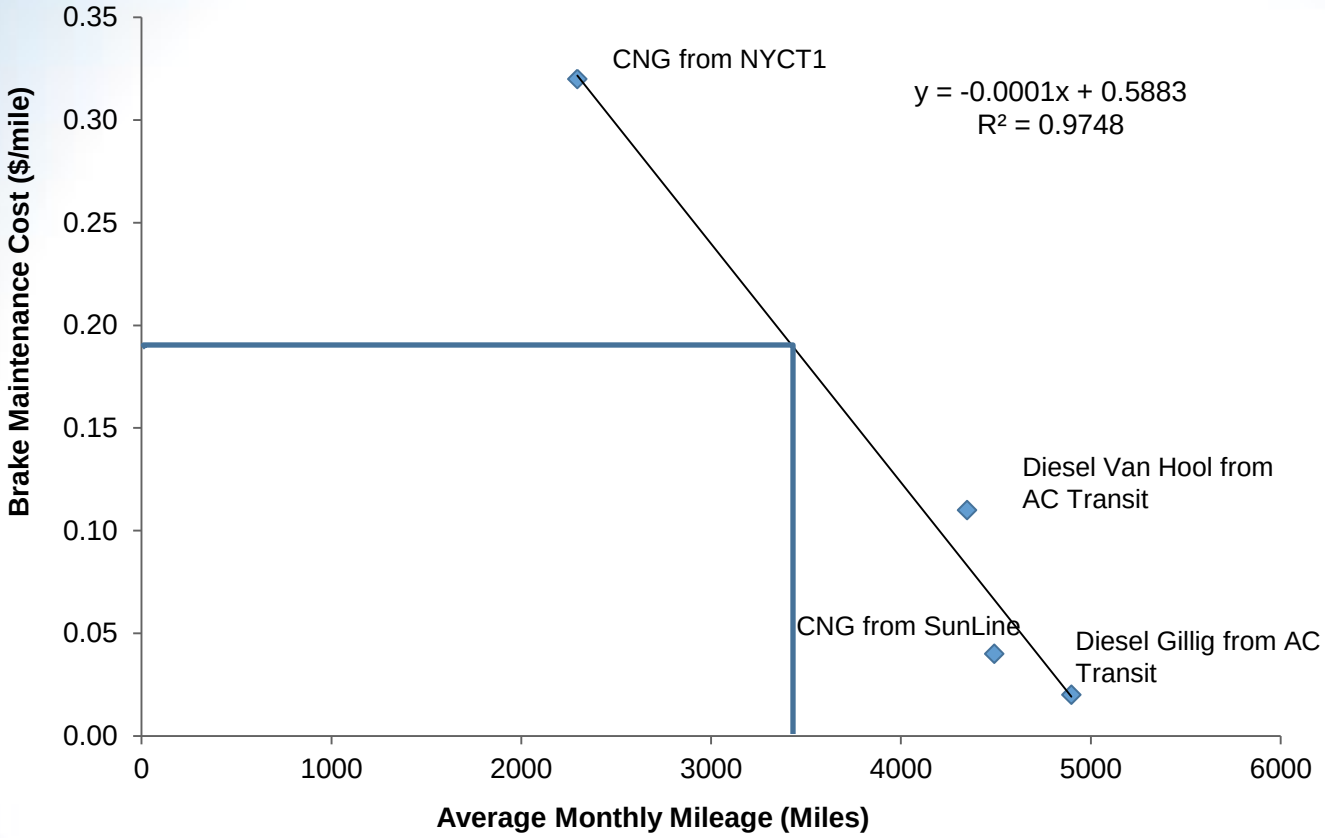


* An inflation rate of 2.34% after 2016 is used to make the conversion from nominal dollars to 2016 constant dollars

Charger Infrastructure

- Antelope Valley Transit Authority full depot conversion
  - $60,000 per bus with backup generator to charge buses
- Golden Gate Transit engineering evaluation
  - Existing transformer has capacity for two chargers on existing meter
  - 10 chargers requires new transformer and switchboard on separate meter
    - $500,000 for recommended option ($50,000/bus)

Brake Maintenance Costs



Source: ARB Literature Review on Transit Bus Maintenance Cost (Discussion Draft)
https://www.arb.ca.gov/msprog/bus/maintenance_cost.pdf

Bus Maintenance Cost

- ARB literature review of available studies and reports
- Minimum $0.19 cost savings per mile at typical 12 mph
  - Brake cost savings and avoided regular maintenance from first year of Foothill study
  - No data to compare long term bus repairs
- Manufacturer lifecycle estimates reflect savings of battery electric buses at about $0.25/mile
- Supports hybrid bus brake cost savings of $0.11/mile
- At 40,000 miles/year BEB saves $140,000 per bus compared to CNG and diesel

