2016

California Fuel Cell Partnership

MEDIUM- & HEAVY-DUTY FUEL CELL ELECTRIC TRUCK ACTION PLAN FOR CALIFORNIA - DRAFT

Executive Summary

Vehicular transportation contributes significantly to the adverse effects caused by air pollution on human health and to greenhouse gas (GHG) emissions, which are altering the earth's climate to devastating effect. Within the transportation sector, medium- and heavy-duty vehicles account for one of the fastest growing sources of emissions and energy consumption.[1] Deployment of medium- and heavy-duty zero emission vehicle (ZEV) technologies such as fuel cell electric trucks (FCET) have the potential to significantly reduce the negative impacts associated with freight transport.

The members of the California Fuel Cell Partnership (CaFCP) have prepared this Action Plan to accelerate the development and commercialization of medium- and heavy-duty FCEVs in California. Federal air quality targets, the AB 32 GHG reduction targets, and the State's transport electrification targets, combined with the goals of the California Sustainable Freight Transport Initiative, make California a favorable place to launch zero emission medium- and heavy-duty transportation technologies.

To ensure a focused and effective strategy, two vocational categories were selected as being the most feasible near-term vehicle platforms: Class 4-6 urban "last mile delivery" trucks (14,001-26,000 pound gross vehicle weight) and Class 7-8 short haul/drayage trucks (26,001-33,000+ pound gross vehicle weight). The Action Plan introduces metrics in order to set forth clearly-stated national proposals for targets for both truck categories. Technology demonstration and validation of these initial categories can provide a sound basis for applying the technology to additional truck classes and vocations. The Action Plan outlines the elements of a sustainable business case (see Appendix C) in order to capture the broad effort that is required to successfully introduce any fuel cell truck product to market.

A second major element of the Action Plan pertains to establishing the necessary hydrogen fueling infrastructure to match demand. Planning for capacity, distribution, and siting of this fueling infrastructure needs to start in 2016 to support the initial deployments and demonstrations. Both commercial conventional fuel and hydrogen fuel providers need to be included in this effort.

The operational data and lessons learned from the envisioned rollout of vehicles and infrastructure can be translated to a statewide and national level over time, working toward broad deployment of FCEV technology.

California hosts the largest heavy-duty FCEV programs in North America, including the bus programs at Alameda-Contra Costa Transit Agency and SunLine Transit Agency in the Coachella Valley. These demonstration programs are showing increasing availability of fuel cell electric buses (FCEBs). Reliability has surpassed both 2016 interim and ultimate technical targets set forth by the Department of Energy. Both SunLine and AC Transit have on-site, self-provided technician training programs, demonstrating a technology readiness level for deployment.

[1] http://www.eia.gov/beta/aeo/#/?id=7-AEO2015

Although these two successful FCEB demonstrations provide some knowledge and data for FCET development, they represent a minority: few ZEV demonstrations in California focus on medium- and/or heavy-duty FCEV technologies. It is crucial that the currently planned and funded FCET projects are deployed successfully and that the experience gained from these projects be leveraged for additional deployments to create progress along the commercialization path.

The Action Plan contains recommendations to support the commercialization of FCETs. These include recommendations specific to State and Federal governments and to industry stakeholders, as well as recommendations where government and industry collaboration is needed. The overall highest priority recommendation is to support FCET fueling infrastructure development, which should be given priority and undertaken as soon as possible. The highest priority recommendations drawn from each section are:

Chapter 2: Medium- and Heavy-Duty Truck Focus (Technology Advancement)

1) Transfer the lessons learned from implementing and operating fuel cell bus programs to truck vocations, especially as these lessons relate to technology, and help identify or reduce risk to the financial community (industry).

2) Conduct data collection using a consistent set of fleet operation variables for comparison, feasibility assessments, and decision making; this should be a basic requirement for all government-funded truck projects (government and industry collaboratively).

3) Prove reliability of MD and HD FCETs to show that the cost-per-mile economics of transported freight; this is critical to the sustainable operation of this technology (industry).

4) Build a better mutual understanding of the truck manufacturing product creation process in the context of FCET technology development (government and industry collaboratively).

5) When setting targets, stakeholders should assume a timeline of 7-15 years for developing new truck platforms with completely new propulsion and power train systems in their decision-making process (government and industry collaboratively).

6) Establish separate stakeholder groups (drayage and package delivery) to discuss and provide realistic market information about the baseline requirements for vehicle technology, operational cycles, supplier expectations, etc. (industry).

Chapter 2: Medium- and Heavy-Duty Truck Focus (Cost Reduction)

1) Support FCEB Centers of Excellence to prove infrastructure and fuel cost reduction, and develop expertise and understanding about hydrogen fueling for large fleets (federal and state government).

2) Establish targets and priorities for future MD and HD FCEV funding programs (federal government).

3) Initiate, expand, and direct national efforts to perform in-depth studies of fuel cell technology in trucks to understand the components of the total cost of ownership and opportunities for cost reduction (federal government).

4) Assess options for developing a ZEV credit or long-term incentive strategy for MD and HD ZEVs to encourage truck integrators and OEMs to invest in the RD&D of fuel cell technology in trucks (federal and state government).

Chapter 3: Hydrogen Stations and Fueling Experience

1) Fund initial private or commercial hydrogen fueling infrastructure, with consideration of public funding for station operation and maintenance (O&M) in early years (state government).

Chapter 4: Meeting the Challenges Ahead

1) Develop the current SAE J2601/2 TIR "Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles" to the level of a full standard and generate data to resolve SAE J2601 not including 35 MPa fueling (6-10 kg) to address the current gaps in fueling protocol related codes and standards (government and industry collaboratively).

2) Consolidate funded truck projects and development of commercial HD fueling infrastructure, so stations have higher throughput, reducing the cost of fuel and capital expense of infrastructure (industry and government collaboratively).

Chapter 5: Timing Considerations

1) Assess corporate operating structure options to create economic benefits for MD and HD FCET operators and initiate within the next 5 to 10 years (government and industry collaboratively).

1. Introduction

Market adoption of full and partial zero emission vehicle (ZEV) technologies appears poised to contribute significantly to the attainment of California's greenhouse gas (GHG) emission reduction targets, as well affording air quality benefits by lowering levels of criteria pollutants. The State is currently on track to achieve its 2020 GHG emission reduction target to 1990 levels, as established by AB 32 (2006). However, the significantly steeper reduction targets for 2030 and 2050[2] are prompting stakeholder discussion and planning to formulate pathways that will lead to the development and commercialization of ZEV technologies in freight transport, which accounts for about 23% of on-road GHG emissions.[3]

With this Action Plan, the California Fuel Cell Partnership (CaFCP) set out to identify actions needed to demonstrate fuel cell technologies in medium-duty and heavy-duty (MD and HD) vocational trucking applications in California in order to better define the path to commercialization. Although consideration was given to mid- and long-term objectives, stakeholders recognized a near-term (before 2020) imperative for demonstrations to underpin planning for an introduction strategy and technology validation path for fuel cells in the on-road freight vehicle market in California.

This intention subsequently led to a focus on demonstrating community based vocational and last-mile delivery vehicles such as MD parcel delivery trucks and HD drayage trucks in the near term. The selection of these two applications was based on:

1. The ability to cover and represent, as best possible, the greatest number of MD and HD applications and uses with limited early deployments
2. The initial viability and capability of success based on other fuel cell related experiences
3. Minimal fueling infrastructure requirements; the short-haul, return-to-base duty cycle can be supported by relatively few hydrogen stations
4. Potential for technology transfer from previous and ongoing FCEV technology development projects such as fuel cell electric buses (FCEBs)
5. Potential for near-term emission reduction benefits from demonstration fleets operating in highly urbanized and/or impacted airsheds; among candidate truck vocations, MD parcel delivery and HD drayage trucks are large contributors to air pollution based on the mileage and fuel consumption

Technology validation through demonstration of fuel cell electric trucks (FCET) in these applications will provide the vehicle and fleet operational data that is essential to mapping a course toward commercialization in California and the United States. Furthermore, the prospect of transferring lessons learned from these demonstrations to fuel cell technology in other vocations should be recognized as a potential benefit. Industry stakeholders place the development of long haul FCETs in the long term due to the unique characteristics of these trucks, which must be designed to cover great distances carrying

[2] 40% below 1990 levels by 2030; 80% below 1990 levels by 2050.
[3] http://www.energy.ca.gov/2015publications/CEC-600-2015-014/CEC-600-2015-014-CMF.pdf

heavy loads. The experience gained from fuel cell technology in other truck types, particularly, HD drayage trucks, can serve to inform efforts to extend the technology to long haul trucks.

In examining the challenges facing FCET development, the Action Plan notes the current need to identify or develop hydrogen fueling to support demonstration fleets. Longer-term planning for the hydrogen infrastructure should account for the specialized nature of FCETs, which like conventional trucks, will require dedicated stations. The Plan offers recommendations for stakeholders in industry and in state and federal government to help advance and incentivize FCETs and the hydrogen infrastructure.

California Policy Context

Support from state leadership, which has been critical to establishing nascent ZEV markets in California, is expected to continue and help accelerate FCET technology development and commercialization. State incentive programs, such as the California Air Resources Board's (CARB) Low Carbon Transportation Investments and Air Quality Improvement Program[4] (AQIP), the California Energy Commission's (Energy Commission) Alternative and Renewable Fuel and Vehicle Technology Program[5] (ARFVTP), and funding from local air districts collectively encourage the market introduction of more efficient, low-emission vehicle technologies through targeted technology demonstration projects and direct consumer incentives. AQIP and ARFVTP provide important tools for addressing the incremental capital cost and operational barriers and uncertainties associated with current FCEVs, and are expected to encourage the development of MD and HD FCET technology.

Initial direction toward establishing a strategy and technical targets for air quality and emission goals was provided in CARB's Vision Scenario Planning effort, which foresees a strong need for zero emission MD and HD vehicles.[6]

In July 2015, the Governor signed Executive Order B-32-15, [7] ordering state agencies to develop an integrated action plan by July 2016 that establishes clear targets to improve freight efficiency, transition to zero emission technologies, and increase competitiveness of California's freight system. The draft *California Sustainable Freight Action Plan,*[8] which was released for comments on April 26, 2016, sets forth the following targets:

- Improve freight system efficiency 25% by increasing the value of goods and services produced from the freight sector, relative to the amount of carbon that it produces by 2030.
- Deploy over 100,000 freight vehicles and equipment capable of zero emission operation and maximize near-zero emission freight vehicles and equipment powered by renewable energy by 2030.
- Foster future economic growth within the freight and goods movement industry by promoting flexibility, efficiency, investment, and best business practices through State policies and programs

[4] Includes funds from Greenhouse Gas Reduction Fund (GGRF).
[5] California Energy Commission Alternative and Renewable Fuel and Vehicle Technology Program: http://www.energy.ca.gov/altfuels/
[6] Vision for Clean Air: A Framework for Air Quality and Climate Planning - http://www.arb.ca.gov/planning/vision/vision.htm
[7] Executive Order B-32-15: http://gov.ca.gov/news.php?id=19046
[8] http://www.casustainablefreight.org/news_items/view/165

that create a positive environment for growing freight volumes, while working with industry to lessen immediate potential negative economic impacts.

Appendix A contains additional information on California and federal legislative, policy, and programmatic actions relating to FCEV development, while Appendix B discusses 11 currently funded projects with 54 FCETs that pertain to FCET development.

Fuel Cell Vehicle Market Context

To date, ZEV technologies have primarily targeted the passenger vehicle market. Other markets such as MD parcel delivery trucks, HD trucks, and HD transit buses are smaller volume, although the overall emissions impact of these vehicles is recognized as significant. MD and HD vehicles above 10,000 pounds make up about 3% of California's registered vehicle stock but account for some 23% of on-road GHG emissions, and therefore represent an opportunity to reduce GHG emissions from a relatively small number of vehicles.[9] Of the emission reduction technology activities that are underway within the MD and HD ZEV market, the predominant emphasis has been on plug-in electric vehicle (PEV) applications.

Few ZEV technology applications in California focus on MD or HD FCEV application, with the notable exception of FCEB programs at Alameda-Contra Costa Transit Agency and at SunLine Transit in the Coachella Valley, which are the largest HD FCEV programs in North America. The FCEBs in these demonstrations are performing well in revenue service, collectively meeting DOE's 2016 performance targets for range and fueling. They demonstrate similar availability compared to conventional buses with near double the fuel efficiency.[10]

Relatively new within the freight handling sector is the commercial availability of fuel cell powered material handling equipment (MHE), such as forklifts.[11] Within the captive vehicle fleet market, the application of fuel cell technology in MHE appears to offer an opportune investment strategy without the continued need for government funding incentives. The capability to eliminate indoor emissions and provide longer operational time compared to conventional technologies, as well as consistent power output and quick refueling capabilities, contribute to making this application of fuel cell technology cost-effective. Over 10,000 units have been purchased and put in operation with little or no support from government incentives.

