CALIFORNIA HYDROGEN BUSINESS COUNCIL

Hydrogen Means Business in California!

Zero Emission Goods Movement

Class 8 Fuel Cell Electric Truck Fact Sheet

In California, 40% of greenhouse gas emissions are sourced from the transportation sector. Heavy-duty trucking makes up 21% of these emissions and 26% of statewide emissions of oxides of nitrogen (NOx).[i] Therefore, the State is implementing the Advanced Clean Trucks (ACT) regulation, to drive adoption of zero-emission Class 8 truck tractors as a percentage of sales in California by 2030.[ii] In response, Class 8 truck OEMs are investing in the development of fuel cell electric trucks (FCETs) to meet market needs.

Benefits:

- Comparable Range to CNG
- Comparable Payload to Diesel
- Multi-shift Operation
- Quick Refueling
- Ease of Operation
- No Self-Discharge
- Zero Emissions

Hydrogen and Infrastructure

Hydrogen fuel storage shows 0% degradation over time, meaning no loss of fuel when parked, which unique among zero emission technologies. Hydrogen as a fuel requires minimal change to fueling logistics and shift operation compared to diesel and natural gas. The ability to refuel vehicles in rapid succession means fleets have similar operator experience as diesel and CNG. Figure 1 shows that a long-haul Class 8 hydrogen truck can achieve an approximate 280-mile range after 10 minutes of refueling, whereas an equivalent 350kW DC fast charger would only provide sufficient charge to travel 30 miles in the same 10 minute refueling time. The future case for hydrogen will be similar to diesel as far as time at the pump, whereas even with a 1,500 kW DC fast charger, battery electric trucks (BETs) still fill only at about ¼ of the rate as a modern diesel vehicle – charging to approximately 250 miles in 10 minutes.[iii]

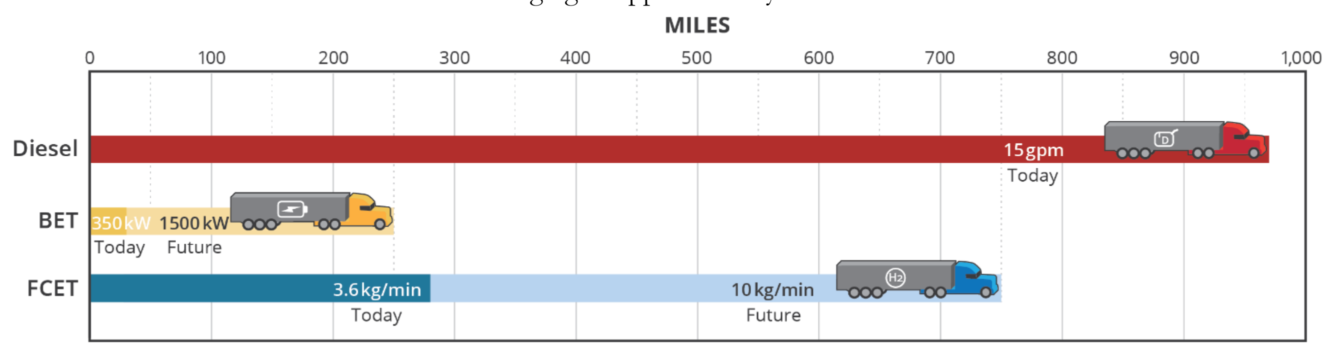

Figure 1 Comparison of range for 10 minutes of refueling for Diesel, Battery Electric and Fuel Cell Electric Trucks

Improving Economics

In a white paper produced by Ballard and Deloitte, it conservatively estimates the Total Cost of Ownership for commercial hydrogen vehicles will fall by more than 50% in the next 10 years.[iv] The cost of fuel is estimated at more than 40% of the total cost of operating a commercial truck, not including driver costs.[v] It is vitally important that the cost of hydrogen fuel decreases to a level that will support the commercialization of FCETs. DOE estimates hydrogen cost at $5.00/kg.[vi]

In their most recent report, NREL found the average cost of hydrogen incurred by the Stark Area Regional Transit Authority (SARTA) was $5.27 per kilogram (kg).[vii] Bloomberg recently estimated the cost of producing renewable hydrogen could decrease to $1.40/kg as soon as 2030, which would support a pump price approaching $4.00/kg for renewable hydrogen.[viii] The result is a lower overall cost than BETs and comparable cost to CNG/LNG/Diesel trucks for urban and port operation.

