Advanced Clean Trucks Cost Discussion

Workgroup Meeting

December 4, 2018

Sacramento, California

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Cost Discussion Goals

- Help us understand cost saving opportunities and find well-suited market segments
  - Costs and emission benefits should be consistent with timeframe for operations in California
- Share data sources we are aware of and receive feedback on them
- Use cost sources to develop total cost of ownership model for rulemaking purposes
  - Advanced Clean Trucks
  - Future fleet rules

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Total Cost of Ownership

- Total Cost of Ownership (TCO) is the discounted sum of all costs of a vehicle
- Includes capital costs (vehicle purchase, infrastructure) and operational costs (fuel, maintenance, LCFS credits) as well as other miscellaneous expenses
- TCO depends on how the vehicle is operated – vehicle miles travelled, years of operation, and other factors

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Topics for discussion

- Vehicle operations
- Capital costs
  - Vehicle purchase price
  - Residual values
  - Midlife refurbishment
- Operating costs
  - Fuel
  - Low Carbon Fuel Standard
  - Maintenance
- Infrastructure
- Other

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Vehicle Operating Assumptions

- Annual miles
  - Numerous sources estimate annual or daily miles for vehicle populations including CalHEAT, CARB's EMFAC, the Vehicle Inventory and Use Survey (VIUS), and the upcoming CalTrans Truck Survey (CalVIUS)
- Vehicle life
  - Based on DMV data and other sources, the average lifetime of a truck is 15-25 years
  - Based on surveys, the typical first life of a vehicle is 8-10 years but varies significantly by truck type, usage, fleet priorities, and other factors