Spurred by the limited attention to FCEV deployment in the MD and HD vehicle market beyond transit buses, this Action Plan seeks to provide initial direction for supporting operational demonstration of this technology for specific classes of illustrative vehicles in California, namely MD parcel delivery trucks and HD drayage trucks. Passenger FCEVs and urban transit FCEBs are not part of this plan, but have been covered in the CaFCP publications: "*A California Road Map: The Commercialization of Hydrogen Fuel Cell*

[9] http://www.energy.ca.gov/2015publications/CEC-600-2015-014/CEC-600-2015-014-CMF.pdf
[10] California Air Resources Board. Draft Technology Assessment: Medium- and Heavy-Duty Fuel Cell Electric Vehicles. November 2015. http://www.arb.ca.gov/msprog/tech/techreport/fc_tech_report.pdf
[11] http://energy.gov/sites/prod/files/2014/03/f9/early_markets_mhe_fact_sheet.pdf

Vehicles" (2012),[12] *"2014 Update: Hydrogen Progress, Priorities and Opportunities (HyPPO) Report"*[13] and *"A Road Map for Fuel Cell Electric Buses in California – A zero-emission solution for public transit"* (2013).[14]

Priority Regions Context

To make the greatest positive impact environmentally, the deployment of FCETs ideally occurs in California's main freight movement regions and corridors, also referred to as priority regions. It should be noted that the areas of greatest freight activity overlap with the regions and communities most in need of air quality improvement. These include the South Coast air basin, the San Francisco Bay Area, and the San Joaquin Valley. Although the goal of advancing FCET technology along the commercialization path does not require early demonstrations to be located in areas of poor air quality, a co-benefit of environmental improvement can be realized if this is the case.

[12] http://cafcp.org/sites/files/A%20California%20Road%20Map%20June%202012%20%28CaFCP%20technical%20version%29_1.pdf
[13] http://cafcp.org/sites/files/Roadmap-Progress-Report2014-FINAL.pdf
[14] http://cafcp.org/sites/files/A_Roadmap_for_Fuel_Cell_Electric_Buses_in_California_FINAL.pdf

2. Medium- and Heavy-Duty Truck Focus

The MD and HD truck population is historically classified in federal and state vehicle standard classes based on weight (Table 1),[15] and increasingly by related categories based on vocation and technology applicability.

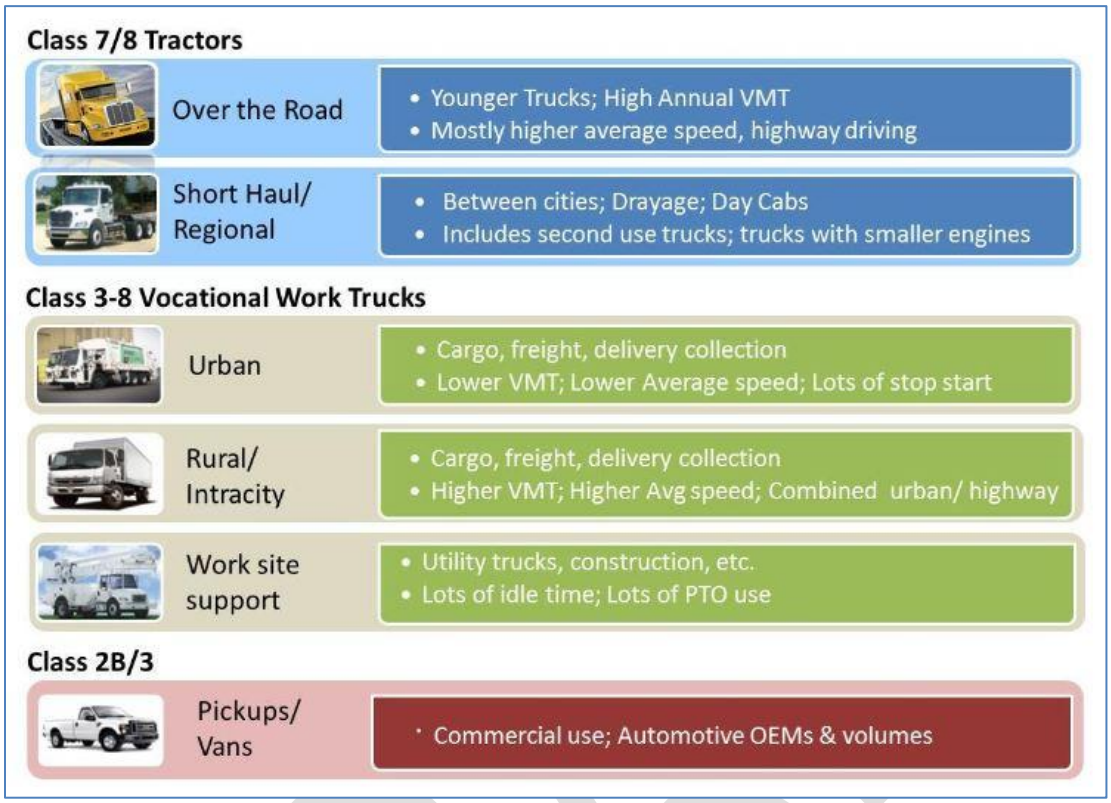
Table 1. Vehicle weight classes and categories

Gross Vehicle Weight Rating (lbs)	Federal Highway Administration		US Census Bureau
	Vehicle Class	GVWR Catagory	VIUS Classes
<6,000	Class 1: <6,000 lbs	Light Duty <10,000 lbs	Light Duty <10,000 lbs
10,000	Class 2: 6,001 – 10,000lbs		
14,000	Class 3: 10,001 – 14,000 lbs	Medium Duty 10,001 – 26,000 lbs	Medium Duty 10,001 – 19,500 lbs
16,000	Class 4: 14,001 – 16,000 lbs		
19,500	Class 5: 16,001 – 19,500 lbs		
26,000	Class 6: 19,501 – 26,000 lbs		Light Heavy Duty: 19,001 – 26,000 lbs
33,000	Class 7: 26,001 – 33,000 lbs	Heavy Duty >26,001 lbs	Heavy Duty >26,001 lbs
>33,000	Class 8: >33,001 lbs		

Application of fuel cell technologies to MD vocational trucks such as parcel or package delivery was considered previously, as part of the CalHEAT Roadmap[16] planning for California. Through the efforts of the CalHEAT Truck Research Center—an Energy Commission funded initiative facilitated by CALSTART—multiple stakeholders helped develop the categorization shown in Figure 1.[17] This method provides more specific information about the operating cycle, operational characteristics, and potential benefits of a transition to fuel cell technology as a main power source for specific truck vocations.

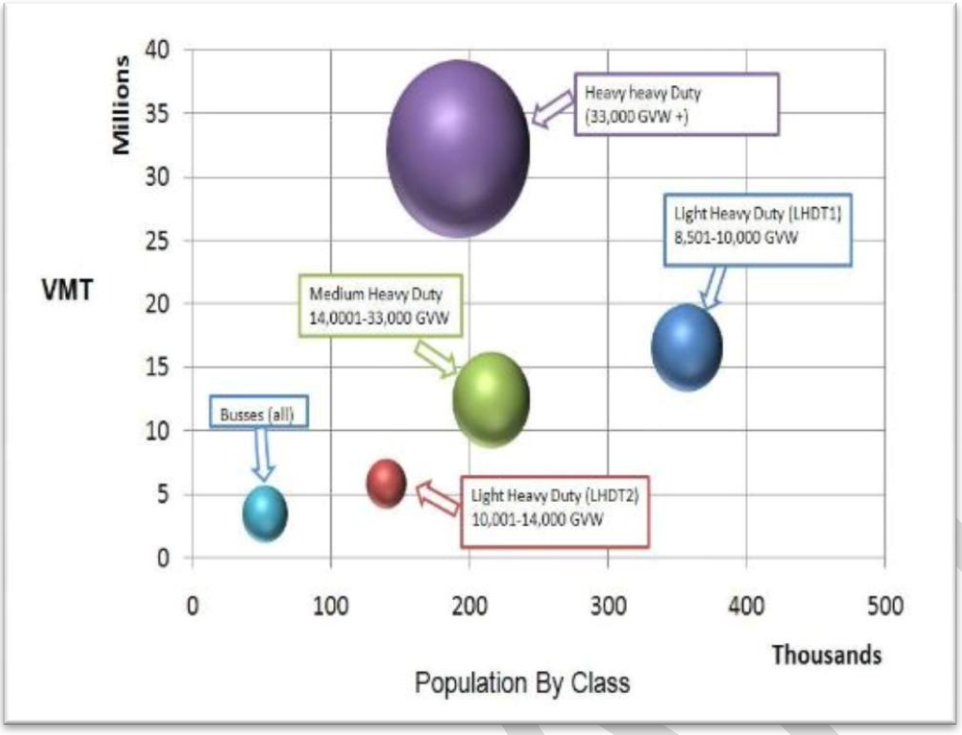
[15] http://www.afdc.energy.gov/data/10380
[16] CalHEAT Technology and Market Transformation Roadmap. http://www.calstart.org/Libraries/CalHEAT_2013_Documents_Presentations/CalHEAT_Roadmap_Final_Draft_Publication_Rev_6.sflb.ashx
[17] http://www.calstart.org/Libraries/CalHEAT_2013_Documents_Presentations/CalHEAT_Roadmap_Final_Draft_Publication_Rev_6.sflb.ashx

Figure 1. Truck categories based on technology applicability



The CalHEAT Technology Roadmap indicates that the total California truck population was approximately 950,000 vehicles in 2013, which covers all vehicles within classes 2B/3 through 8. When this population is divided into the different standard classes previously identified, it results in the graph shown in Figure 2.

Figure 2. 2013 California truck categories by truck population and annual vehicle miles traveled



"The horizontal axis represents the population's size, the vertical axis is vehicles miles travelled (VMT), and the area of the circles represents the gallons of fuel consumed. The graph demonstrates that population, VMT, and efficiency must all be considered when calculating a segments impact, and also shows that certain segments may be bigger contributors and better targets for improvement than others."

This Action Plan focuses on trucks in classes 4-8, the vehicle populations represented by the purple and green spheres in the above graph, which represent the majority of VMT opportunities and coverage. The graph also shows how these markets compare to the bus market at large, where fuel cell technology was previously introduced in the public transit setting, and where it continues to be demonstrated and operated.

CaFCP members' decision to focus on MD parcel delivery trucks and HD drayage trucks in the near term aligns with CARB's vision to introduce ZEV technology in early target truck vocations presented in the Sustainable Freight and Mobile Source Strategy discussion drafts,[18,19] benefiting air quality in the communities most severely impacted by MD and HD vehicle operation. Simultaneously, based on operational demonstration data and lessons learned, this focus will allow technology stakeholders to consider expansion of the rollout approach for these vehicles from a community/regional level to a broader statewide and national level over time, working toward broad public acceptance of this ZEV

[18] California Air Resources Board. Sustainable Freight: Pathways to Zero and Near-Zero Emissions, Discussion Draft. http://www.arb.ca.gov/gmp/sfti/sustainable-freight-pathways-to-zero-and-near-zero-emissions-discussion-document.pdf
[19] http://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.htm

technology. Both vehicle vocational categories are assumed to be fueled with 35 MPa hydrogen fuel, because other hydrogen storage and delivery methods are currently not used for U.S. projects (such as 70 MPa, other fuel pressures, and cryo-compressed hydrogen).

Class 4-6 Urban Trucks

Class 4-6 Urban "last mile delivery" trucks deliver packages at the end of their journey to customers. These vehicles travel from regional distribution centers to customers in local communities and return to a distribution hub at the end of the operational day. Battery electric trucks with fuel cells as range extenders to reach distances greater than 60 miles appear to have good potential to be cost-effective in this vocational category, depending on the operational cycle.[20] A range of over 125 miles per fueling was selected as the parameter for the MD FCET in this Action Plan, which would extend the range beyond what battery powered package delivery trucks are expected to achieve.

Minimum operational requirements for the MD FCET are shown in Table 2. These metrics are presented for the first time in order to provide a clearly-stated national proposal for targets for this truck class.

Table 2. Parameters and requirements for MD fuel cell package delivery truck

Parameter	Minimum requirement for MD FC package delivery truck	Gasoline or CNG package delivery truck (ultimate) benchmark
Range per fueling[1]	>125 miles (daily)	400 miles (before refueling)
Performance[2]	0-60 MPH in 26 sec (for Class 5)	0-60 MPH in 12 sec
Top speed	65 MPH	85 MPH
Refueling interval	1 day	Multiple days, depending on duty cycle and 400 miles range
Operating time per day	12 hrs	14 hrs
Flexibility to assign to a subset of routes[3]	95%	100%/full service
Gradability[4]	5% - launch to top cruising speed of 30 mph in 7 sec 10% - launch to top cruising speed of 20 mph in 2 sec 15% - launch to top cruising speed of 20 mph in 3 sec	
Durability – miles	TBD	300,000 miles
Durability – hours	>5000 hours	
Durability – years	10-12 years	22 years
Uptime/availability[5]	95% (5% scheduled maintenance)	≥98%[21]
Warranty	TBD	3 yrs/50,000 miles

1. Assumption is fueling with 35 MPa hydrogen fuel. In some cases, depending on vehicle technology configuration, plug-in for charging the battery energy storage may be required in addition, but is assumed at same frequency as hydrogen fueling.
2. Performance in acceleration.
3. Daily route assignment of vehicles is done within operator organization by route/logistics planners within organization and is an indicator to what extent a specific vehicle can be used for a scheduled freight delivery route.
4. Gradability is an indicator of the % of slope grade that a vehicle can handle after a full stop in subsequent take-off/launch.
5. Availability of a vehicle at the start of or throughout the operational day after assignment has been made in route planning.

[20] Wood, E., Wang, L., Gonder, J., and Ulsh, M., "Overcoming the Range Limitation of Medium-Duty Battery Electric Vehicles through the use of Hydrogen Fuel-Cells," SAE Int. J. Commer. Veh. 6(2):2013, doi:10.4271/2013-01-2471. Available at: http://www.nrel.gov/docs/fy14osti/60053.pdf

[21] http://www.nrel.gov/docs/fy11osti/50042.pdf

Class 7-8 Drayage Trucks

Class 7-8 short haul/drayage trucks are heavy-duty trucks in a tractor-trailer configuration used to transport freight over a short distance, generally from an ocean port to a rail loading area, warehouse, or other similar destination (or vice-versa). The minimum operational requirements are shown in Table 3. These are based on a 2013 CALSTART truck operators study report, "Key Performance Parameters for Drayage Trucks Operating at the Ports of Los Angeles and Long Beach."[22] This Action Plan modifies the CALSTART parameters to include:

- A minimum range requirement of 100 miles; anything less can be addressed by battery powered drayage trucks
- Expansion of the refueling interval to 1 or 2 days due to operator preference to fuel as few times as possible within an operator's assigned operational cycle
- The warranty is to be determined because a standard warranty may not be appropriate. This should be established based on technology assessment input from operators.