Key Features and Performance

FCETs are performing well in pre-commercial testing in real world port and freight applications. Multiple OEMs are validating that FCETs are a 1-to-1 zero emission replacement for Class 8 diesel trucks both in terms of vehicle performance and operations. Active FCET projects include:

Project Name	*OEM*	*# of FCETs*	*Deployment Date*
ZECT II [ix]	Multiple	6	2016-2020
Project Portal [x]	Toyota	2	2017-2018
Shore-to-Store [xi]	Toyota/Kenworth	10	2019-2020
XCIENT[xii]	Hyundai	1,600	2020-2025

Fuel cell powertrains offer distinct advantages over incumbent powertrains, including zero tailpipe emissions, zero well-to-wheel GHG emissions (when using renewable hydrogen), higher energy efficiency, and reduced noise. For goods movement, FCETs have several advantages over BETs: longer driving range, quick refueling, near-conventional payload capacity, and improved performance in extreme temperatures. The latest generation of fuel cells are capable of starting and operating at temperatures of -25C (-13F)[xiii], with continued development towards even lower temperatures.

Prolonged fuel cell durability in demanding environments has been proven in transit bus fleets where fuel cells far-surpassed 30,000 hours of operation over the course of 8 years at TFL in London, UK[xiv] and AC Transit[xv] in the San Francisco East Bay in Northern California.

FCETs provide a comparable freight capacity to diesel, whereas BETs will have a significantly reduced payload as shown in Figure 2.[xvi]

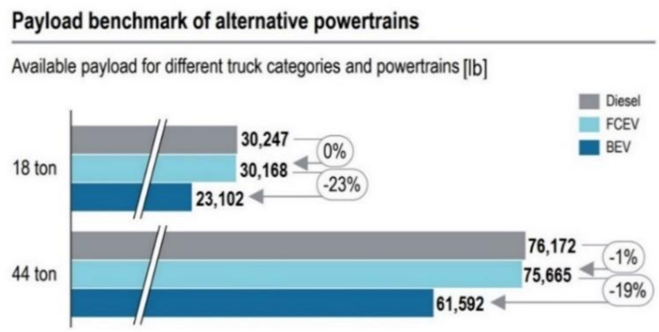

Figure 2 Comparison of available payload for Diesel, Battery Electric and Fuel Cell Electric Trucks

Available Funding

Recently, the California Energy Commission (CEC) announced $47.5 million available in 2020 for zero emission medium/heavy-duty vehicles and infrastructure.[xvii] The Volkswagen Mitigation Trust will provide $90 million in funding for Zero-Emission Class 8 Freight and Port Drayage Trucks. The first $27 million installment is now available statewide on a first-come, first-served basis; up to $200,000 per truck.[xviii]

The California Air Resources Board and CEC will jointly release a $40 million solicitation for a Zero-Emission Drayage Truck Pilot project seeking large-scale deployments of battery electric and fuel cell electric Class 8 trucks plus supporting fueling infrastructure. Additionally, the CEC is proposing to invest $134.8 million in medium/heavy-duty zero emission vehicles and infrastructure from July 2020 through December 2023. For more information on the most current funding opportunities, contact the California Hydrogen Business Council at www.californiahydrogen.org.