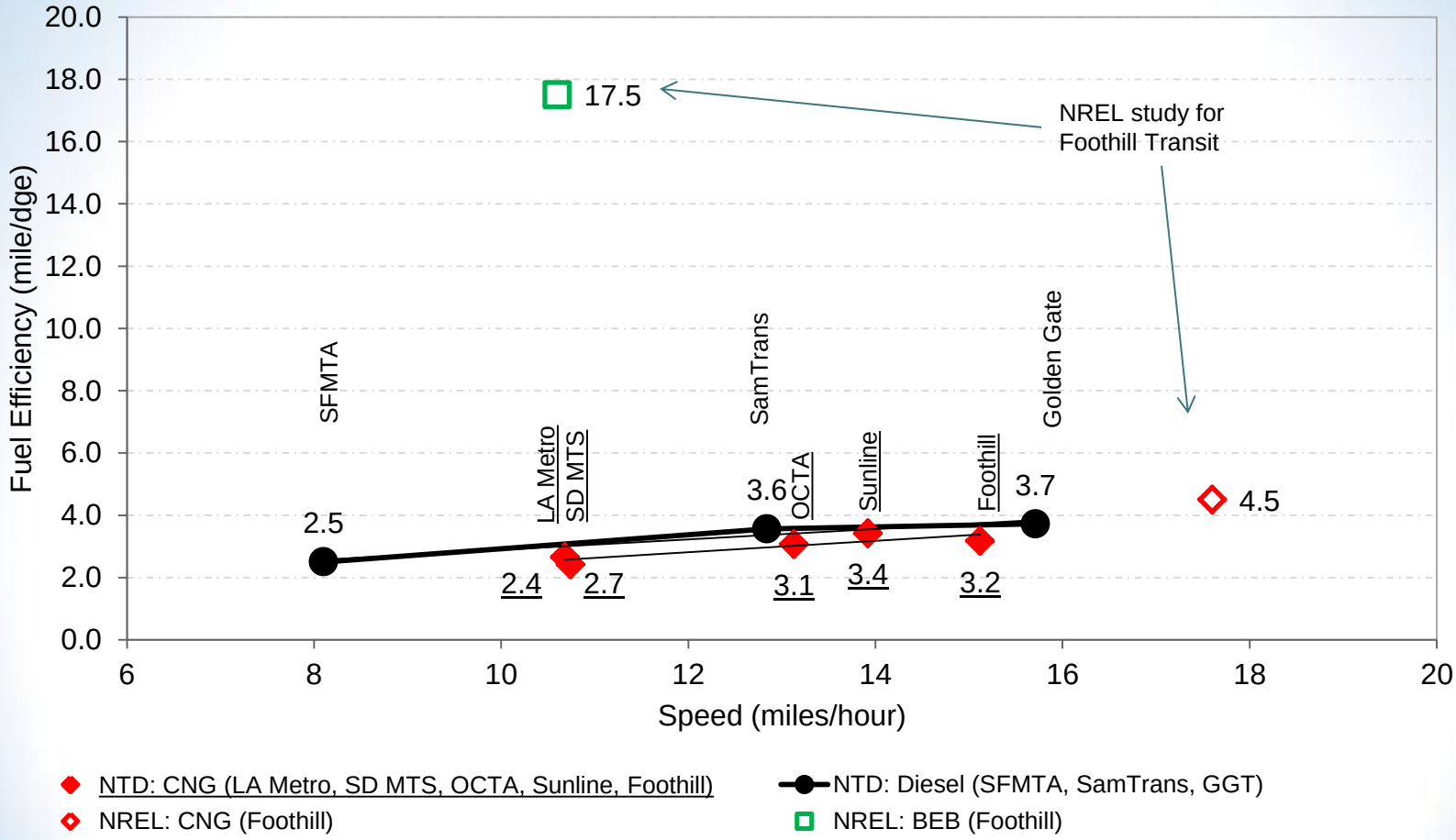
Discussion document at https://www.arb.ca.gov/msprog/bus/battery_cost.pdf