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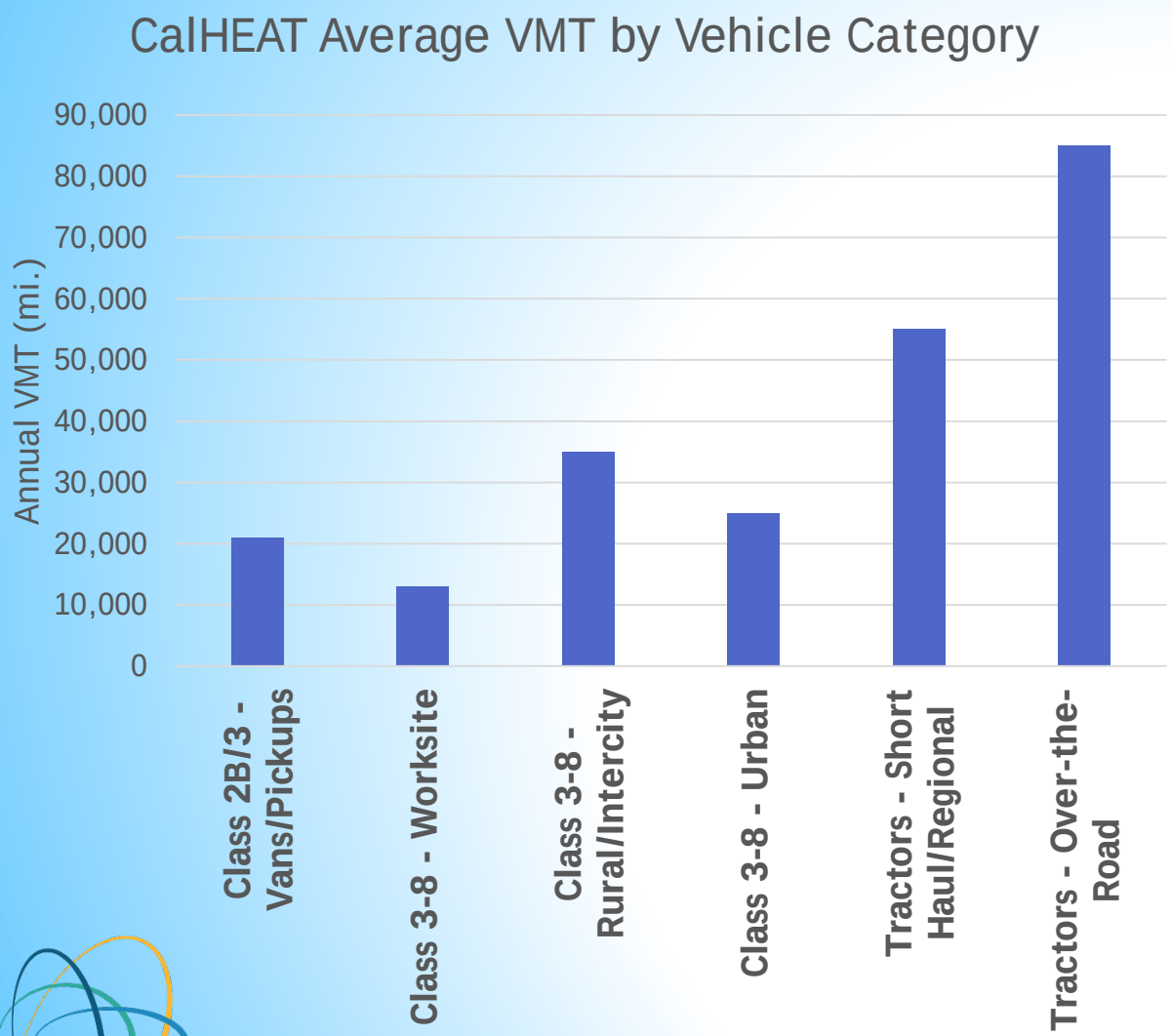
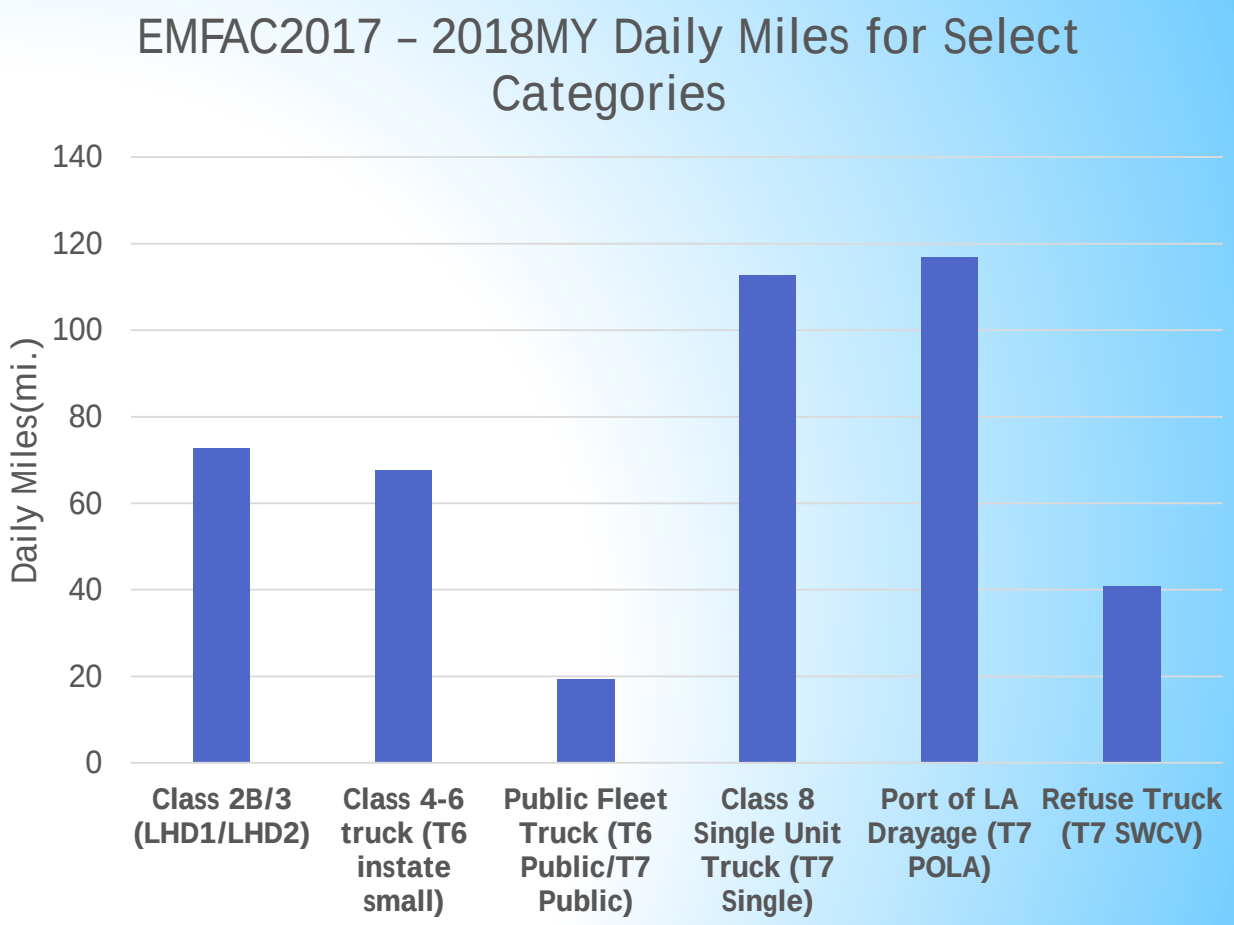
Mileage Examples