Although referred to as "drayage trucks," OEMs do not manufacture or market truck models identified as such, but as HD trucks that have many applications and can be used by freighting companies for drayage operations. For the purpose of this document, the zero tailpipe emission drive train configurations can be either fuel cell range extended battery electric or fuel cell electric with a hybrid battery in which the fuel cell system serves as the main power source.

Minimum operational requirements for the HD FCET are shown in Table 3. Like the previous table, these metrics are presented in order to provide a clearly-stated national proposal for targets for this truck class.

Table 3. Parameters and requirements for HD fuel cell short haul/drayage truck

Parameter	Minimum requirement for HD FC short haul/drayage truck	Diesel drayage truck (ultimate) benchmark
Range per fueling[1]	100-200 miles (daily)	400 miles (before refueling)
Performance[2]	1,200-1,800 ft-lbs of torque	400 HP/1,200-1,800 ft-lbs of torque
Top speed	62-65 MPH	62-65 MPH
Refueling interval	1-2 days	2-4 days
Operating time per day	10-14 hrs	10-14 hrs
Flexibility to assign to a subset of routes[3]	"Full service"	"Full service"
Gradability[4]	6.5%	6.5%
Durability – miles	~500,000 miles	~500,000 miles
Durability – years	≥8 years	≥10 years
Uptime/availability[5]	≥90%[23]	≥90%[24]

[22] http://www.calstart.org/Libraries/I-710_Project/Key_Performance_Parameters_for_Drayage_Trucks_Operating_at_the_Ports_of_Los_Angeles_and_Long_Beach.sflb.ashx

[23] Or 100% minus scheduled maintenance.

[24] Or 100% minus scheduled maintenance.

Parameter	Minimum requirement for HD FC short haul/drayage truck	Diesel drayage truck (ultimate) benchmark
Warranty	TBD	3 yrs/300,000 miles
1. Assumption is fueling with 35MPa hydrogen fuel. In some cases, depending on vehicle technology configuration, plug-in for charging the battery energy storage may be required in addition, but is assumed at same frequency as hydrogen fueling. 2. Performance in acceleration. 3. Daily route assignment of vehicles is done within operator organization by route/logistics planners within organization and is an indicator to what extent a specific vehicle can be used for a scheduled freight delivery route. 4. Gradability is an indicator of the % of slope grade that a vehicle can handle after a full stop in subsequent take-off/launch. 5. Availability of a vehicle at the start of or throughout the operational day after assignment has been made in route planning.		

The underlying assumption is that the parameters and requirements shown in Table 2 and Table 3 will render the freight capacity of the selected vehicle categories equal to conventional technology. This means that operators can use the FCET interchangeably with conventional trucks in the fleet with regards to freight capacity. Because these are preliminary parameters based on operator experience with conventional technology, each performance parameter will need to be validated based on operational data and experience with FCEV technology.

It is worth noting that from a cost reduction and production volume perspective, Class 2-3 vehicles could be of nearer- or medium-term interest for fuel cell technology implementation because they can use the same fueling infrastructure as passenger FCEVs. Currently, only one project in the class 2-3 FCEV category has been selected for funding for development and demonstration efforts in North America; therefore, this vehicle class may warrant inclusion in future strategizing initiatives.

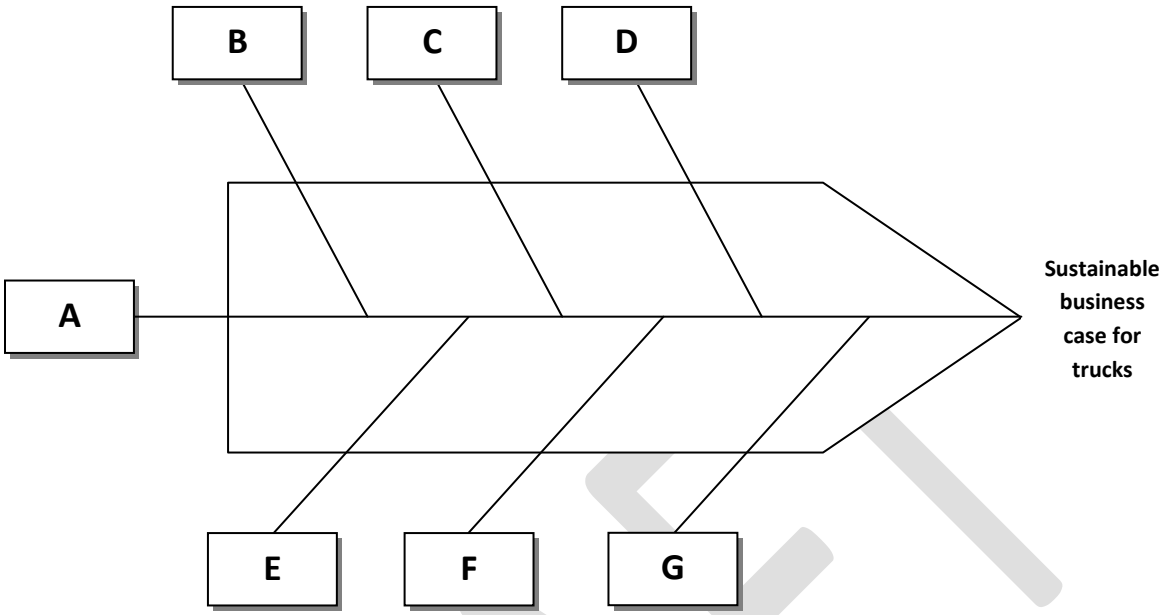
Truck Manufacturers' Perspective

Large-volume HD truck OEMs are presently working on the inclusion of fuel economy improvements for the U.S. market through the increased electrification of components, aerodynamic improvements to vehicle designs, and limited drive-train component electrification. This status is exemplified by the U.S. Department of Energy's (DOE) SuperTruck program, the announced SuperTruck II program, and the resulting Class 8 long haul truck efficiency advances showcased by the different U.S. truck OEMs.[25]

Truck OEMs do not, at this time, have plans to build commercial fuel cell trucks and will need to develop "from-the-ground-up designs for MD and HD trucks around fuel cell systems" to be commercially successful. Figure 3 shows the major overarching elements that are essential for business case sustainability. Appendix C contains a more detailed listing of these elements and further discussion of what is needed to make a successful business case for FCETs.

[25] "The U.S. SuperTruck Program: Expediting the Development of Advanced Heavy-Duty Vehicle Efficiency Technologies". O. Delgado, N. Lutsey (June 2014). Available at: http://www.theicct.org/sites/default/files/publications/ICCT_SuperTruck-program_20140610.pdf

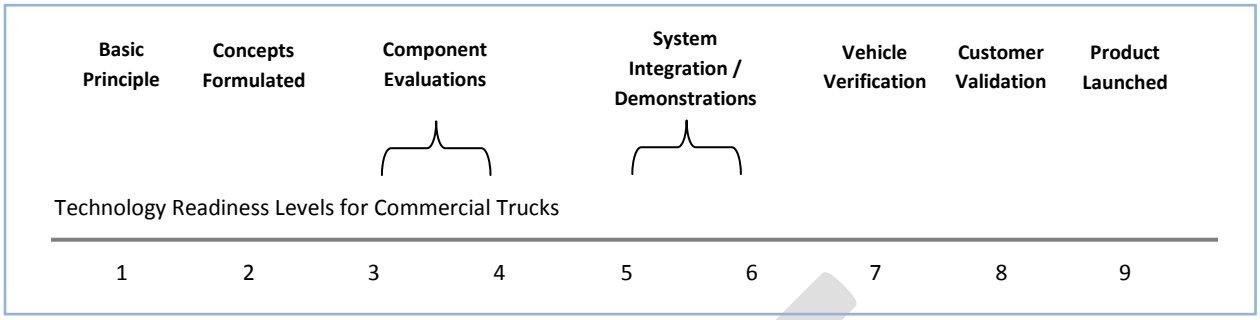
Figure 3. Major components of a sustainable business case



A. Meets customer requirements
B. Favorable operating environment
C. Regulatory stability for product planning
D. OEM essentials
E. Incentives support the path to sustainable sales
F. Reliable, accessible, and affordable fueling
G. Go/no-go milestone

To illustrate the OEM perspective, Figure 4 shows the major phases of truck commercialization aligned to the 9 Technology Readiness Levels (TRL). The truck manufacturing industry uses both the TRL and a similar continuum referred to as the Manufacturing Readiness Levels (MRL), which has 10 levels that map progress toward target cost and manufacturing goals for vehicles and vehicle components. For both TRL and MRL, a new commercially available truck platform with a new propulsion and power train system can take 7 to 15 years to develop. In the case of fuel cell trucks, this timeframe may be shorter if components from previously developed MD and HD electric vehicle platforms and fuel cell systems can be adapted.

Figure 4. Technology Readiness Levels continuum for truck commercialization process[26]



Conventional fuel-powered solid oxide fuel cell auxiliary power units (SOFC APU) were considered as an option in the SuperTruck program,[27] and several truck OEMs have been involved in testing SOFC APUs in truck demonstration projects,[28] indicating a willingness to consider diesel reformate powered fuel cells. However, adopting hydrogen powered fuel cells as the engine replacement for full power train integration does not currently lend itself to product planning given the limited experience base of fuel cells in trucks; hence, the focus on more prototypes, demonstrators, and operational data to help to close the learning curve and determine the optimal configuration and extent of fuel cell integration in trucks.

As previously noted, experience with fuel cells in transit buses is much greater than for trucks, and knowledge sharing from FCEB demonstrations can be used to accelerate FCET development. Transit bus fuel cell systems, fuel storage systems, and hybrid drive train systems can be expected to transfer to HD FCETs. It should be recognized that FCEBs are not an exact match for FCETs, particularly for class 7-8 drayage trucks. A truck that transports heavy loads at highway speeds has a different drive cycle and other technical requirements than a passenger bus that travels at much slower speeds, making frequent stops and starts. New approaches will therefore be required to integrate fuel cell technology into HD trucks used for freight distribution, as well as for other truck types with vocations that differ significantly from buses.

Another important component for FCET development is the balance between batteries and fuel cells. This represents an entirely new area of investigation that will entail substantial testing and evaluation.

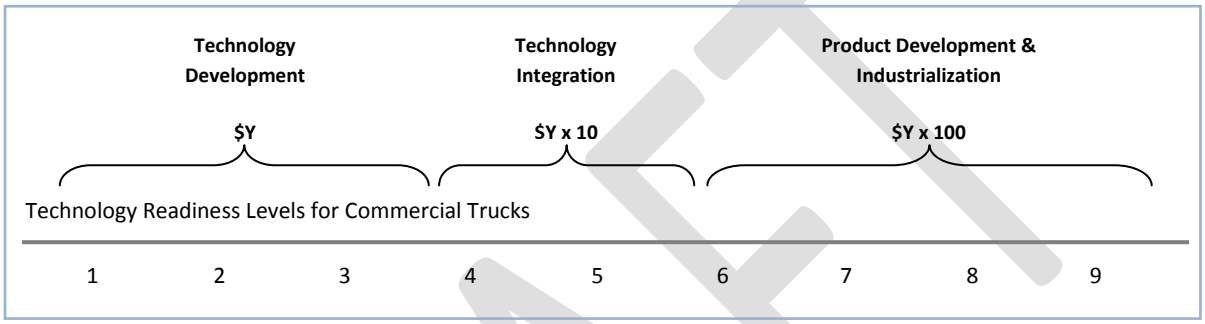
[26] December 3, 2015 "Investment Considerations: Medium & Heavy Duty Truck Technologies in California" Volvo Group presentation at ITS UC Davis & CEC STEPS Symposium: http://steps.ucdavis.edu/files/12-03-2015-Fenton-CEC-12-3-15-FINAL.pdf

[27] "The U.S. SuperTruck Program: Expediting the Development of Advanced Heavy-Duty Vehicle Efficiency Technologies". O. Delgado, N. Lutsey (June 2014). Available at: http://www.theicct.org/sites/default/files/publications/ICCT_SuperTruck-program_20140610.pdf

[28] "Solid Oxide Fuel Cell Diesel Auxiliary Power Unit Demonstration" presentation by D. Hennessy, DELPHI (May 2013). Available at: http://www.hydrogen.energy.gov/pdfs/review13/h2ra002_hennessy_2013_o.pdf and "Fuel Cell Auxiliary Power Units for Heavy Duty Truck Anti-Idling" presentation by C. Greisen, Topsoe Fuel Cell (August 2014). Available at: http://www.tinv.dk/public/dokumenter/tinv/Konferencer%20og%20arrangementer/Afholdte%20arrangementer/Driving%20Green%2014/DG%20Br%E6ndselsceller/7%20Tops%F8e%20Fuel%20Cell%20-%20Christoffer%20Greisen.pdf

Finally, the development process of new trucks is accompanied by an investment component, which has to be taken into consideration for laying out a commercialization path. As shown in Figure **Error! Reference source not found.**, investment requirements typically increase as a new truck product advances along the technology readiness continuum toward commercialization. As exemplified by the SuperTruck program, where new truck technologies achieve improved fuel economy, marketing, purchasing, aftermarket, manufacturing, and product development will occur after TRL 6.[29] Currently, FCETs are generally considered to be at or around TRL 3. The demonstration projects are expected to advance the selected vocations into the 4-5 range.