Fuel Costs

Fuel Cost Issues

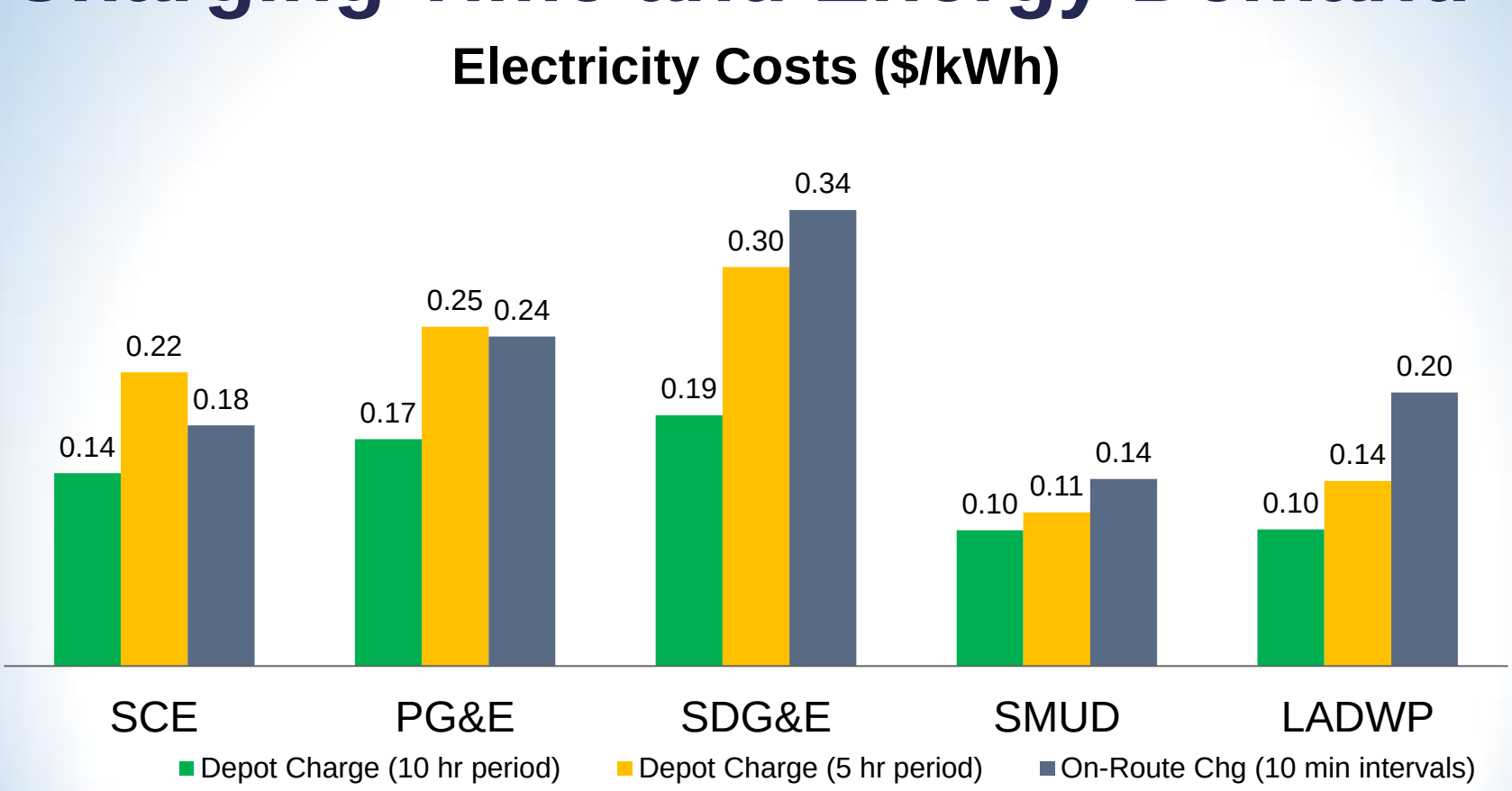
- Fuel consumption and fuel type varies by fleet
- Conventional bus fuel economy lowest at slow speeds
- Slow speed routes have lowest daily range
- Depot charging similar to existing fueling practices
- Electricity cost depends on charging strategy
  - Lower cost during off-peak (lower demand charges)
  - Managed charging over 10 hr period has lower cost than charging all buses at same time in 4-5 hrs
- LCFS credits lowers costs for most fuels except diesel
  - Credit generator and number of credits vary

Real World Fuel Efficiency



Data from National Transit Database (NTD), 2014 and National Renewable Energy Laboratory (NREL) report, Foothill Transit Battery Electric Bus Demonstration Results, January 2016.

Electricity Costs Depend on Utility, Charging Time and Energy Demand



- Depot charge assumptions: 100% off-peak (80 kW charger); 100 fleet size; 130 miles/day; 2.1 kWh/mile
  - Depot charge in 10 hour period means no more than 50% of buses charged at the same time at 4-5 hrs per bus
  - Depot charge in 5 hour period means all buses charged at the same time during the billing period
- On-route charge assumptions: charging up to 10/15 min (500 kW charger); 6 buses/charger; 130 miles/day; 2.1 kWh/mile

LCFS Credit Value Based on Fuel Use

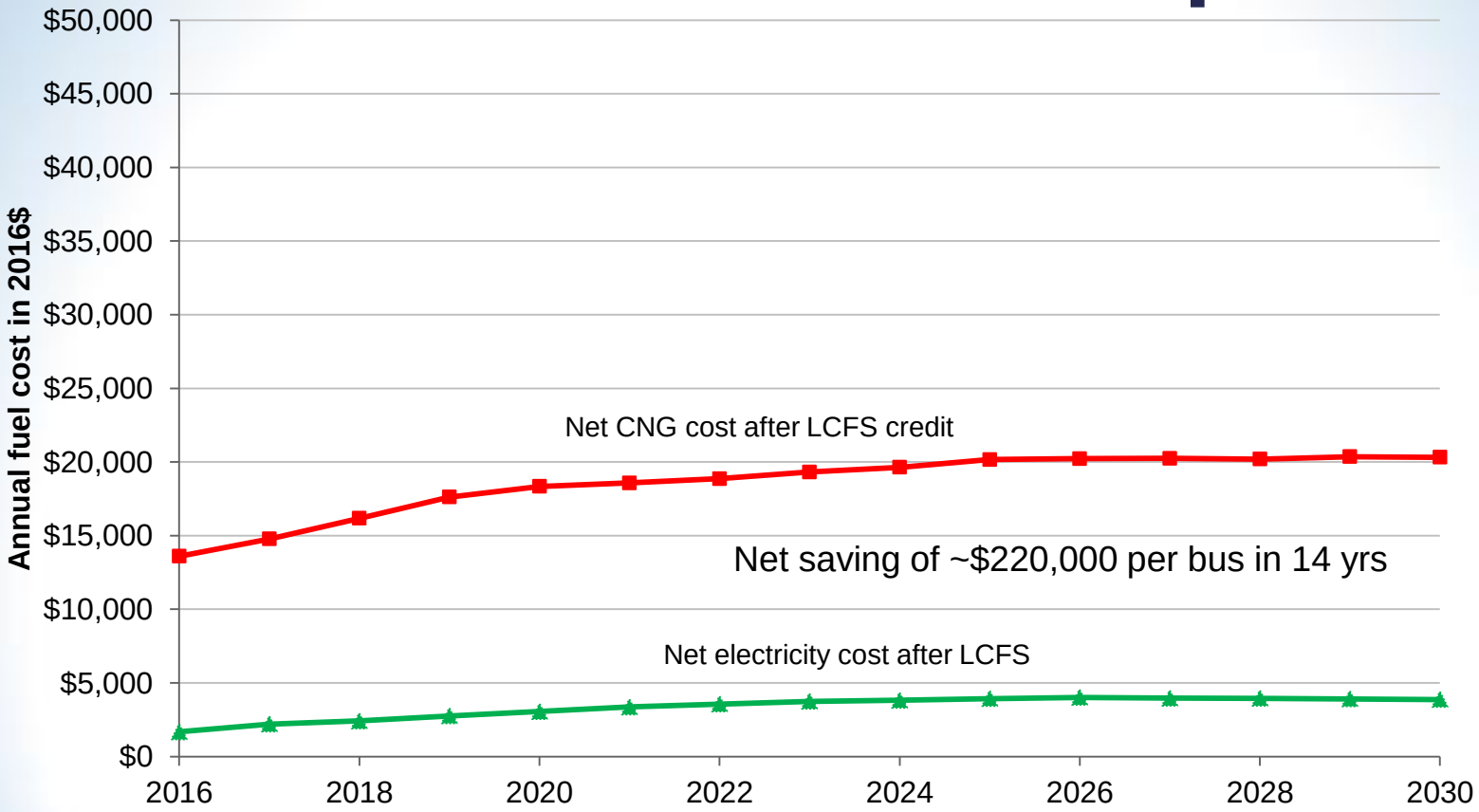
Table 1. LCFS credit revenue for selected fuels in 2016 and in 2020[a] at credit price $100/MT