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Vehicle Prices

- Manufacturer websites and online truck marketplaces
  - Includes TruckPaper.com and CommercialTruckTrader.com
  - Future truck prices influenced by GHG Phase 2 compliance costs
- Zero-emission vehicle prices can be calculated using estimated glider costs and component-level cost estimates
  - Heavy-duty sources include CARB, the International Council on Clean Transportation, Ricardo, University of California, Davis and others
  - Can we use light-duty projections for some vehicles i.e. Class 2B-3?
- Residual values for vehicles
  - Battery-electric
    - A SAE paper estimates BEV battery's residual value of $20-$100/kWh for BEV batteries
  - Hydrogen fuel cell

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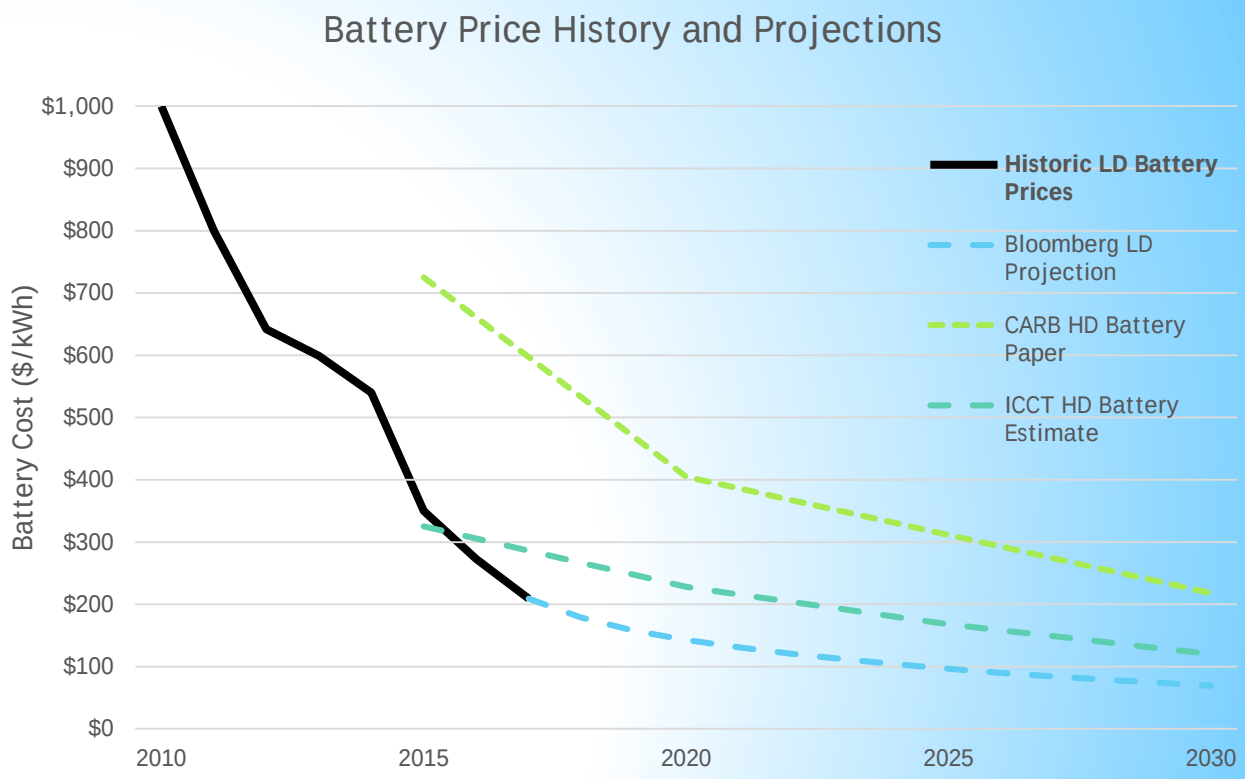
SAE International, A Techno-Economic Analysis of PEV Battery Second Use: Repurposed-Battery Selling Price and Commercial and Industrial End-User Value, 2012. https://www.nrel.gov/docs/fy12osti/53799.pdf