Figure 5. Investment Levels related to Technology Readiness Levels for truck commercialization[30]



Recommendations

Following is the list of initial recommendations in order of priority to advance FCETs to a higher TRL or MRL. A more extensive list of recommendations can be found in Appendix D. Each individual recommendation is followed by a proposed lead entity or entities.

1) Transfer the lessons learned from implementing and operating fuel cell bus programs to truck vocations, especially as these lessons relate to technology, and help identify or reduce risk to the financial community (industry).

2) Conduct data collection using a consistent set of fleet operation variables for comparison, feasibility assessments, and decision making; this should be a basic requirement for all government-funded truck projects (government and industry collaboratively).

3) Prove reliability of MD and HD FCETs to show that the cost-per-mile economics of transported freight; this is critical to the sustainable operation of this technology (industry).

4) Build a better mutual understanding of the truck manufacturing product creation process in the context of FCET technology development (government and industry collaboratively).

[29] December 3, 2015 "Investment Considerations: Medium & Heavy Duty Truck Technologies in California" Volvo Group presentation at ITS UC Davis & CEC STEPS Symposium: http://steps.ucdavis.edu/files/12-03-2015-Fenton-CEC-12-3-15-FINAL.pdf
[30] Idem.

5) When setting targets, stakeholders should assume a timeline of 7-15 years for developing new truck platforms with completely new propulsion and power train systems in their decision-making process (government and industry collaboratively).

6) Establish separate stakeholder groups (drayage and package delivery) to discuss and provide realistic market information about the baseline requirements for vehicle technology, operational cycles, supplier expectations, etc (industry).

Cost Reduction Considerations

The cost to develop these new FCET technologies and the opportunity for investment cost recovery are related to the volume of units manufactured and sold in the North American market (not solely the California market). Cost is also related to competition in the market leading to cost reduction investments, which in turn increasingly relate to emission and petroleum reduction requirements. For the truck market, conventional technology costs and reliability parameters set the baseline in parallel with the time required to earn back incremental investments. Based on the status of the technology, as assessed using development status continuums such as TRL or MRL, initial rollout should be expected to serve as proof of concept and/or for demonstration purposes to collect data, understand gaps, and learn about the long-term feasibility of the technology.

Sustainable commercialization (see Appendix C) of vehicle technologies includes a parallel need for verification, development, and adoption of vehicle and building codes and standards to warrant an acceptable level of safety for integrated MD and HD fuel cell electric drive systems and the supporting fueling infrastructure. This will also help with cost reduction because it lays out a path toward equipment standardization, component supply network development, and scaled-up manufacturing. To date, state and federal government agencies have not yet included an evaluation and impact assessment of this aspect in their planning efforts for increasing the numbers of ZEV trucks on the road in 2031 and 2050.

In simple terms, near-term vehicle fleet pilot demonstrations are important to provide a basis for setting longer-term goals that can lead to the cost reductions necessary for commercialization.

Directly related to the potential for cost reduction, according to established truck OEMs, is the decision to invest in new vehicle technology development, which is based on stable and consistent long-term policy, regulations, and expected return on investment. Finally, return on investment in new technology development and commercialization is achieved through large numbers of vehicles (10,000s) sold throughout North America, not through limited truck sales volumes in a small region. As such, this Action Plan potentially serves as a template for other states and for national efforts to advance fuel cell technology in these vehicle categories in order to accelerate progress through the TRL stages to reach commercial volumes.

Recommendations

The following is a list of prioritized initial recommendations to achieve cost reduction. A more extensive list of recommendations can be found in Appendix D. Each individual recommendation is followed by a proposed lead entity or entities.

1) Support FCEB Centers of Excellence to prove infrastructure and fuel cost reduction, and develop expertise and understanding about hydrogen fueling for large fleets (federal and state government).

2) Establish targets and priorities for future MD and HD FCEV funding programs (federal government).

3) Initiate, expand, and direct national efforts to perform in-depth studies of fuel cell technology in trucks to understand the components of the total cost of ownership and opportunities for cost reduction (federal government).

4) Assess options for developing a ZEV credit or long-term incentive strategy for MD and HD ZEVs to encourage truck integrators and OEMs to invest in the RD&D of fuel cell technology in trucks (federal and state government).

3. Hydrogen Stations and Fueling Experience

Sufficient supplies of hydrogen are essential to FCET fleet implementation and adoption. Both passenger FCEV and transit FCEB fleet rollouts have demonstrated that fueling infrastructure should be a focus of early planning and ongoing support.

The anticipated fuel capacity of HD fuel cell drayage trucks will be in the range of 20-30 kilograms,[31] which is similar to the daily amount consumed by a FCEB. With this assumption in mind, consideration of current fueling station systems used in FCEB programs is warranted.

An analog to fueling MD and HD trucks is SunLine Transit's hydrogen station in Thousand Palms, which opened in April 2000 and is the longest operating hydrogen transit bus fueling station in the United States. The station has on-site production of hydrogen through the use of an auto-thermal reformer, with a capacity of 212 kilograms per day. The five FCEBs currently in service are filled daily with 25-35 kilograms of 35 MPa hydrogen fuel in about 25 minutes per bus. Excluding the capital cost for hydrogen station implementation, the combined cost of O&M and hydrogen is approximately $8.00/kg dispensed.[32]

AC Transit's hydrogen station in Emeryville, which is currently one of the largest and most modern HD vehicle fueling stations in the United States, provides a second example. Starting operation in 2011, the dual-use station serves buses at a dedicated dispenser inside the yard and passenger vehicles at a public dispenser outside the yard. A single storage system is used by both. This setup capitalizes on the need for fueling by both the transit and private-use vehicle markets. The station has a scalable capacity, with a baseline capacity of 360 kg of 35 MPa fuel per day for buses and 240 kg per day for cars at both 35 and 70 MPa, an amount sufficient to fuel 12 fuel cell buses with 25 kg/bus and between 40 and 60 cars. Excluding the implementation and capital costs for the hydrogen station equipment, the combined cost of O&M and hydrogen to fuel buses at this station is approximately $8.62/kg dispensed.[33]

The performance of this last station to fill multiple buses consecutively at a speed of 6 to 8 minutes per fill—a rate equivalent to diesel bus fueling at AC Transit—is achieved through the use of fast-fuel technology. Should AC Transit decide to increase the number of FCEBs, the station system is designed to easily expand its capacity to accommodate up to 24 buses by adding additional compression and gaseous storage equipment. This scalability factor should be considered for the gradual rollout and increase in size of FCET fleets. AC Transit opened a second station in Oakland in 2014 with a design capacity to fuel 12 buses rapidly and in succession, which can also be expanded to fuel 24 buses. Typical scheduling and service requirements make it necessary to fuel all transit buses within a 4-6 hour time slot at night to enable the buses to stay in continuous service from 5 a.m. to 11 p.m. Both AC Transit

[31] http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2014/2014-dec5-003.pdf?sfvrsn=2
[32] American Fuel Cell Bus Project Evaluation: Second Report. L. Eudy and M. Post, NREL (Sept 2015). http://www.nrel.gov/docs/fy15osti/64344.pdf
[33] Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report. L. Eudy, M. Post, and M. Jeffers, NREL (June 2016). http://www.nrel.gov/docs/fy16osti/66039.pdf

fueling stations are supplied with hydrogen using liquid hydrogen delivery, with supplemental on-site renewable fuel production at the Emeryville station.

When considering the implementation of a hydrogen station for MD or HD FCETs, based on the operational schedule of Class 8 drayage trucks and Class 5-6 package delivery trucks, stations can be expected to have a similar design for either of these two vehicle classes. For FCEBs, however, there is no one-size-fits-all because each transit agency is unique in regard to specific requirements due to geographic characteristics.

Currently, the four most feasible hydrogen fuel delivery methods for larger trucks fleets based on the required capacity and design assumptions are:

- Delivered liquid hydrogen with compression and storage on site. Hydrogen production and liquefaction occurs at a central production plant, delivery is by truck.
- Hydrogen pipeline with purification, compression, and storage on site. Hydrogen production is at a central location connected to an industrial hydrogen pipeline.
- On-site reformation. Hydrogen fuel is generated on site from natural gas, with compression and storage is on site.
- On-site electrolysis. Hydrogen fuel is generated on site from splitting water (using electricity), with compression and storage on site.

Delivery of gaseous hydrogen is not considered an optimal solution for larger truck fleets, but is sufficient for smaller demonstration projects. An exception would be the use of high-capacity trailers with more than 500 kg capacity.

In 2013, hydrogen fuel and station equipment suppliers provided fueling station cost information for the aforementioned hydrogen delivery methods. Costs per location are anticipated to be approximately $5 million or less, which includes $1 million for site improvements and local jurisdiction use requirements to install a H35 (35 MPa /350 bar hydrogen fuel) fueling station with a capacity to fuel 40 FCEBs.[34] Station O&M costs are expected to be $200,000 per year. The cost of fuel delivered to the station is $4-7 per kilogram, depending on hydrogen station location, mode of hydrogen supply, and access to production facilities. This fuel cost is equivalent to $2.26 to $4.75 per gallon of diesel fuel, taking into account the improved fuel economy (1.6 to 2.0 times better) of a FCEB over a diesel bus. All fuel delivery options listed above can use renewable resources (e.g., renewable natural gas or electricity) to reduce or eliminate GHG emissions.

Recommendation

The following initial recommendation is crucial to providing sufficient supplies of hydrogen fuel for FCETs. A more extensive list of recommendations can be found in Appendix D. The recommendation is followed by a proposed lead entity.

[34] http://cafcp.org/sites/default/files/A%20Roadmap%20for%20Fuel%20Cell%20Electric%20Buses%20in%20California.pdf

1) Fund initial private or commercial hydrogen fueling infrastructure, with consideration of public funding for station O&M in early years (state government).

4. Meeting the Challenges Ahead

Development of FCETs and fueling infrastructure must occur in parallel and therefore require coordinated planning to time the rollout of both components to ensure mutual support. This important lesson is exemplified by the experience gained from the planning and rollout of passenger FCEVs and their fueling infrastructure.[35] For a hydrogen-powered truck fueling infrastructure, it is important to consider the variables of coverage and capacity. Initially, fuel costs will be relatively high due to low demand and the high capital cost of small capacity fueling stations. For larger truck fueling stations, the business case should be better, due to higher volumes dispensed and predictable fuel demand figures. Ideally, both MD and HD FCETs should be served by the same fueling stations. Based on results shown with FCEBs, FCETs should be able to fuel within the same timeframes as conventional trucks.

Fueling Approach for FCETs

For small demonstrations of 2-3 MD FCETs or single vehicle Class 8 truck projects, existing hydrogen stations may be candidates for fueling. Alternatively, co-located fueling would minimize the impact on passenger fuel availability and on drivers of FCEVs. MD FCETs can only fuel at passenger hydrogen stations without assistance if the on-board vehicle storage capacity is less than 10 kg at 70 MPa or 6 kg at 35 MPa and verification of fueling protocol lies within SAE J2601 parameters needed to facilitate non-operator supported vehicle fueling (operator supported fueling adds to vehicle fueling cost). To fuel FCETs with a H35 capacity above 6 kg but less than 10 kg at passenger FCEV station dispensers, FCET developers and passenger station operators will need to generate, verify, and assess a sufficiently large fueling test dataset to fill the gap that currently exists in the SAE J2601 fueling protocol. Class 2(b) FCEVs and class 3 FCETs could use existing fueling stations assuming passenger vehicle sized on-board hydrogen storage systems (<10 kg at 70 MPa or <6 kg at 35 MPa). The fueling stations for passenger vehicles may be utilized for co-located FCET fueling, provided different fueling lane and protocols are available.

Although opportunities exist for FCETs to share facilities used by fuel cell powered forklifts, this is unlikely because forklifts are fueled with 1-2 kg of hydrogen per fill, while MD FCETs are expected to hold about 10 kg and HD trucks 20-30 kg. Thus a FCET deployment would dramatically impact the fuel availability for the forklift (or require much greater hydrogen fueling capacity). Moreover, forklifts are often fueled inside of warehouses, where truck traffic is not feasible. The sharing of facilities would therefore mainly extend to the bulk fuel storage, which would yield economies of scale benefits from co-utilization.

While some limited sharing of existing fueling infrastructure may be possible to advance early small demonstration projects, deployment of FCETs will require dedicated fueling stations. The Action Plan advocates development of commercial HD fueling infrastructure in the priority regions, beginning with

[35] McKinney, Jim, et al. 2015. Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California. California Energy Commission. Publication Number: CEC-600-2015-016. Available at: www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf

1-2 stations. Initial private or commercial hydrogen fueling infrastructure for FCETs should receive support from public funding sources, with consideration also given to providing public funding for station O&M in the early years.