	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.

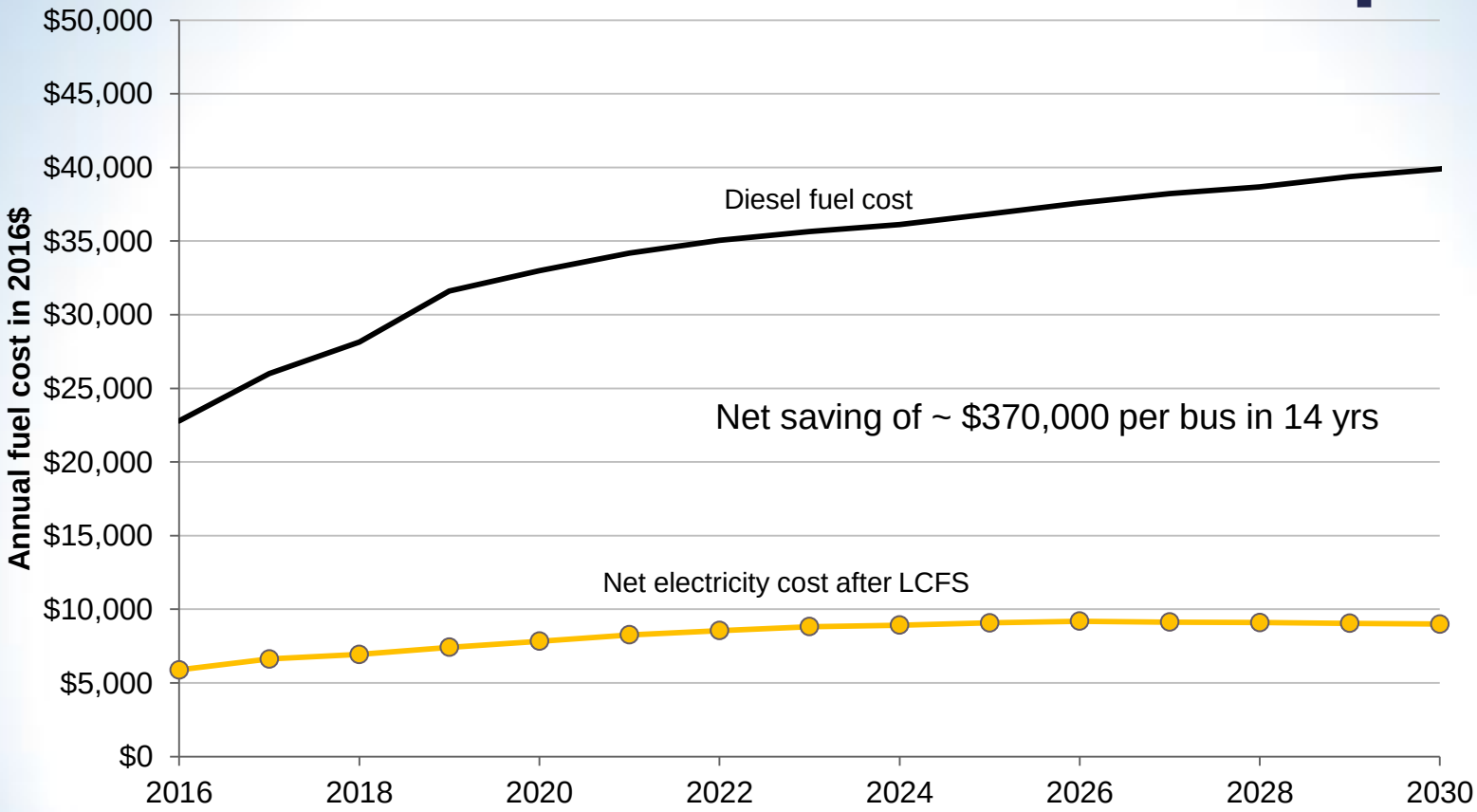
Source: ARB 8/17/2016 discussion draft, How LCFS Credits Change (https://www.arb.ca.gov/msprog/bus/lcfs.pdf)