Battery Costs

- The cost of the battery is the largest component of battery-electric vehicles
  - Light-duty battery costs have declined dramatically over the last decade
- Cost reductions expected for other EV components
- Today, heavy-duty batteries cost more than light-duty batteries. It is unclear if this trend will continue.
  - Companies may use LD batteries in HD applications



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CARB, Battery Cost for Heavy-Duty Electric Vehicles, 2016. https://www.arb.ca.gov/msprog/bus/battery_cost.pdf

International Coalition for Clean Transportation, Transitioning to Zero-Emission Heavy-Duty Freight Vehicles, 2017. https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

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Midlife Costs

- Midlife costs include diesel engine rebuilds, battery replacements, and fuel cell stack refurbishments
- Dependent on vehicle life and usage – more miles means one or more midlife expenses
- Battery replacement
  - Based on battery price curve, battery size, warranty period, and other factors
- Hydrogen fuel cell stack refurbishment
  - Ricardo estimates a refurbishment costs 1/3 of the fuel-cell stack's cost

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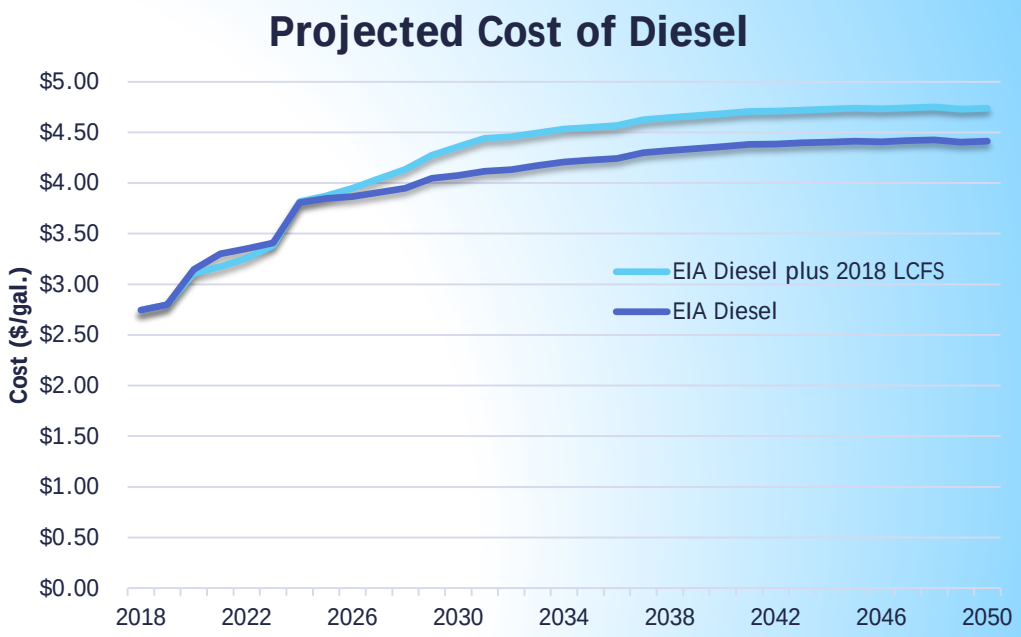
Ricardo, Economic Models for Truck TCO and Hydrogen Refueling Stations, 2017.