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[i] California Air Resources Board. (2019). *GHG Current California Emission Inventory Data*. https://ww2.arb.ca.gov/ghg-inventory-data.
[ii] California Air Resources Board. (2020, June 25). *Advanced Clean Trucks Fact Sheet*. https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-act-fact-sheet.
[iii] Assumptions: **Diesel:** (1) Typical HD vehicles achieve 6.5 mpg (Davis and Boundy 2019; Schoettle, Sivak, and Tunnell 2016). (2) Fueling rates for diesel truck dispensers are commonly 15 gpm or faster; **BET:** (1) Tesla and Daimler advertise vehicle efficiencies of ~2 kWh/mile (Tesla 2020; Daimler Trucks North America LLC 2020). Therefore, setting case today at 2 kWh/mile and future case at 1 kWh/mile, 50% reduction in energy use. (2) Charge rates for today will be 350kW fast charger and future case 1,500kW fast charger; **FCET:** (1) Nikola Motor predicting 600-mile range with 80 kg of hydrogen, which equates to 7.5 mi/kg, so at 100kg of hydrogen total capacity provides 750-mile total range. In context of FCEBs showing efficiency around 4–6 mi/kg for on-road efficiency and bus drive cycles being tougher than drive cycles for trucks, so 7.5 mi/kg estimate reasonable, and use this for both today and future case. (2) Fill rates for today and the future case will be 3.6 kg/min and 10 kg/min, respectively.
[iv] Ballard Power. (2020, January 7). *Deloitte-Ballard Joint White Paper Assesses Hydrogen & Fuel Cell Solutions for Transportation*. https://www.ballard.com/about-ballard/newsroom/news-releases/2020/01/08/deloitte-ballard-joint-white-paper-assesses-hydrogen-fuel-cell-solutions-for-transportation.
[v] Murray, D., & Glidewell, S. (2019, November). *An Analysis of the Operational Costs of Trucking: 2019 Update*. https://truckingresearch.org/wp-content/uploads/2019/11/ATRI-Operational-Costs-of-Trucking-2019-1.pdf.
[vi] Marcinkoski, J., Vijayagopal, R., Adams, J., James, B., Kopasz, J., & Ahluwalia, R. (2019, October 31). *DOE Advanced Truck Technologies: Subsection of the Electrified Powertrain Roadmap Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks*. https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.
[vii] Eudy, L., Post, M., Norris, J., & Sokolsky, S. (2019, October). *Zero-Emission Bus Evaluation Results: Stark Area Regional Transit Authority Fuel Cell Electric Buses, FTA Report No. 0140*. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/134491/zero-emission-bus-evaluation-results-sarta-fta-report-no-0140_0.pdf.
[viii] Mathis, W., & Thornhill, J. (2019, August 21). *Hydrogen's Plunging Price Boosts Role as Climate Solution*. https://www.bloomberg.com/news/articles/2019-08-21/cost-of-hydrogen-from-renewables-to-plummet-next-decade-bnef.
[ix] https://www.energy.gov/sites/prod/files/2019/06/f63/elt158_impullitti_2019_o_5.29_1.01pm.pdf
[x] https://pressroom.toyota.com/the-future-of-zero-emission-trucking-takes-another-leap-forward/
[xi] https://www.act-news.com/news/ca-zero-emission-freight-projects/
[xii] https://www.h2-view.com/story/hyundai-ships-first-hydrogen-trucks-to-switzerland/
[xiii] Eudy, L., Post, M., Norris, J., & Sokolsky, S. (2019, October). *Zero-Emission Bus Evaluation Results*.
[xiv] Ballard Power. (2019, May 13). *Ballard Announces Order From Wrightbus For 20 Fuel Cell Modules to Power London Buses*. https://www.ballard.com/about-ballard/newsroom/news-releases/2019/05/13/ballard-announces-order-from-wrightbus-for-20-fuel-cell-modules-to-power-london-buses.
[xv] US DOE 2019 AMR, NREL
[xvi] Fuel Cells and Hydrogen 2 Joint Undertaking. (2017, August). *Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities: FCH Heavy-duty trucks*. https://www.fch.europa.eu/sites/default/files/171121_FCH2JU_Application-Package_WG1_Heavy duty trucks (ID 2910560) (ID 2911646).pdf.
[xvii] California Energy Commission. (2020). *2020-2021 Investment Plan Update Proceeding*. https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/clean-transportation-program-investment-5.
[xviii] Volkswagen Environmental Mitigation Trust for California. (2020). *About the Volkswagen Environmental Mitigation Trust*. https://www.aqmd.gov/vw/.