LA Metro Fuel Cost Example



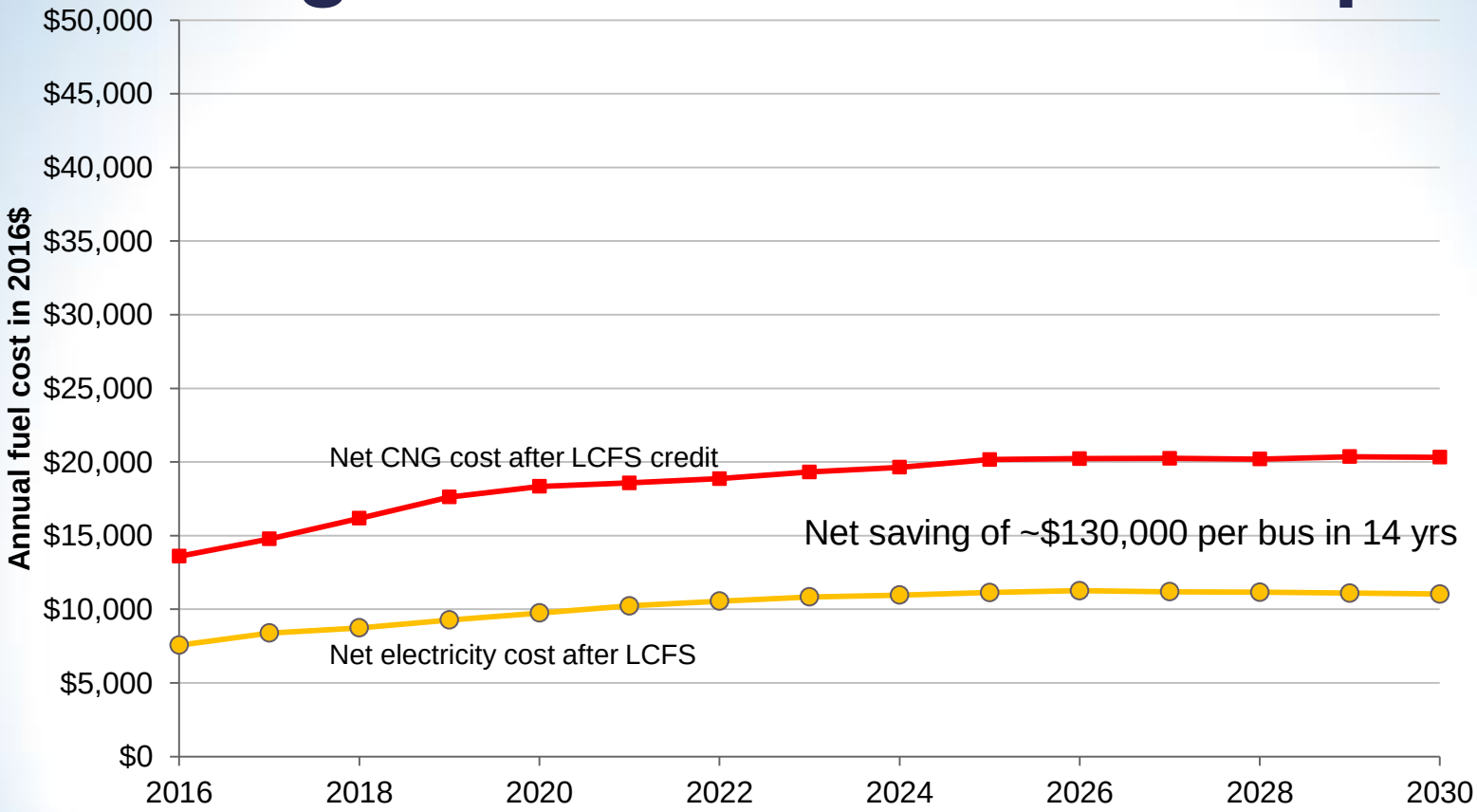
Assumes bus travels 130 miles per day and LCFS credit sold at $100 per credit and CNG bus with 2.7 miles/DGE
CNG price from Energy Information Administration (EIA) Annual Energy Outlook 2016. Reference case for the Pacific Region with beginning price of 1.08 per gallon in 2016 and receives LCFS credit.
Battery electric bus travels 0.48 miles/kWh. Charges at cost of $0.12/kWh (per LA Metro analysis) minus $0.10/kWh from LCFS in 2016.

Golden Gate Fuel Cost Example



Assumes bus travels 130 miles per day and LCFS credit sold at $100 per credit, and 3.7 miles/gallon.
Diesel price from EIA Annual Energy Outlook 2016. Reference case for the Pacific Region with beginning price of $2.11/gal in 2016.
Battery electric bus travels 0.48 miles/kWh. Charges off-peak (PG&E E-19) at cost of $0.17/kWh in 2016 minus $0.10/kWh from LCFS.