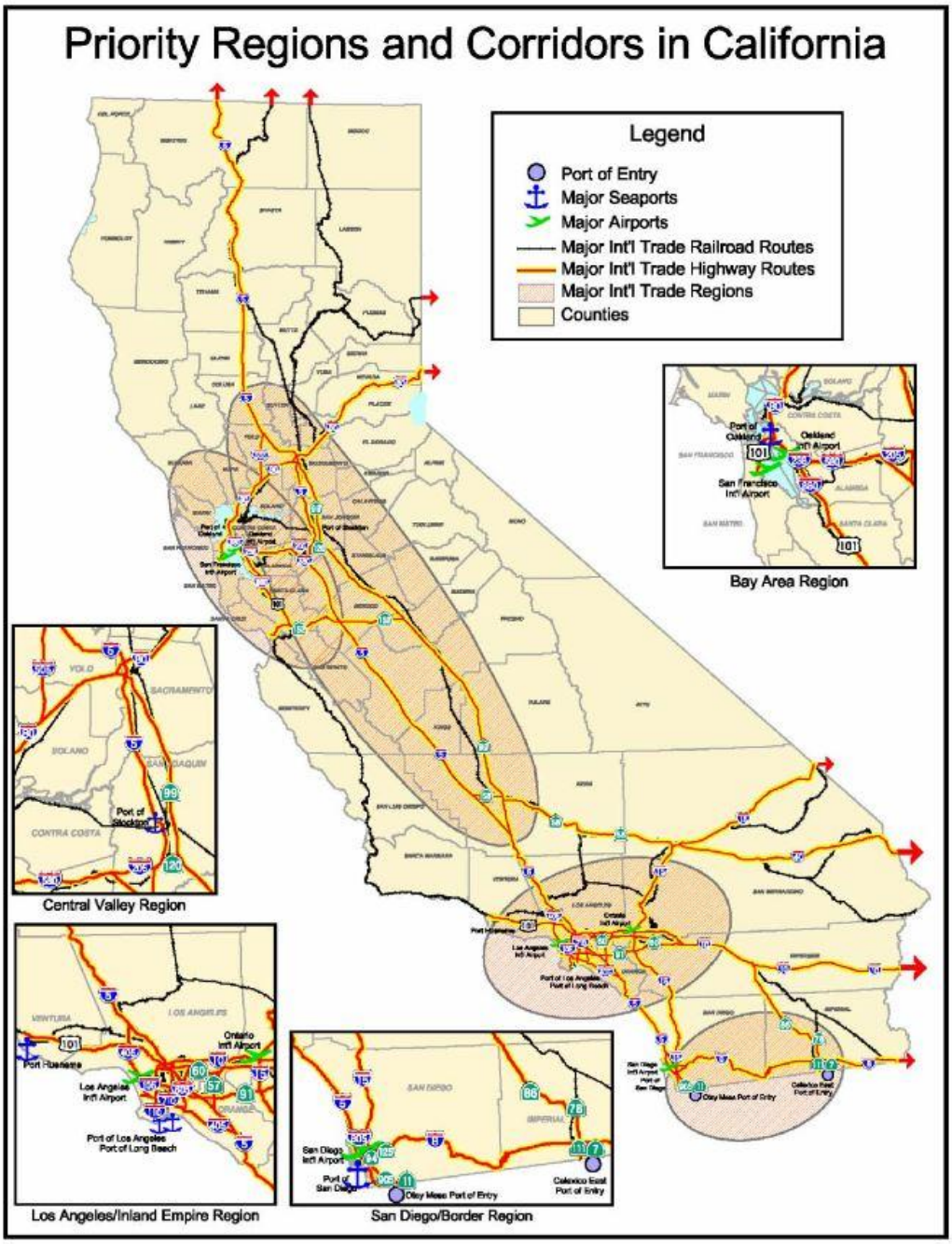
Factors that will impact FCET fueling include:

- The cost per kg ($/kg) is important for overall operational cost per mile. Initial cost of fuel will be high, due to low demand and capital cost of small capacity fueling stations.
- Different fueling equipment solutions will be needed for different sizes of fleets, with corresponding cost of fuel.
- For larger demonstration fleets, dedicated stations will be needed to facilitate initial rollout:
    - HD: commercial stations, comparable to current diesel truck fueling at dedicated fueling islands that facilitate MD/HD trucks.
    - MD: fleet fueling infrastructure, typically in a behind-the-fence fueling station setup.

Deployment Approach for FCETs – Priority Region Focus

In California, the areas of greatest freight activity (see Figure 6) overlap with the regions and communities most in need of air quality improvement. These include the South Coast air basin, the San Francisco Bay Area, and the San Joaquin Valley. Although the goal of advancing FCET technology along the commercialization path does not require early demonstrations to be located in areas of poor air quality, a co-benefit of environmental improvement can be realized if this is the case. The Action Plan supports focusing on the priority regions of heavy truck traffic for early demonstrations of FCETs. This approach aligns with projects that have been funded to date, which are described in Appendix B.

Figure 6. Priority regions and corridors of freight movement throughout California[36]



Within the South Coast air basin, the focus for Class 7-8 HD FCET drayage operations is on the ports of Los Angeles and Long Beach, and the I-710 Corridor connecting these ports to the locations where incoming freight is processed for transportation into the United States and/or processed for export from mainland United States through the ports (e.g., warehouses and rail yards). In addition, as indicated in CALSTART's 2013 report on drayage trucks operational characteristics, the locations of these processing

[36] Goods Movement Action Plan January 2007, Figure II-1: http://www.arb.ca.gov/gmp/docs/gmap-1-11-07.pdf

facilities can be found as far east as the Inland Empire and to the north in Bakersfield in the San Joaquin Valley.[37]

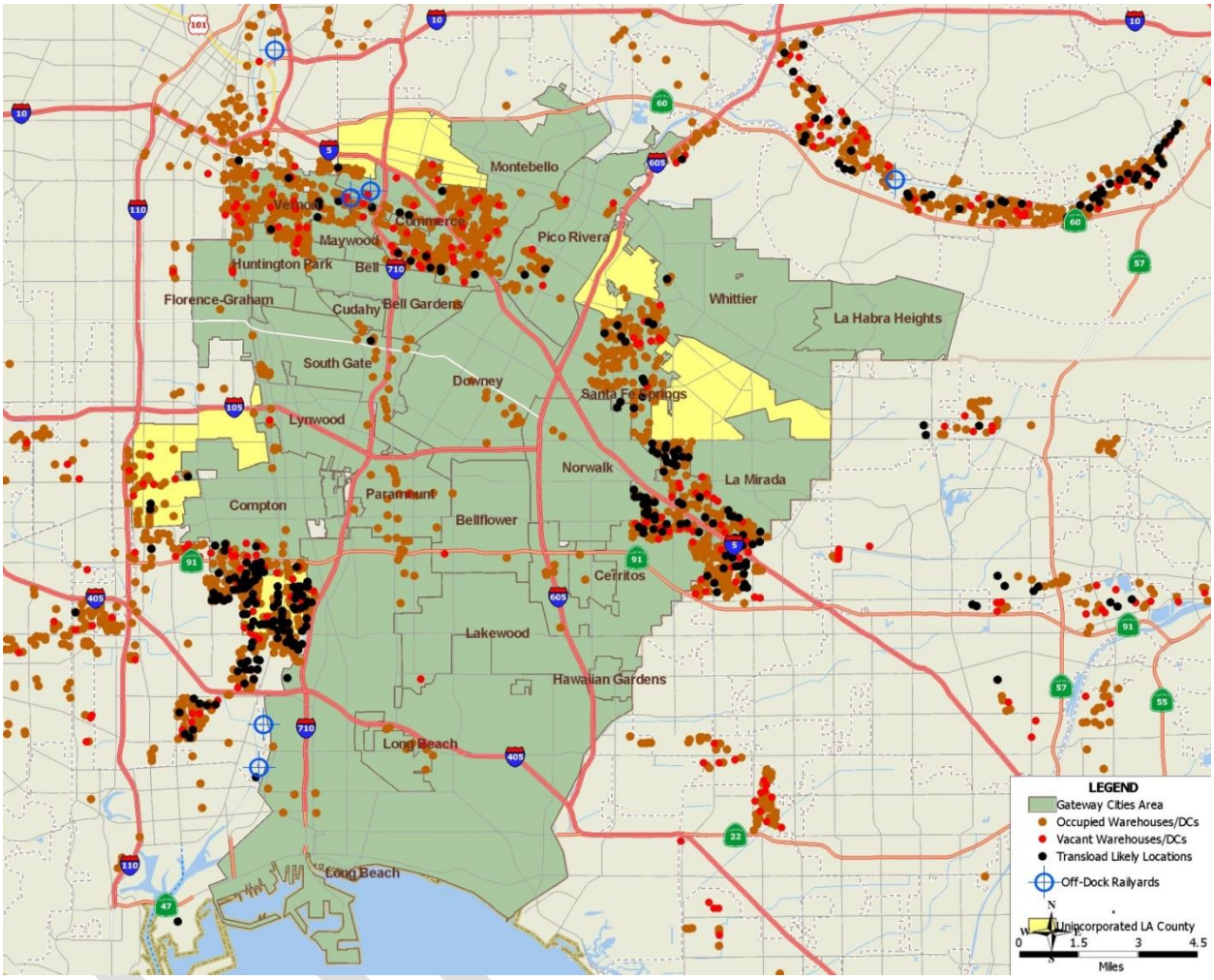
Within the San Francisco Bay Area air basin, FCET drayage and/or short haul truck pilot demonstrations should focus on the Port of Oakland as the focus point of the I-580, I-880, and I-80 corridors that connect the Bay Area to the Sacramento region and San Joaquin Valley air basin.

In the San Joaquin Valley air basin, demonstrations can include HD short haul FCETs between populated areas such as Fresno, Stockton, and Bakersfield, from agricultural sources to warehouses, or around distribution centers using HD yard tractors. A demonstration showcasing fuel cell drayage truck operational capabilities between Bakersfield and the San Pedro Bay Ports in the South Coast basin may result in significant lessons learned for the potential of zero emission truck operation on the most demanding routes with long and steep grades.

Figure 5 shows drayage warehouses and intermodal facilities locations for the South Coast basin, Inland Empire, and South San Joaquin Valley.

[37] http://www.calstart.org/Libraries/I-710_Project/Key_Performance_Parameters_for_Drayage_Trucks_Operating_at_the_Ports_of_Los_Angeles_and_Long_Beach.sflb.ashx

Figure 5. HD drayage/short haul truck loading/unloading locations around I-710 Corridor on CALSTART Map



HD drayage truck operation and infrastructure planning stakeholders should consider including 100-200 mile range zones from the Ports of Los Angeles, Long Beach, and surrounding rail yards, for additional truck fueling infrastructure. This puts the short-haul destinations and freight points of origin in the Inland Empire and Bakersfield within reach of HD FCET operation. For the Port of Oakland, as a point of drayage origin and destination, Sacramento and the South San Francisco peninsula should be considered equally for future truck demonstration projects and to implement truck fueling infrastructure.

For MD package delivery, the focus should be on regions surrounding the distribution centers operated by package delivery fleet operators in high profile areas such as Los Angeles, San Francisco, and San Diego. For this vehicle category, the expectation is that ZEV technology demonstration or pilot projects will occur where there is an overlap of priority regions (Figure 6), non-attainment regions (as identified by EPA and CARB), and existing locations of MD package delivery vehicle fleet operator distribution centers. These projects will require implementation by motivated parties at locations of their own

choosing. Organizations operating private package delivery fleets in the priority regions are UPS, FedEx, and DHL. Package distribution centers lie within population centers such as Fresno, Bakersfield, and Stockton in the San Joaquin Valley, a variety of locations throughout the South Coast basin, Sacramento, San Diego, and on the San Francisco peninsula.

As mentioned earlier, for MD package delivery truck demonstrations, decision makers should consider inclusion of select passenger hydrogen station locations (e.g., Coalinga, West Sacramento, Burbank, Thousand Palms, and Laguna Niguel) that may have the capacity to facilitate the operation of 2 to 3 MD FCETs in addition to serving passenger FCEVs.

Recommendations

Following are initial prioritized recommendations to address the challenges described in this chapter. A more extensive list of recommendations can be found in Appendix D. Each recommendation is followed by a proposed lead entity.

1) Develop the current SAE J2601/2 TIR "Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles" to the level of a full standard and generate data to resolve SAE J2601 not including 35 MPa fueling (6-10 kg) to address the current gaps in fueling protocol related codes and standards (government & industry collaboratively).

2) Consolidate funded truck projects and development of commercial HD fueling infrastructure, so stations have higher throughput, reducing the cost of fuel and capital expense of infrastructure (industry and government collaboratively).

5. Timing Considerations

For the purpose of this document, near-term strategy is defined as the period before 2020, which focuses on establishing the foundational understanding required for decision making about FCET commercialization.

Medium term is the period up to 2031, during which the technology, depending on development progress by 2020 and related investment decisions, may enter early commercialization in the priority regions, as well as spreading beyond these areas. In this market context, long term is defined as the period up to 2050, during which full commercialization could be considered in the product planning of truck OEMs and for fueling infrastructure development to facilitate full adoption throughout all MD and HD truck vocations and market segments.

The rapid timing of this rollout for an entirely new vehicle technology requires funding support beyond market forces to deliver the desired outcomes. As a result, a corporate operating structure—perhaps utilizing a new business model or ownership structure—is needed that can create economic benefits for MD and HD FCET operators. Such an operating structure should be initiated within the next five to ten years. In addition, clear and consistent indicators of air quality regulatory compliance timelines should complement these efforts. These can provide definite timing requirements that will serve to advance this new vehicle technology toward market introduction.

Given the extent of the new fueling infrastructure that will be required to meet the needs of a portion of the potential market of Class 7-8 zero emission trucks (e.g., a portion of the up to 10,000 ZEV trucks for the I-710 corridor), planning for capacity, distribution, and siting of MD and HD FCET fueling infrastructure needs to start in 2016 and include both commercial conventional fuel and hydrogen fuel providers.

While this infrastructure implementation effort gets underway, demonstration evaluations and lessons learned from fueling transit FCEBs with similar capacities will identify tradeoffs between the speed of refueling, costs of installation and equipment, and the impacts to the local distribution capacity.

For the I-710 Corridor, planning will also need to account for the anticipated vehicle turnover timeline already set in motion by the San Pedro Bay Ports Clean Truck Program. The initial investment that was made to facilitate a rapid transition to trucks compliant with EPA 2007 and later emissions standards has resulted in a significant quantity of trucks ready for replacement by 2020 and years following. One of the lessons learned from this program is not to replace a trusted and proven vehicle technology with new technologies that have been insufficiently tested and verified. Introducing fuel cell technology will have to be done in a manner that instills confidence in operators who must rely on this technology for their business.