Fuel Cost

- Diesel fuel cost – Energy Intelligence Agency's (EIA) Annual Energy Outlook (AEO) 2018
  - Add in projected 2018 Low Carbon Fuel Standard Amendment costs
- Electricity fuel cost – CARB Battery-Electric Truck and Bus Charging Calculator for initial cost
  - EIA AEO 2018 – models cost increase over time
- Hydrogen fuel cost
  - Production method and volume dependent



Energy Intelligence Agency, Annual Energy Outlook 2018, 2018. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2018&cases=ref2018&sourcekey=0

Trillium, Fuel Cell Bus Infrastructure for 100+ Bus Depot, 2018. https://www.apta.com/resources/standards/quarterly-webinar-series/Documents/APTA%20Webinar%20on%20Fuel%20Cell%20Electric%20Bus%20Infrastructure%20for%20100-Bus%20Fleet%209-20-18%20FINAL.pdf

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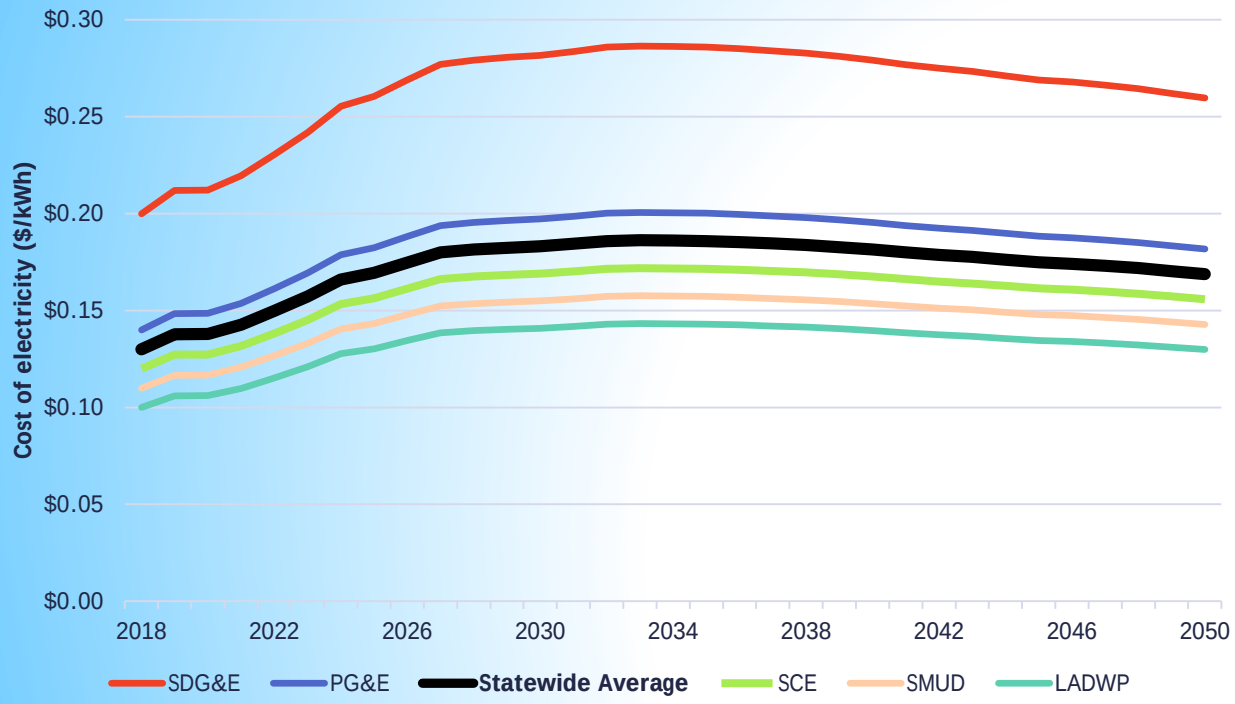
Fuel Cost (Cont'd)

Cost of Electricity (Delivery Van)



Cost of Hydrogen* (Trillium Estimate)

Buses	kg/day	GH2 Delivery	LH2 Delivery	Onsite SMR	Onsite Electrolysis
5	150	$11+	$12+	$11	$11-$16
35	1,000	$8+	$7+	$6	$7-$12
200	6,000	$6+	$4+	$4	$4-$10

*Deduct $6/kg for 5 buses, $1.50/kg for 200 buses for direct CapEx purchase

- Input for electricity graph: 20 vehicle deployment, 19 kW charger, 100 mi./day, 0.96 kWh/mi. 90% charging efficiency, 10PM-6AM charging period, managed charging strategy, 3% local taxes and fees, LADWP – A-2(B), PG&E – CEV-L @ 400kW, SMUD – GS-TOU3, SDG&E – AL-TOU2/EECC-CPP-D, SCE – EV-8
- Note: The graph shows Pacific Gas and Electric's CEV-L rate and Southern California Edison's EV-8 rate, both of which are awaiting approval.