San Diego MTS Fuel Cost Example



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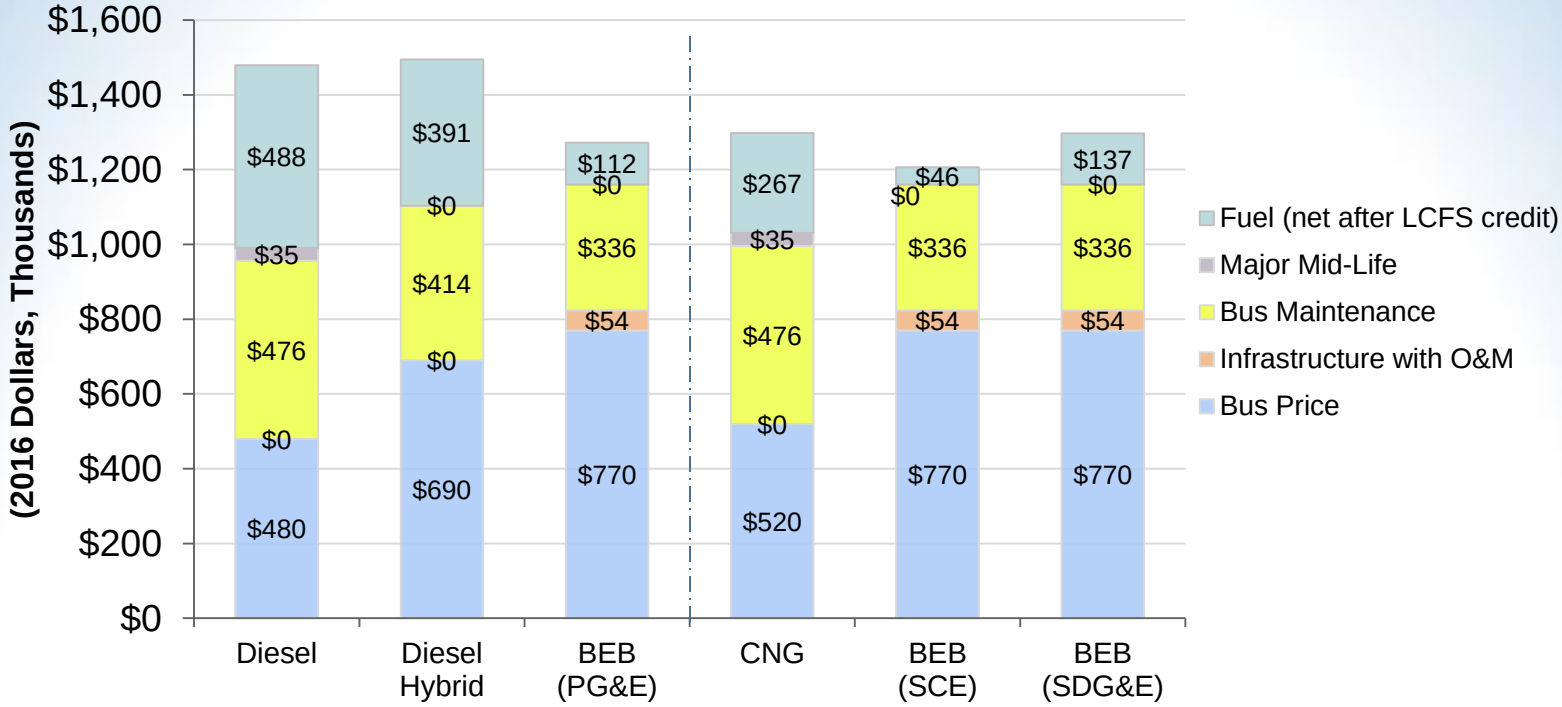
CNG price from EIA Annual Energy Outlook 2016. Reference case for the Pacific Region with beginning price of 1.08 per gallon in 2016 and receives LCFS credit.
Battery electric bus travels 0.48 miles/kWh. Charges off-peak (SDG&E AL-TOU) at cost of $0.19/kWh minus $0.10/kWh from LCFS in 2016.

Other Costs

- Diesel/CNG to BEB
  - Install shop charger, and software for diagnosis
  - Maintenance bay bus roof top access (diesel)
  - Technician training
- Hybrid to BEB
  - No changes needed for maintenance bay
  - Minimal technician training
- Driver training (~4 hours per driver)
- Off-ramps or other mechanism to address technological or operation barriers

Total Cost of Ownership for a Bus Purchased Today



Note: Analysis period is 14 years at 40,000 miles/year and LCFS credit value of $100 (claimed by transit agency).