Achieving ZEV deployment success will require the involvement of the major MD and HD vehicle OEMs. Each OEM has its own strategy for ZEV-enabling technology based on their product mix, plans for fuel economy, and global market considerations, factoring in the demand and supply for trucks, future

potential for profitability, and regulatory context. Although full ZEV technology is not central to their current product plans, several OEMs have begun internal development efforts. As recommended in this Action Plan, the lessons learned and operational data from the FCET demonstrations are expected to provide direction to OEMs to better define the direction and scope of their efforts.

Recommendation

The following is the initial recommendation to facilitate rollout of FCET technology within the described short, medium, and long term.

1) Assess corporate operating structure options to create economic benefits for MD and HD FCET operators and initiate within the next 5 to 10 years (government and industry collaboratively).

6. Conclusion and Final Recommendation

The information and recommendations provided herein support implementation of FCEV technology in MD and HD trucks, specifically in California. The State is well positioned to encourage the introduction of this technology, which may be able to capitalize on some of the lessons learned from FCEB programs.

Characteristics of the truck market such as the vehicle population and the need to establish a sustainable business case led to this Plan's identification of two proposed truck vocations (i.e., last-mile delivery trucks and short-haul drayage trucks) for demonstration, validation, data collection, and learning. Focus on these initial truck vocations in the near and medium term can lay the groundwork for adoption of fuel cell technology by additional truck classes and vocations, including potentially long haul trucks, in later years.

The limited support for fueling infrastructure implementation is identified as a central challenge. No funding awards or other funding sources have been dedicated to the implementation of permanent hydrogen fueling infrastructure for MD and HD FCETs, including projects already under contract. It is essential to have sufficient fuel available in order to determine how fuel cell technology performs in truck applications and not make the assumption that FCETs will be comparable to FCEBs. As such, funding for fueling infrastructure should be prioritized before any major technology development decisions are made.

During the development and operation of currently funded FCET projects, involved organizations such as vehicle integrators and truck OEMs can make technology assessments using the TRL and/or MRL systems. These assessments will inform vehicle manufacturers' decision making on subsequent development steps and could result in determining what targets should be set to reach to a reasonable total cost of ownership (TCO) for truck operators.

Lastly, demonstrations should take place in regions where medium and heavy trucking coincides with poor air quality. Priority should be given to the South Coast air basin, San Joaquin Valley, the San Francisco Bay Area, and identified adjacent areas.

Appendix A: Actions Promoting Advances toward FCEVs in Freight Transportation

Air monitoring data show that a large majority of the California's population breathes unhealthy levels of air pollutants during at least part of the year. California's unique air quality challenge is due to a combination of factors including the state's weather patterns, topographical formations, rapid population growth, and point source pollution—much of it from mobile sources used in the movement of freight.[38]

California is on a path to achieve its 2020 greenhouse gas (GHG) emission reduction targets to 1990 levels, as established by AB 32 (2006). Additionally, California has a goal of reducing statewide GHG emissions to 80% below 1990 levels by 2050. To achieve this long-term goal, medium- and heavy-duty trucks were identified as the next mobile source categories for significant tailpipe emission reduction (after passenger vehicles), with ZEV technology implementation wherever feasible. The achievements from near-term demonstrations are expected to set the stage for long-term vehicle technology performance requirements, while moving in parallel from the community and regional levels to a broader national approach. Starting at the community level will also help in the longer term with public acceptance at the state level. However, as of the publication date of this document (August 2016), there is no established full or partial ZEV regulatory requirement for the MD and HD truck market.

In 2012, CARB, South Coast Air Quality Management District (SCAQMD), and San Joaquin Valley Air Pollution Control District (SJVAPCD) published *"Vision for Clean Air: A Framework for Air Quality & Climate Planning."*[39] This joint effort took a coordinated look at the strategies needed to meet California's multiple air quality and climate change mitigation goals between 2012 and 2050. To achieve these goals and meet federal air quality requirements, a number of regulations and incentive programs are underway, which were established by industry stakeholders and a variety of different government entities.

California Actions

To achieve the goal of 1.5 million ZEVs on the road by 2025, as set in Governor Brown's March 2012 Executive Order B-16-2012,[40] the 2013 Zero Emission Vehicle Action Plan (ZEV AP) identified the strategies and actions for state agencies to advance the state's ZEV goals.[41] These actions include directions for State agencies and related regional agencies to work on supporting ZEVs for freight transportation by 2020 by reducing cost barriers to ZEV adoption for freight vehicles and integrating ZEVs into high level freight planning considerations. In 2015, the revised draft ZEV AP[42] explicitly provides strategies and actions directing CARB, the Energy Commission, and the Governor's Office of

[38] http://www.arb.ca.gov/research/health/fs/fs1/fs1.htm
[39] http://www.arb.ca.gov/planning/vision/docs/vision_for_clean_air_public_review_draft.pdf
[40] Available at: https://www.gov.ca.gov/news.php?id=17472
[41] "2013 ZEV Action Plan A roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025". February 2013: http://opr.ca.gov/docs/Governor%27s_Office_ZEV_Action_Plan_%2802-13%29.pdf
[42] Draft 2015 ZEV AP: http://gov.ca.gov/docs/DRAFT_2015_ZEV_Action_Plan_042415.pdf

Business and Economic Development (GO-Biz) to analyze at which connector stations hydrogen dispensers for fueling MD and HD FCETs can be co-located with passenger FCEV fueling. In addition, the following MD and HD ZEV related strategies are laid out in the "Expand Zero Emission Freight, Rail, and Other Medium- and Heavy-Duty Technologies" section.

- Complete integrated planning among state agencies to develop appropriate incentives, partnership, and regulatory approaches to expand the use of zero emission vehicle technologies in the freight sector.
- Ensure that electricity rates for industrial, commercial, and institutional customers are fair and reasonably enable the electrification of freight and public transportation.
- Expand demonstrations and commercialization of zero emission and near-zero emission technologies in the heavy-duty and off-road sectors.
- Support medium- and heavy-duty ZEV infrastructure planning and investment by public and private entities.
- Build awareness about new heavy-duty technologies and support businesses' use of these technologies.
- Support expansion of new technologies at California ports and key freight transportation corridors.

In his January 2015 inaugural address,[43] Governor Brown laid out new goals for the State, directing State agencies to work toward achieving the following goals by 2030:

1) Reduction of petroleum use by cars and trucks up to 50%[44]
2) Increase the renewable content of electricity in the grid from 33% to 50%
3) Reduce emissions of short-lived climate pollutants

In April 2015, the Governor signed Executive Order B-30-15,[45] which includes the overarching goal to achieve 40% emission reduction below 1990 levels by 2030.

In July 2015, the Governor signed Executive Order B-32-15, ordering state agencies to develop an integrated action plan by July 2016 that establishes clear targets to improve freight efficiency, to transition to zero emission technologies, and to increase competitiveness of California's freight system.[46] This plan will identify policies, programs, and investments to achieve these targets, based on existing strategies, including the California Freight Mobility Plan, Sustainable Freight Pathways to Zero and Near-Zero Emissions, Integrated Energy Policy Report, as well as broad stakeholder input.
To ensure progress toward a sustainable freight system, the state agencies were directed to initiate work in 2015 on corridor-level freight pilot projects within the State's primary trade corridors that integrate advanced technologies, alternative fuels, freight and fuel infrastructure, and local economic

[43] Governor Edmund G. Brown Jr. 2015 inaugural address: http://gov.ca.gov/news.php?id=18828
[44] This goal was dismissed through legislative direction in SB350.
[45] Executive Order B-30-15: http://gov.ca.gov/news.php?id=18938
[46] Executive Order B-32-15: http://gov.ca.gov/news.php?id=19046

development opportunities. Aside from agencies under direct authority of the Governor, other public and private entities are encouraged to assist in this development and implementation as appropriate.

For several years, state agencies have worked on incentivizing clean transportation technologies. Using funds generated under Assembly Bill 118, AB 8, and AB 32 (Cap-and-Trade auction proceeds), the Energy Commission administers the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) funding and CARB administers the Low Carbon Transportation and AQIP funding. Both programs were initiated to accelerate technology development and deployment toward achieving California's 2030 and 2050 air quality mandates and climate change goals. Below is a description of these programs and other sources that provide regional funding for projects using advanced MD and HD vehicle technology.

The California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program
Established through AB 118, and subsequently amended by AB 109 and AB 8 in 2013, the ARFVTP has an annual budget of up to $100 million from 2014-2023 to fund eligible stakeholder projects that support alternative and renewable low-carbon fuels generation, expansion of fuel infrastructure, improvement of all categories of vehicle technologies, retrofit on-road and non-road vehicle fleets, decrease the impact and footprint of alternative and renewable fuels, increase sustainability, expand infrastructure for public and private fleets and transportation corridors, and establish related training and outreach. To achieve this, the Energy Commission annually prepares and adopts an Investment Plan.[47] Per the ratified language of AB 8, $20 million per year of the total ARFVTP budget is assigned and dedicated to reach the goal of 100 light-duty passenger FCEV hydrogen fueling stations.[48] Aside from limited fueling infrastructure funding under AQIP and GGRF that is directly tied to select MD and HD ZEV fleet projects funded through these programs, there is currently no dedicated funding or guarantee for the implementation of a MD and HD hydrogen vehicle fueling infrastructure to support operation of these vehicles.

CARB's Low Carbon Transportation Investments and Air Quality Improvement Program
Established through AB 32 and the same assembly bills as the Energy Commission's ARFVTP, the CARB Low Carbon Transportation Investments and AQIP provide incentives for the development of advanced technology and clean transportation by mobile sources to meet California's air quality targets. Each year, the legislature appropriates funding to CARB for low carbon transportation projects.[49] AQIP is a voluntary incentive program to fund clean vehicle and equipment projects, research biofuels production and the air quality impacts of alternative fuels, and conduct workforce training. Guidelines and annual Funding Plans provide direction for the implementation of AQIP.[50]

[47] For more information: http://www.energy.ca.gov/altfuels/
[48] As of 1/14/2016, over $100 million has been invested.
[49] In fiscal year (FY) 2014-15, $200 million was allocated for low carbon transportation projects.
[50] For more information: http://www.arb.ca.gov/msprog/aqip/aqip.htm

Goods Movement Emission Reduction Program
Established through the $1 billion Proposition 1B passed by voters in 2006, this program is a partnership between CARB and local agencies (like air districts and seaports) to quickly reduce air pollution emissions and health risk from freight movement along California's trade corridors (see Figure 6). Local agencies can apply for CARB funding, allowing those agencies to offer financial incentives to owners of equipment used in freight movement to upgrade to cleaner technologies. Projects funded under this program must achieve early or extra emission reductions not otherwise required by law or regulation.

South Coast Air Quality Management District Technology Advancement Office
The SCAQMD uses cooperative partnerships to cosponsor projects intended to demonstrate the successful use of clean fuels and technologies that lower or eliminate emissions. Public-private partnerships have enabled the SCAQMD to leverage its public funds with an average of $3 from outside investment for every dollar contributed by SCAQMD, providing funding to encourage the use of commercially available, low-emission mobile and stationary technologies.[51] Annual funding for these projects is about $10 million, with a recent emphasis on goods movement related projects including MD and HD fuel cell vehicles, along with other low or zero emission technologies.

San Joaquin Valley Air Pollution Control District Technology Advancement Program
The Technology Advancement Program (TAP) is the District's strategic approach to encouraging innovation and development of new emission reduction technologies. The TAP consists of an ongoing review of new technology concepts, interagency partnerships, funding for technology advancement programs, and collaborations to build and expand local capacity for research and development in the San Joaquin Valley. Mobile source projects demonstrate zero or near-zero emission solutions to mobile source categories with emphasis on goods and people movement, off-road equipment, or agricultural equipment.[52]

Bay Area Air Quality Management District Incentive Program
BAAQMD is planning to launch an incentive program for the purchase/lease of MD and HD electric vehicles. FCEVs would be included in this category for funding and the program is tentatively scheduled to launch in 2016.

In 2013, CARB announced the development of the California Sustainable Freight Strategy, confirmed through adoption of Resolution 14-2 in 2014, which seeks to outline the steps needed to transform California's freight transport system to one that is sustainable, more efficient, and competitive. The goals of the strategy include:

1) Movement of goods more efficiently and with zero/near-zero emissions
2) Transition to cleaner, renewable transportation energy sources
3) Providing reliable velocity and expanded system capacity

[51] http://www.aqmd.gov/home/library/technology-research
[52] http://valleyair.org/grants/technologyadvancement.htm

4) Integration with national and international freight transportation systems
5) Support for healthy, livable communities.

This effort builds on work that has shown the growing contribution of freight-related emissions sources and the need to transition to zero and near-zero emission technologies to meet National Ambient Air Quality Standard (NAAQS) attainment deadlines in regional airsheds and statewide GHG reduction goals. This transition will likely need to include widespread use of alternative transportation fuels such as grid-based electricity, hydrogen, and renewable fuels such as biogas, which will consequently have significant impacts for energy providers in California. In its discussion draft,[53] CARB shares its objective to prioritize the use of zero emission technology wherever possible.