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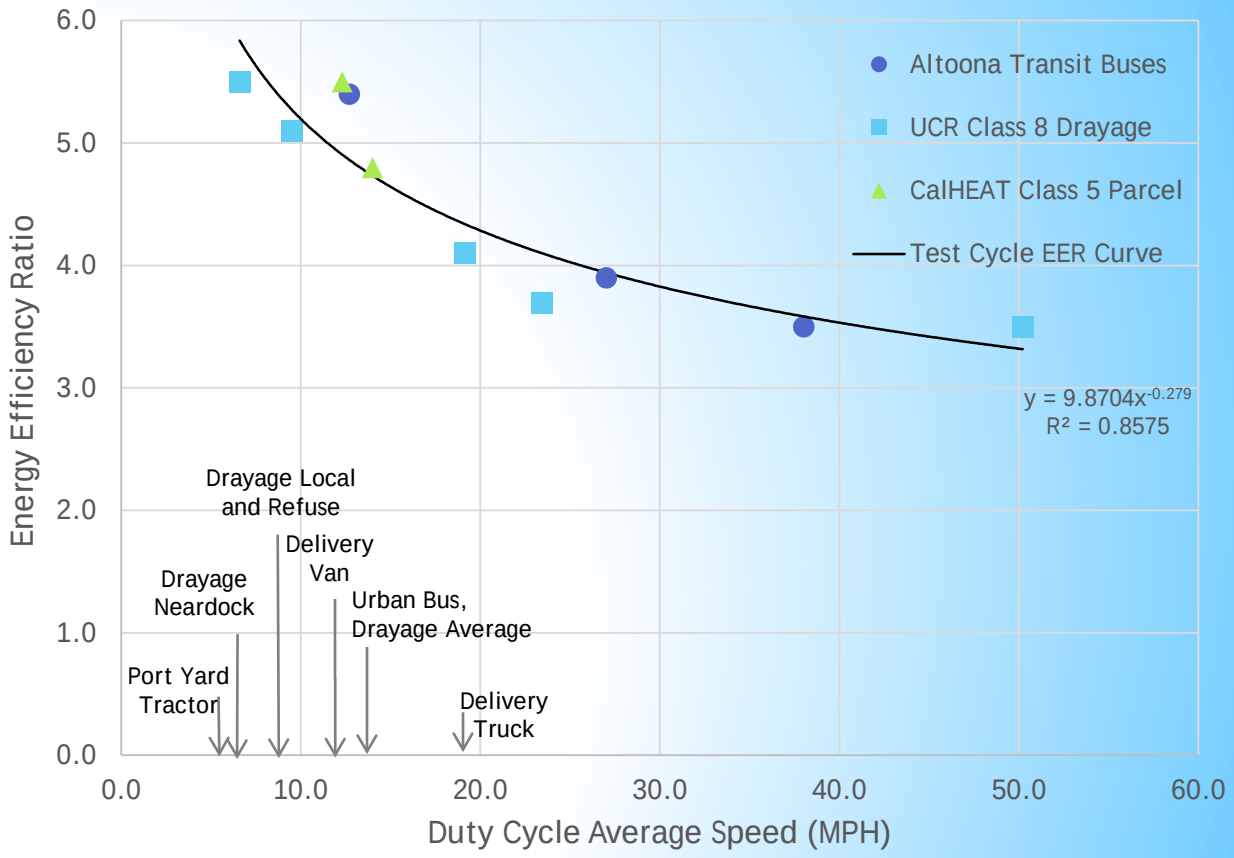
Efficiency of Electric Vehicles

- Electric vehicles operate more efficiently at lower speeds compared to diesel
- Most vocational vehicles operate at low average speeds under 20 mph