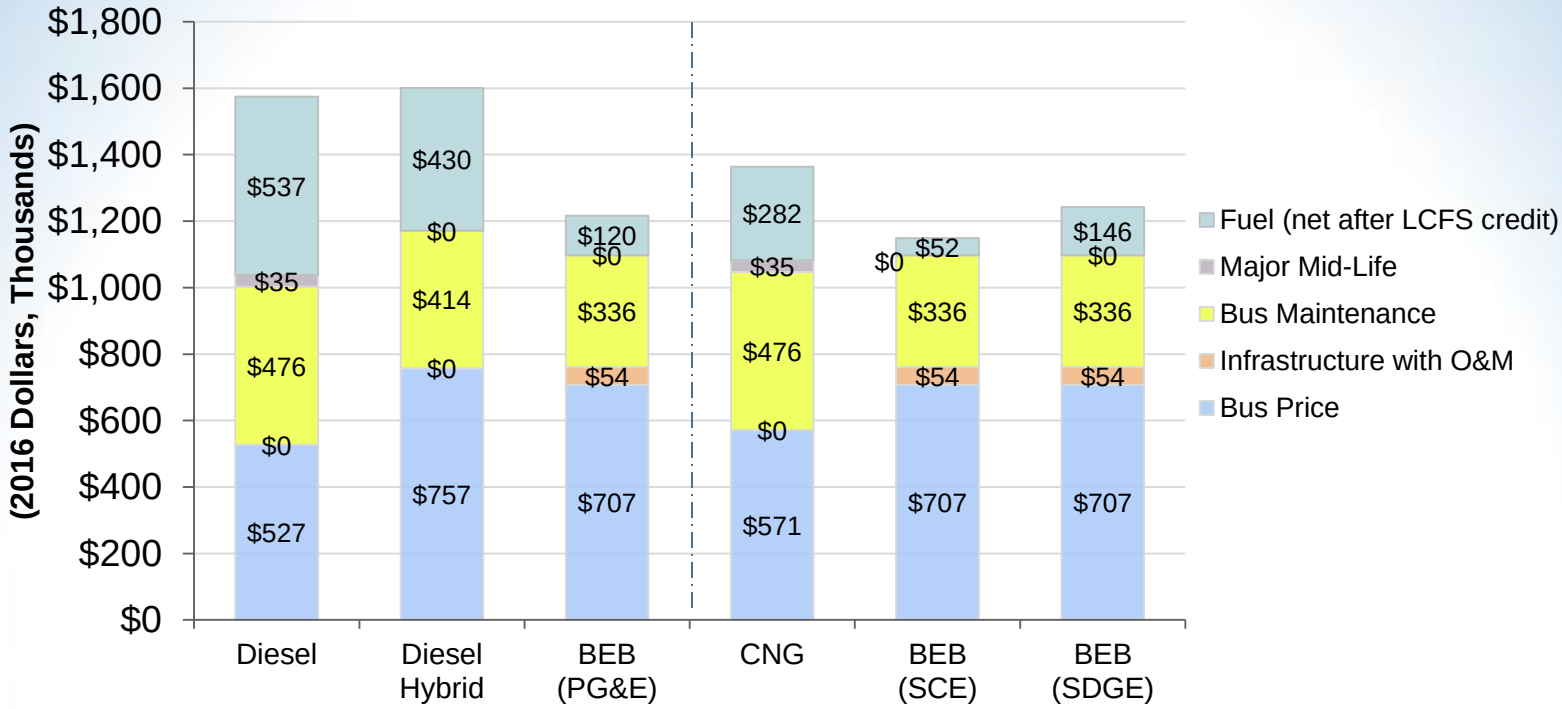
Conventional Buses

- CNG 2.7 mile/dge per LA Metro report and diesel 3.7 mile/gallon
- Maintenance is $0.85/mile + $35,000 mid life rebuild except hybrid is $0.74/mile with $0 mid life rebuild
- CNG price is $1.08/dge and diesel price is $2.11/gallon in 2016 per EIA

Battery Electric Bus

- 2.1 kWh/mile for depot charge overnight in 10 hour period
- Maintenance is $0.60/mile with 12 year battery warranty
- Electricity cost for depot charging is $0.17/kWh for PG&E, $0.12/kWh for SCE (per LA Metro analysis), and $0.19/kWh for SDG&E in 2016

Total Cost of Ownership for a Bus Purchased in 2020



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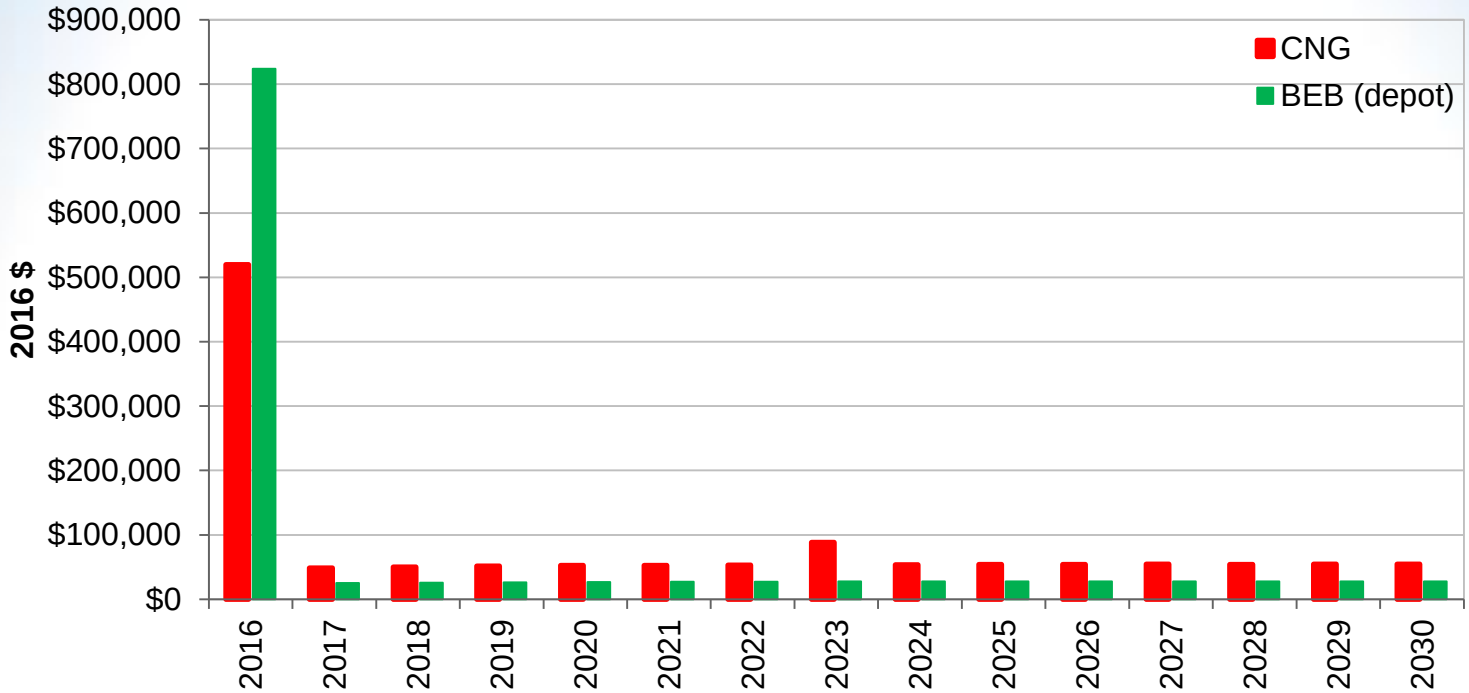
Cash Flow for BEB and CNG Bus