To plan adequately for the future, CARB formed a permanent scenario planning program. This program is intended to help CARB evaluate hypothetic contextual changes in the future and gain insight on what is necessary to achieve long-term targets. The "CARB Vision 2.0" tool used in this scenario planning program builds on most recent policy developments and emission projections[54] and includes modules for all HD freight vehicles heavier than 8,500 lbs.[55]

In 2015, CARB released a draft mobile source strategy, which seeks to simultaneously meet air quality standards, achieve GHG emission reduction targets, reduce petroleum consumption, and decrease health risk from transportation emissions over the next 15 years. To position the heavy-duty sector for longer-term targets that extend beyond the timeframe of the strategy, actions to promote the use of clean-burning and near-zero emission vehicles must be complemented by targeted introduction of zero emission technologies in heavy-duty applications that are suited to early adoption of ZEV technologies.[56]

The California's statewide, long-range plan for freight, titled "California Freight Mobility Plan" (CFMP), was developed by the California State Transportation Agency (CalSTA) and Caltrans in collaboration with public and private freight industry stakeholders. This document helped the State to comply with the federal "Moving Ahead for Progress in the 21st Century Act,"[57] which encourages each state to develop a freight plan, and AB 14 (Lowenthal, 2013[58]), which requires a California state freight plan.[59]

Two of the six CFMP goals are directly related to the application of MD and HD FCEVs:

[53] "Sustainable Freight, Pathways to Zero and Near-Zero Emissions" (discussion draft), California Air Resources Board, April 2015. http://www.arb.ca.gov/gmp/sfti/sustainable-freight-pathways-to-zero-and-near-zero-emissions-discussion-document.pdf
[54] http://www.arb.ca.gov/planning/vision/vision.htm
[55] See ARB staff March 2015 Vision Workshop presentation: http://www.arb.ca.gov/planning/vision/docs/vision_workshops_march2015_staff_presentation.pdf
[56] http://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.htm
[57] http://www.dot.ca.gov/hq/tpp/offices/ogm/CFMP/MAP-21_Freight_Provisions_Fed_Register_04_18_13.docx
[58] http://www.dot.ca.gov/hq/tpp/offices/ogm/CFMP/AB14_Statutory_Authority_for_Freight_Planning.docx
[59] http://www.dot.ca.gov/hq/tpp/offices/ogm/california_freight_mobility_plan.html

- ***Innovative Technology and Practices***: Use innovative technology and practices to operate, maintain, and optimize the efficiency of the freight transportation system while reducing its environmental and community impacts.
- ***Environmental Stewardship***: Avoid and reduce adverse environmental and community impacts of the freight transportation system.

Federal Actions

Several California regions are designated as nonattainment areas for one or more of EPA's National Ambient Air Quality Standards. This indicates that much of California suffers from chronically unhealthy levels of air pollution.

Many state and federal policy and planning efforts related to achieving established air quality mandates and GHG emission reduction targets highlight the need for a dramatic acceleration in the deployment and adoption of zero and low emission transportation technologies.

EPA/NHTSA Heavy-Duty Greenhouse Gas & Fuel Efficiency Standards[60]

This joint EPA/National Highway Traffic Safety Administration (NHTSA) rulemaking seeks to reduce fuel use and GHG emissions from model year 2021-2027 medium- and heavy-duty on-highway vehicles, with standards for trailers starting in 2018 for EPA and in 2021 for NHTSA. This proposed program fully harmonizes EPA and NHTSA standards, and the agencies have worked closely with CARB in developing this program. All three agencies are committed to the final goal of a single national program that will allow manufacturers to continue to build a single fleet of vehicles and engines. Equipment covered by the proposed standards includes: semi-trucks/combination tractors, trailers pulled by combination tractors, vocational vehicles, and pick-ups and vans. Note that the stringency of the Phase 2 standards is not based on the use of zero-emission vehicles in the medium- and heavy-duty sector. However, the use of zero emission technology can help manufacturers meet the Phase 2 requirements, particularly if advanced technology multipliers, which were under consideration, are included in the final rulemaking.

U.S. Congress 2015 "Fixing America's Surface Transportation" Act

The FAST Act is 5-year legislation to improve the United States' surface transportation infrastructure, including roads, bridges, transit systems, and rail transportation network. The bill reforms and strengthens transportation programs, refocuses on national priorities, provides long-term certainty and more flexibility for states and local governments, streamlines project approval processes, and maintains a strong commitment to safety. Section 1413 of the FAST Act, titled "National Electric Vehicle Charging and Hydrogen, Propane, and Natural Gas Fueling Corridors" applies to hydrogen infrastructure implementation.[61]

[60] Proposed 6/19/15.

[61] https://www.congress.gov/bill/114th-congress/house-bill/22/text#toc-H865D62BE169A4F53862109E8B166350F

A number of federal funding programs applicable to the California context and that could be used for MD and HD FCET projects, are in place to support achievement of these targets.

U.S. DOE Hydrogen and Fuel Cells Program

DOE is the lead federal agency for directing and integrating activities in hydrogen and fuel cell R&D as authorized in the Energy Policy Act of 2005. DOE's Office of Energy Efficiency & Renewable Energy's Fuel Cell Technologies Office is responsible for coordinating the R&D activities for DOE's Hydrogen and Fuel Cells Program, which includes activities within other DOE offices. FCTO's mission is to enable the widespread commercialization of a portfolio of hydrogen and fuel cell technologies through applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges. In recent years, the annual budget for this program was close to $100 million.[62]

EPA's Diesel Emissions Reduction Act (DERA) Program

DERA [63] authorizes funding of up to $100 million annually through FY2016 to help fleet owners reduce diesel emissions. Current programs:

a. The National Clean Diesel Funding Assistance Program awards rebates and competitive grants to fund projects that implement EPA or CARB verified and certified diesel emission reduction technologies.

b. The State Clean Diesel Grant Program allocates funds to participating states to implement grant and loan programs for clean diesel projects. Base funding is distributed to states using a specific formula based on participation, and incentive funding is available for any states that match their base funding.[64]

U.S. DOT Federal Highway Administration (FHWA) Congestion Mitigation Air Quality Program

The CMAQ program provides funding for projects and programs in air quality nonattainment and maintenance areas that reduce transportation related emissions. Available program funds are apportioned according to a formula based on population and severity of pollution. States and metropolitan planning organizations (MPOs) that receive funding are required to prioritize projects and programs that include diesel retrofits, alternative fuel vehicle procurement, alternative fuel infrastructure deployment, as well as other cost-effective emission reduction and congestion mitigation activities that provide air quality benefits.[65]

U.S. DOT Federal Aviation Administration Voluntary Airport Low Emissions (VALE) Program

The VALE Program is a national program intended to reduce all sources of ground emissions at commercial service airports in specific air quality areas identified by EPA. Established in 2004, VALE helps airport sponsors to be proactive and meet their state-related air quality responsibilities under the

[62] http://energy.gov/eere/fuelcells/about-fuel-cell-technologies-office
[63] http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid=f:h6enr.txt.pdf
[64] http://www.epa.gov/cleandiesel
[65] https://www.fhwa.dot.gov/safetealu/factsheets/cmaq.htm

Clean Air Act. Through this program, airport sponsors can use Airport Improvement Program (AIP) funds and Passenger Facility Charges (PFCs) to finance low emission vehicles, supporting fueling infrastructure and other airport air quality improvements.[66]

U.S. DOT FAA Airport Improvement Program (AIP)

Through AIP, U.S. DOT FAA makes grant funding available to public agencies, and in some cases to private owners and entities, for the planning and development of public-use airports that are included in the National Plan of Integrated Airport Systems (NPIAS). Projects eligible for funding include improvements related to enhancing airport safety, capacity, security, and environmental concerns. Because the demand exceeds available funds, FAA distributes the funds based on present national priorities and objectives.[67]

U.S. DOT FAA Zero Emissions Airport Vehicle and Infrastructure Pilot Program

The Zero Emissions Airport Vehicles and Infrastructure Pilot Program allows the FAA to grant Airport Improvement Program (AIP) funds for the purchase of zero emissions vehicles at an airport and for implementing infrastructure changes to facilitate the delivery of the energy necessary for the use of these vehicles.[68]

USDA Rural Energy for America Program (REAP)

This program provides guaranteed loan financing and grant funding to agricultural producers and rural small businesses to purchase or install renewable energy systems (including hydrogen) or make energy efficiency improvements. Its purpose is to help increase energy independence by increasing the private sector supply of renewable energy and decreasing the demand for energy. In the longer term, these investments can also help lower the cost of energy costs for small businesses and agricultural producers.[69]

Other federal incentive programs, for example tax exemption measures and grant programs, are not mentioned here, but could provide future funding for FCET development, demonstration, or introduction. However, the technology must first be developed to a more robust level, so that demonstrations can provide the data and lessons learned needed to promote other incentives.

[66] http://www.faa.gov/airports/environmental/vale/
[67] http://www.faa.gov/airports/aip/overview/
[68] http://www.faa.gov/airports/environmental/zero_emissions_vehicles/
[69] http://www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency

Appendix B: Currently Funded Projects

Several fuel cell truck demonstration projects are funded and under development in California and the United States. Although some are outside the selected vocational categories targeted in this Action Plan, these projects are expected to generate valuable operational data thereby providing better insight and understanding of the development, integration, and commercialization potential of fuel cell technology in all classes of MD and HD trucks. Although a handful of fuel cell vehicles in the Class 4-8 truck category were previously demonstrated in Hawaii[70] and Michigan,[71] none are currently in operation in the package delivery and drayage truck vocational vehicle market segments. This appendix provides an overview of currently funded projects, most of which are expected to begin operation in 2016.

Project	***FCET type***	***Location(s)***	***Number of FCET(s)***
CTE/UPS package delivery vans	MD FCET	California TBD	1 + 17
FedEx/PlugPower package delivery vans	MD FCET	Tennessee and California	20
US Hybrid refuse truck	HD FCET	TBD	1
H-GAC drayage trucks	HD FCET	Port of Houston, TX	3
Hydrogenics drayage truck	HD FCET	Ports of Los Angeles and Long Beach, CA	1
US Hybrid/CALSTART shuttle buses	MD FCET	Coachella Valley and Los Angeles, CA	4
CTE/BAE/Ballard/Kenworth drayage truck	HD FCET	South Coast basin, CA	1
Transpower/Hydrogenics drayage trucks	HD FCET	South Coast basin, CA	2
US Hybrid drayage truck	HD FCET	South Coast basin, CA	2
Transpower short haul truck	HD FCET	San Joaquin Valley, CA	1
US Hybrid shuttle bus	MD FCET	Fresno County, CA	1

U.S. Department of Energy projects

In 2013, DOE's Fuel Cell Technology Office provided $6 million for two MD fuel cell vehicle development and demonstration projects:[72]

- Center for Transportation and the Environment ($3 million DOE investment and SCAQMD): CTE, in collaboration with the University of Texas Center for Electromechanics, USL LLC, Hydrogenics USA and Valence Technology will develop a fuel cell hybrid electric walk-in delivery van with a 150-mile range per fueling. Following the development of a test vehicle, the project will retrofit 17 UPS delivery vans with fuel cell hybrid power trains and test these vehicles at distribution facilities in metropolitan areas across California.

[70] http://htdc.org//hcatt.html
[71] http://www.greencarcongress.com/2004/08/ups_sprints_ahe.html
[72] http://energy.gov/articles/energy-department-invests-over-7-million-commercialize-cost-effective-hydrogen-and-fuel

- FedEx Express ($3 million DOE investment): In collaboration with PlugPower and Workhorse, FedEx Express will develop a hydrogen fuel cell delivery truck with a range of up to 150 miles per fueling and will test 20 of these trucks at FedEx facilities in Tennessee and California.

As part of the May 2014 Technology-To-Market Small Business Innovation Research (SBIR) DOE EERE award:[73]

- US Hybrid will develop a proof-of-concept design approach for a fuel cell-battery electric hybrid truck for waste transportation in Phase 1 of this project. If this project proceeds to Phase 2 and develops a full-scale prototype that is ultimately commercialized, this fuel cell refuse truck will have no harmful emissions, reduce oil dependence, and result in significant fuel savings over its operational life.

The 2012 DOE EERE FCTO Zero Emission Cargo Transport Demonstration grant program provided a $3.2 million funding award.[74,75]

- The Houston-Galveston Area Council (H-GAC), Gas Technology Institute (GTI), US Hybrid, Environmental Defense Fund (EDF), Richardson Trucking, and the University of Texas Center for Electromechanics are partnering on a three-year demonstration project at the Port of Houston by developing and operating three Class 8 fuel cell drayage trucks.[76,77]

California Energy Commission Projects

The Energy Commission awarded funding for the following projects in 2015 through the Alternative and Renewable Fuel and Vehicle Technology Program.[78]

- Hydrogenics will design, build, and integrate its fuel cell power system technology into a Class 8 drayage truck. The truck will be operated by Total Transportation Services, Inc. (TTSI) in and around the Ports of Los Angeles and Long Beach.
- US Hybrid, in collaboration with CALSTART, SunLine Transit, and Cal State University Los Angeles, will build and demonstrate four Class 5 fuel cell shuttle buses.[79] The demonstration will occur in and around disadvantaged communities in Los Angeles and the Coachella Valley.

South Coast Air Quality Management District Projects

In combination with funding from DOE, the Energy Commission, Los Angeles Department of Water and Power, Ports of Long Beach and Los Angeles, and SoCalGas, SCAQMD funded three Class 8 fuel cell range

[73] http://energy.gov/eere/fuelcells/articles/fuel-cell-project-selected-first-ever-technology-market-sbir-award
[74] http://blogs.edf.org/texascleanairmatters/2015/07/07/houston-as-a-hydrogen-haven/
[75] http://www.fuelcelltoday.com/news-archive/2012/october/us-doe-to-potentially-co-fund-20-tyrano-fuel-cell-trucks-in-texas
[76] http://www.h-gac.com/agendas/board/documents/February%202015/tp-DOE-ZECT-Agreement-GTI.pdf
[77] Project also received funding support from SCAQMD.
[78] http://www.energy.ca.gov/contracts/PON-14-605_Revised_NOPA.pdf
[79] Project included due to similarities of vehicle platform with Class 5-6 package delivery vehicles.

extended drayage truck projects (5 trucks total) for operation in the Port of Los Angeles and South Coast basin in 2014:[80]

- CTE, BAE Systems, and Ballard Power Systems will develop and demonstrate one Class 8 fuel cell range extended hybrid electric drayage truck powered by Ballard's 100 kW fuel cell system.
- TransPower, using Hydrogenics provided fuel cell technology, will develop and demonstrate two Class 8 plug-in fuel cell range extended electric drayage trucks. For comparison purposes, one truck will use a 30 kW fuel cell and the second truck will use a 60 kW fuel cell.
- US Hybrid will develop and demonstrate two Class 8 fuel cell range extended electric drayage trucks, each powered by 80 kW hydrogen fuel cell generators operating in charge sustaining mode.