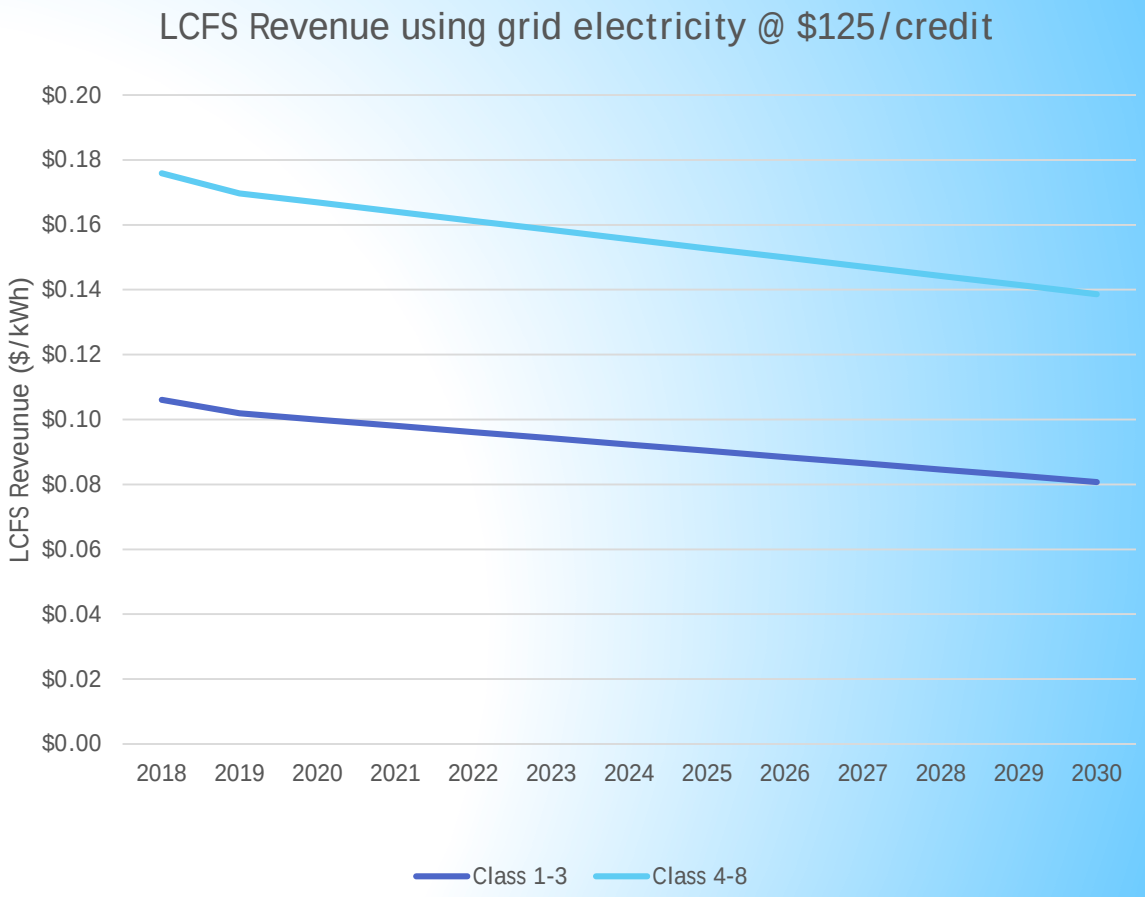
California Air Resources Board, Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles, 2018. https://ww2.arb.ca.gov/sites/default/files/2018-11/180124hdbevefficiency.pdf

Fuel Economy

- Diesel – can be derived from GHG Phase 2 standards
- Battery-electric – based on in-use data
  - Passenger van – 0.56 kWh/mi.
  - Delivery van – 0.7 to 1.0 kWh/mi.
  - Cutaway shuttle – 1.0 kWh/mi.
  - Day cab tractor – 2.1 kWh/mi
  - Refuse truck – 2.5 to 3.0 kWh/mi.
- Hydrogen fuel-cell – Apply Low Carbon Fuel Standard Energy Economy Ratios to diesel fuel economy
  - Class 1-3 – hydrogen fuel-cell is 2.5 times more efficient than diesel
  - Class 4-8 – hydrogen fuel-cell is 1.9 times more efficient than diesel
- BE and HFC fuel economy will improve over time like diesel

Low Carbon Fuel Standard

- The Low Carbon Fuel Standard (LCFS) program requires fuel producers to lower the carbon intensity (CI) of their fuel or purchase credits from low-CI fuel producers
  - Electricity and hydrogen can generate revenue
- LCFS credits for hydrogen will vary based on production method
  - Renewable versus fossil sources, electrolysis vs steam methane reformation
  - $0.30/kg to $2.60/kg in 2018



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BEV Fuel Cost Saving Opportunities

EV: 0.56 kWh/mi. Diesel: 22 mpg

Airport Shuttle

EV: 1.04 kWh/mi. Diesel: 10 mpg

Package Delivery

EV: 2.1 kWh/mi. Diesel: 3.5 mpg

Local Drayage

	Airport Shuttle	Package Delivery	Local Drayage
vs Diesel	15%	35%	50%
with LCFS	**45%**	**75%***	**80%***