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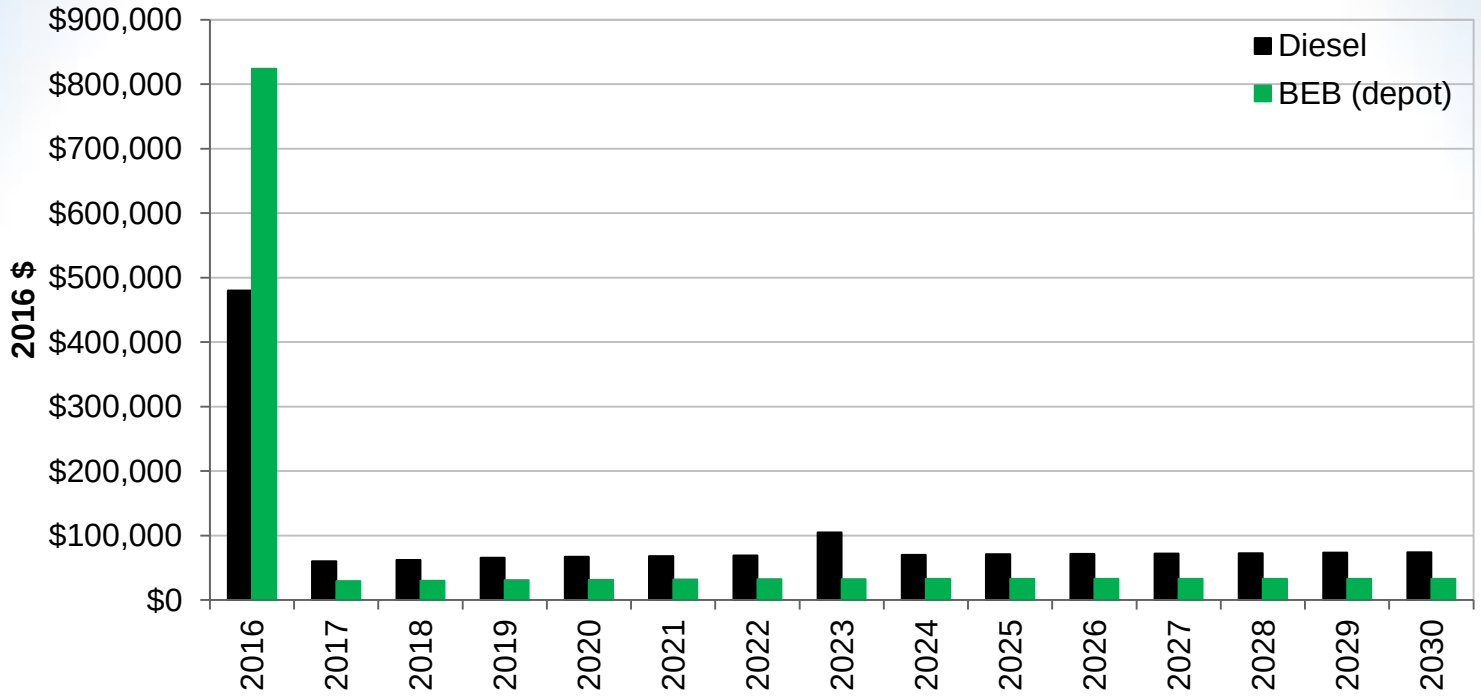
Los Angeles Metro CNG bus travels 2.7 miles/DGE with CNG price of 1.08 per gallon in 2016 and receives LCFS credit.
Battery electric bus travels 0.48 miles/kWh. Charges off-peak at cost of $0.12/kWh (per LA Metro analysis) minus $0.10/kWh from LCFS in 2016.

Cash Flow for BEB and Diesel Bus



Assumes bus travels 130 miles per day and LCFS credit sold at $100 per credit.
Golden Gate Transit diesel bus travels 3.7 miles/gallon with diesel price of 2.11 per gallon in 2016.
Battery electric bus travels 0.48 miles/kWh. Charges off-peak (PG&E E-19) at cost of $0.17/kWh minus $0.10/kWh from LCFS in 2016.

Proposed Fleet Case Studies

- Antelope Valley
- Foothill transit
- Victor Valley
- LA Metro
- San Diego
- Orange County
- Fairfield
- Sacramento

Next Steps

- Publish ARB fleet cost model for comment
- Update battery electric bus charging cost calculator
- Meet with individual fleets
  - Discuss barriers, survey results, and cost information
- Transit subcommittee meeting end of October