San Joaquin Valley Air Pollution Control District Projects

SJVAPCD's Technology Advancement Program will provide funding for the following fuel cell truck projects:[81]

- TransPower will build and support operation of a Class 8 plug-in battery electric truck augmented with a hydrogen fuel cell to extend its operating range. This truck will be operated at Harris Ranch in the San Joaquin Valley near Coalinga.
- US Hybrid will build a Class 5 plug-in hybrid electric fuel cell shuttle bus for operation in west Fresno County on the Huron-Coalinga route of Fresno County Rural Transit Agency.[82]

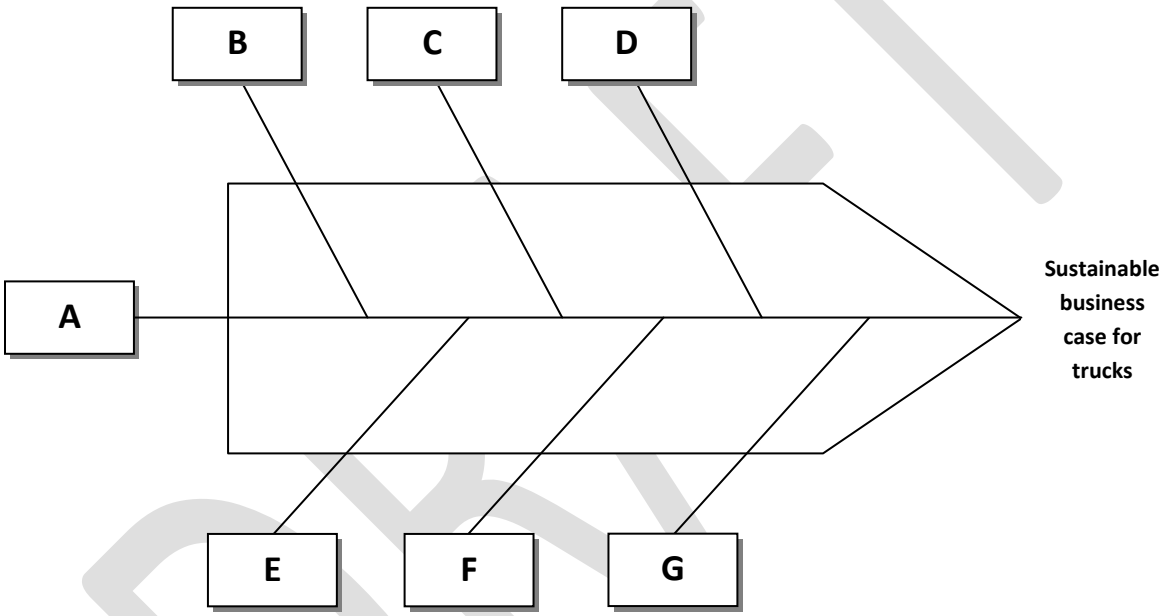
Additionally, several demonstration projects have been completed or are underway using plug-in battery-electric truck technology. Battery-electric trucks are developed and manufactured by companies such as Balqon, EVI, Mitsubishi, Motiv Power, Smith Electric, TransPower, US Hybrid, Workhorse, and Zenith Motors. These manufacturers have developed drive trains that can be used for fuel cell technology integration. Additionally, they have expertise in the early manufacturing and operation of such vehicles in demonstration or test programs, which will transfer to MD and HD FCET applications. MD battery powered delivery truck projects can be found throughout North America, while HD battery powered short haul drayage trucks and yard tractors are mainly operational in the South Coast and San Joaquin Valley regions.

It should be noted that the awards listed above did not provide funding for the implementation of fueling infrastructure, due to funding limitations or assumptions about using passenger FCEV fueling infrastructure or other fueling solutions that are still under discussion or development.

[80] http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2014/2014-dec5-003.pdf?sfvrsn=2
[81] http://www.valleyair.org/Board_meetings/GB/agenda_minutes/Agenda/2015/March/final/12.pdf
[82] Project included due to similarities of vehicle platform with Class 5-6 package delivery vehicles.

Appendix C: Business Case Expectations

For any new vehicle technology, and particularly fuel cell technology as a new vehicle platform technology compared to the diesel or CNG baseline vehicles, to be feasible from an ownership, operator and truck OEM perspective, the business case has to be sustainable and create an acceptable risk for all stakeholders throughout the entire value chain. For this to occur, a number of elements should be in place to shape the context that leads to the total cost of ownership (TCO), which is the primary long term driver for new technology adoption and sustainability. Mapping the aspects of a sustainable business case for trucks will help understand how broad of an effort is required and what specific areas need to be addressed to make any fuel cell truck product successful. The figure below serves as an illustration to show that these elements all have to come together and in place to make a sustainable business case.



The different overarching elements can be represented as follows, not in order of priority or weighted, but all are essential for long term sustainability:

A. Meets customer requirements

a. Customer requirements: capital cost, operational cost, reliability - no concessions
b. Product performance parity with diesel and natural gas: i.e. weight, cost of performance must be competitive to existing trucks.
c. Customers can plan backwards from 2000 trucks (fleet thinking/planning)
d. Port/container terminal access for ZEV trucks - “Fast Pass”
e. Truck financing programs: owner operator and small fleet access to financial support
f. Top end commercial breaking point

B. Favorable operating environment

a. Concentrate stakeholder resources in one area = fleet critical mass
b. Emergency responders on board
c. Broad industry support of technology (including manufacturers and suppliers)

C. Regulatory stability for product planning
   a. Regulatory acceptance – will this technology slow down the rate of regulatory changes
   b. Knowable playing field
   c. Annual cost targets over 15 years
   d. Supportive and consistent legislative and regulatory framework throughout North America

D. OEM essentials
   a. Essential enablers
      i. Manageable warranty and support cost
      ii. Leverage existing OEM manufacturing and product lines
      iii. Shared components (for cost control)
   b. Revenue to sustain operations
      i. Acceptable top line revenue
      ii. Long-term volume sales – multiple markets, mass-market designs
      iii. Revenue growth year-after-year
      iv. Market demand – beyond drayage and/or government market
   c. Return on investment + profit
      i. Acceptable bottom line ROI
      ii. Profitability: investment recovery after reasonable time
      iii. Affordable dealer support network

E. Incentives support the path to sustainable sales
   a. Incentivize freight owners – pull market, have the end-user/owner of the product create/support demand
   b. Incentives: OK at first; cannot rely on these long-term
   c. Predictable time horizon for incentives – will incentives match the development schedule
   d. Time horizon for incentives allows to recoup development costs
   e. "Product demonstration" is not the same as production rollout. Getting to demonstration point is a beginning, not an end.
   f. Development roadmap is aligned with clear large-scale targets that do not change –should not change metrics to measure a level of success

F. Reliable, accessible, and affordable fueling
   a. Fuel: quick turnaround for truck filling, affordable cost per kg, strategic locations, renewable hydrogen credits
   b. Fuel availability: fueling infrastructure network has sufficient coverage and capacity
   c. Predictable fuel costs

G. Go/no-go milestone
   a. Be willing to accept no for an answer: ZEV mandate for all truck vocations may not work
   b. No "non-success based development schedule": milestones move go/no-go reviews, not enough time for iterations to meet minimum requirements.

All these elements are in place for conventional truck technology, where the engineering and policy are related for any new product or component technology commercialization. This leads to observations stating (for example) that for specific truck vocations the incremental cost of HD vehicles compared to conventional technology has to be earned back within 1.5-3 years to be acceptable for adoption by users purchasing vehicles. The bottom line assumption is that the TCO should be competitive with conventional technology. In a process that intends to establish a sustainable business case context for

FC trucks, each of these elements could be potential showstoppers, so identifying challenges with any of these and resolving these will take a consistent and concerted effort involving many stakeholders.

Appendix D: Overview of All Recommendations

Recommendations per chapter with highest priority first, followed by other important recommendations that are all part of establishing a sustainable business case for FCETs.

2. MD and HD Vehicle Focus

Highest priority

Technology Advancement

1) Transfer the lessons learned from implementing and operating fuel cell bus programs to truck vocations, especially as these lessons relate to technology, and help identify or reduce risk to the financial community (industry).

2) Conduct data collection using a consistent set of fleet operation variables for comparison, feasibility assessments, and decision making; this should be a basic requirement for all government-funded truck projects (government and industry collaboratively).

3) Prove reliability of MD and HD FCETs to show that the cost-per-mile economics of transported freight; this is critical to the sustainable operation of this technology (industry).

4) Build a better mutual understanding of the truck manufacturing product creation process in the context of FCET technology development (government and industry collaboratively).

5) When setting targets, stakeholders should assume a timeline of 7-15 years for developing new truck platforms with completely new propulsion and power train systems in their decision-making process (government and industry collaboratively).

6) Establish separate stakeholder groups (drayage and package delivery) to discuss and provide realistic market information about the baseline requirements for vehicle technology, operational cycles, supplier expectations, etc. (industry).

Cost Reduction

1) Support FCEB Centers of Excellence to prove infrastructure and fuel cost reduction, and develop expertise and understanding about hydrogen fueling for large fleets (federal and state government).

2) Establish targets and priorities for future MD and HD FCEV funding programs (federal government).

3) Initiate, expand, and direct national efforts to perform in-depth studies of fuel cell technology in trucks to understand the components of the total cost of ownership and opportunities for cost reduction (federal government).

4) Assess options for developing a ZEV credit or long-term incentive strategy for MD and HD ZEVs to encourage truck integrators and OEMs to invest in the RD&D of fuel cell technology in trucks (federal and state government).

Other recommendations

- Evaluate procurement financing and business models, risk tolerance, technology adoption, etc. for each application (industry).
- Develop a RASIC (Responsible, Approve, Support, Inform, and Consult) process to establish the roles of key resources for activities related to MD and HD FCET product feasibility and project assessments. This could help build a stakeholder map and identify the needs, roles, and responsibilities for each group (industry).
- Conduct research to better understand the balance between batteries and fuel cells (industry).
- Engage the investment community and translate the different scale and demand/supply models compared to the passenger vehicle and transit bus markets (industry).
- Evaluate drayage truck procurement financing and business models to facilitate the sharing of technology risk among end users (industry).
- Examine the option for OEMs to develop and offer electrified MD and HD truck chassis with warranty (e.g., in collaboration with component suppliers) (industry).
- Support efforts that lead to improved hydrogen fuel production and distribution processes for the purpose of fuel cost reduction (federal government).
- Initiate, expand, and direct national efforts to perform in-depth studies of fuel cell technology in trucks to understand the components of the total cost of ownership and opportunities for cost reduction (federal government).
- Consider transition stages that are sufficiently long to facilitate ROI for FCET technology when formulating regulations to promote the demand for MD and HD FCETs (state government).

3. Hydrogen Stations and Fueling Experience

Highest priority

1) Fund initial private or commercial hydrogen fueling infrastructure, with consideration of public funding for station O&M in early years (state government).

Other recommendations

- Document lessons learned from the implementation and operation of the natural gas experience for trucks and buses (federal government).
- Perform in-depth cost studies for hydrogen fueling infrastructure for MD and HD trucks (federal government).
- Explore potential to leverage federal resources, such as FAST ACT funding (see Appendix A), for hydrogen fueling infrastructure in California (all stakeholders).

- CaFCP to initiate a stakeholder discussion to assess the needs for a fueling interface, fuel pressure or storage alternatives, and fueling protocol for MD and HD FCETs to facilitate an optimal fueling and operational experience by truck operators (government and industry collaboratively).
- Assess the feasibility of using existing hydrogen stations for small FCET demonstrations (government and industry collaboratively).
- Explore high-capacity fueling infrastructure near port(s) or specific central locations within freight corridors to decrease the need to address different home bases of potential operators with private fueling stations that are less economical (government and industry collaboratively).
    - Explore hydrogen pipelines near San Pedro ports that can be tapped.

4. Meeting the Challenges Ahead

Highest priority

1) Develop the current SAE J2601/2 TIR "Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles" to the level of a full standard and generate data to resolve SAE J2601 not including 35 MPa fueling (6-10 kg) to address the current gaps in fueling protocol related codes and standards (government and industry collaboratively).

2) Consolidate funded truck projects and development of commercial HD fueling infrastructure, so stations have higher throughput, reducing the cost of fuel and capital expense of infrastructure (industry and government collaboratively).

Other recommendations

- Consider a minimum order of 5 to 10 HD FCETs or 10 to 20 MD FCETs in funding opportunities to achieve reduced cost per vehicle and provide fleet benefits such as more economical fueling on a per kg basis (government).
- Support FCET component development (government).
- Complete a codes and standards gap assessment study for MD and HD FCETs and fueling infrastructure to help inform strategic planning (federal government).
- Support development and adoption of most urgently needed codes and standards (government and industry collaboratively).
- Evaluate hydrogen storage technology needs for MD and HD applications separately (government and industry collaboratively).

5. Timing Considerations

1) Assess corporate operating structure options to create economic benefits for MD and HD FCET operators and initiate within the next 5 to 10 years (government and industry collaboratively).