Data from CARB Paper. Assuming $3.00/gal., $0.17/kWh plus a 15% charging loss, LCFS Credits at $100

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Maintenance

- The maintenance cost reflects the cost of labor and parts for routine maintenance, preventative maintenance, and fixing broken components.
- Diesel-powered maintenance costs
  - Passenger Van - $0.17/mi. – Average of California Energy Commission and Access LA sources
  - Delivery Van - $0.22/mi. – National Renewable Energy Laboratory
  - Cutaway Shuttle - $0.29/mi – Access LA
  - Short-haul Tractor - $0.19/mi. – American Truck Research Institute Report
  - Refuse truck - $0.80/mi. – M. J. Bradley and Associates

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American Truck Research Institute, An Analysis of the Operational Costs of Trucking: 2017 Update, 2017. http://atri-online.org/wp-content/uploads/2017/10/ATRI-Operational-Costs-of-Trucking-2017-10-2017.pdf
California Energy Commission, Maintenance Cost Attributes for Light Duty Vehicles, 2015. https://efiling.energy.ca.gov/getdocument.aspx?tn=206183
National Renewable Energy Laboratory, FedEx Express Gasoline Hybrid Electric Delivery Truck Evaluation: 12-Month Report, 2011. https://www.nrel.gov/docs/fy11osti/48896.pdf
M.J. Bradley & Associates, New York City Commercial Refuse Truck Age Out Analysis, 2013. https://www.mjbradley.com/sites/default/files/EDF-BIC-Refuse-Truck-Report-2013.pdf

Maintenance (Cont'd)

- Data suggests a battery-electric vehicle's maintenance is 25% lower than diesel
  - Limited truck sources exist, data comes from light-duty and buses
- Limited data suggests hydrogen fuel-cells have similar maintenance to diesel vehicles
  - Ballard estimates a fuel cell bus costs the same as a battery-electric bus plus $0.20/mi. for maintaining the fuel cell stack. This puts it in-line with a diesel bus.
- Data shows that maintenance costs start lower and increase over the life of the vehicle

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California Air Resources Board, Literature Review on Transit Bus Maintenance Cost, 2016. https://www.arb.ca.gov/msprog/bus/maintenance_cost.pdf
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Infrastructure

- Electric and hydrogen vehicles new additional infrastructure to operate
- Charging Infrastructure
  - Pacific Gas and Electric and Southern California Edison estimated per-vehicle costs:
    - Light trucks: $3,500-$5,000 for the charger, $12,300-$20,300 for site upgrades
    - Heavy trucks: $15,000 for the charger, $14,200-$29,100 for site upgrades
  - Early truck and bus deployments suggest that Class 8 vehicles may have higher infrastructure costs - $50,000 per charger, $55,000 for site upgrades
- Hydrogen infrastructure - the Trillium hydrogen fuel costs projections include infrastructure costs

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How should infrastructure be included in a vehicle TCO analysis?

- Large upfront cost to install infrastructure should be reflected
- For an initial rollout, infrastructure will be rolled out concurrently with vehicles, meaning costs will be tied to vehicles
- Infrastructure lasts multiple vehicle lifetimes, costs generally should be amortized over the total life of infrastructure
- Small deployments need minimal to no site upgrades
- Utilities have programs to pay for infrastructure upgrades today (SB 350)
- Infrastructure upgrades not necessary if public refueling/recharging exists

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Other

- Discount Rate
  - Regulations typically assume a discount rate of 2.5%-5%
- Taxes
  - Sales tax – Varies across the state from at least 7.25% to 10.25% in some cities
  - Federal Excise Tax – 12% tax on purchase of Class 8 trucks
- Financing
  - Most private vehicles financed, most public vehicles purchased outright
  - What interest rate and period to assume?
- Registration Fees
  - Diesel and ZE vehicles have significantly different fee structures, can be modelled separately
  - ZE vehicles may pay slightly less
- Other costs to consider?

Contact Information

- Please send any information, feedback, data sources, etc. to:

Paul Arneja, Air Resources Engineer

Paul.Arneja@arb.ca.gov

Craig Duehring, Manager

Craig.Duehring@arb.ca.gov