CALIFORNIA HYDROGEN BUSINESS COUNCIL

Hydrogen Means Business in California!

2019

Hydrogen and Fuel Cells for Freight Workshop at ACT Expo

ACT EXPO

California Hydrogen Business Council

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Acknowledgements

The 2019 Hydrogen and Fuel Cells for Freight Workshop was planned and organized by members of the California Hydrogen Business Council's Heavy-Duty, Goods Movement and Clean Ports Sector Action Group. We particularly thank co-chairs Gus Block and Andreas Truckenbrodt, as well as CHBC Development Specialist Cory Shumaker. The workshop attracted over 180 people, the largest half-day event the CHBC has conducted, an indicator of the interest in this topic. The CHBC thanks the organizers of the ACT Expo for assisting the implementation of the workshop at ACT Expo.

The CHBC also thanks the following organizations for their sponsorships, without which this workshop would not have been possible.

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Executive Summary and Takeaways

The transportation sector accounts for 41 percent of the California's total greenhouse gas (GHG) emissions[1], representing a significant target for emissions reduction to address global climate change and improve local air quality. California has made significant progress in zero emission light duty vehicle deployment, but increasing pressure to develop and deploy medium and heavy duty vehicles will drive future decarbonization of the transportation sector. Hydrogen and fuel cells provide a promising technology option for the heavy duty sector, and, with longer range and fast refueling the technology is proving to be one-for-one replacement for the established diesel vehicles.

Industry giants like Toyota and Kenworth are testing ten second generation Class 8 fuel cell electric trucks, in the Port of Los Angeles (POLA) and Port of Long Beach (POLB) with Total Transportation Services (TTSI). Hyundai Motor Company is advancing its fuel cell technology across all transportation sectors, including light, medium, heavy duty, cargo handling, rail and vessels, with plans to produce 700,000 fuel cell systems by 2030. New upstart, Nikola Motor Company, has unveiled its Nikola Two (US model) and Nikola Tre (European model) and will commercially deploy by 2022.

In addition to the progress on zero emission heavy duty trucks, established players in the hydrogen and fuel cell industry are addressing off-road applications and medium duty vehicles. Plug Power has built a commercial market for fuel cell electric forklifts and partnered with FedEx to integrate a fuel cell powertrain into their delivery trucks.

Hydrogen producers Air Liquide and Hydrogenics have entered an agreement to scale up and deploy renewable hydrogen production facilities to support the emerging fuel cell transportation sector. These facilities will utilize Hydrogenics's module electrolyzers that can be combined to increase renewable hydrogen production. Hydrogen station developer Nel and Nikola have announced plans to build 700 stations by 2028 across North America to support the deployment of Nikola's Class 8 trucks, which has already exceeded 13,000 orders.

The California Fuel Cell Partnership (CaFCP) is developing a heavy duty sector road map and determining which actions are the highest priority to move the sector forward. Industry will need to decide whether 700 bar (10,000 psi) or 350 bar (5,000 psi) is the solution for heavy-duty. The CHBC is engaged in accessing cheap renewable electricity (down to $0.03kWh) to reduce the costs of renewable hydrogen production and fueling infrastructure.

With all of the progress in the zero emissions goods movement sector, industry and government must continue to work together to accelerate development and deployment of fuel cell transportation solutions. The California Hydrogen Business Council (CHBC) Hydrogen and Fuel Cells for Freight Workshop found that a comprehensive, multi-stakeholder state action plan for the medium and heavy duty sector is needed to enable that deployment. The action plan must include favorable policies to incentivize fleet operators to transition away from carbon intensive fuels to the zero emission technologies of the future. In conjunction with forward thinking policy and incentives, consistent codes and standards for the heavy duty sector must be adopted for mass deployment.

[1] https://ww3.arb.ca.gov/cc/inventory/data/data.htm

Keynote – The Societal Need for Hydrogen and Fuel Cells

Dr. Jack Brouwer, Director, National Fuel Cell Research Center at the University of California, Irvine

Hydrogen is the most abundant element in the universe. On Earth, it bonds most commonly with oxygen, producing water (H_2O), and carbon, producing methane (CH_4). Hydrogen can be produced by separating it from oxygen in water (electrolysis) and carbon in natural gas (steam methane reformation), then used as a versatile source of energy across many different sectors of the economy. To address global climate change, the hydrogen and fuel cell industry is starting to advance renewable hydrogen production[2].

However, the bulk of hydrogen production today still comes from non-renewable, carbon-emitting fossil fuels, due to its abundant use in oil refining, ammonia and fertilizer production. In order to displace fossil hydrogen for its traditional uses and to meet new demand, industry will need to scale-up renewable hydrogen production beyond the current use rate to address emissions contributing to global climate change and local air quality.

Hydrogen presents a promising grid-scale and seasonal renewable energy storage solution that can be dispatched quickly. While batteries can store energy to meet demand at the end of the day for several hours, they are not well suited for grid-scale storage. Furthermore, the world supply of lithium and cobalt is not sufficient to produce enough batteries to meet the total 20,000 TWh of renewable energy storage (see *Figure 1) that is projected to be needed[3].

Electrolytic hydrogen production and storage complements wind and solar power demand by load shifting between high and low electricity production days to balance the grid. Once produced, renewable hydrogen can be dispatched to the grid, or utilized in other sectors, like transportation and goods movement, providing a zero emission source of energy from well-to-wheels. Hydrogen and fuel cells are the only zero emission technology that can provide fast refueling and long range no matter the payload. Large distribution centers that operate 24/7 are an example of many applications that can transition to hydrogen fuel cells without compromise to current operations. Single distribution centers can have up to 300 forklifts operating continuously; all of those could be powered by zero emission fuel cells.

Table 1 - Storage Requirements - Nuria Tirado, M.S. Thesis, 2018; Brouwer April, 2019 Presentation

	Solar contribution	Wind contribution	Consumption and storage ratio	Consumption (TWh)	Storage (TWh)
Africa	0.70	0.30	8.39	9,123	1,088
America	0.45	0.55	7.83	38,541	4,919
Asia	0.50	0.50	7.95	80,866	10,178
Europe	0.30	0.70	7.50	26,951	3,592
Oceania	0.50	0.50	7.95	1,625	205
TOTAL				157,106	19,981

2 Renewable hydrogen can be produced from electrolysis using renewable or carbon free electricity and steam methane reformation of renewable natural gas or biogas.

3 Nuria Tirado, M.S. Thesis, 2018 – Brouwer April, 2019 Presentation

Keynote – The Need for Hydrogen and Fuel Cells - The Port Community Perspective

Jesse Marquez, Executive Director, Coalition for a Safe Environment

Hydrogen will play a significant role in California's future mix of renewable and zero carbon energy sources, helping accomplish the state's climate goals through deep decarbonization. California's thriving Environmental Justice (EJ) community emerged in the 1980s as an offshoot of the civil rights movement of the 1960s.

EJs in California focus on improving air quality within disadvantaged communities, which are historically low-income and predominantly communities of color subjected to disproportionate impacts from one or more environmental hazards, socio-economic burdens, or both. The EJs leverage their grassroots power to address these economic and environmental burdens by addressing air quality to improve health outcomes.

The Coalition for a Safe Environment (CSAFE) sued the Port of Los Angeles over the China Shipping Terminal for a lack of an environmental impacts study and won. CSAFE and other EJ organizations have provided input on the Ports of Los Angeles (POLA) and Long Beach (POLB) Clean Air Action Plan to address air quality.

With its influence on California's climate and air quality policies, EJs have become the de facto gatekeepers for public acceptance of alternative and zero emission technologies, especially in the transportation sector. The hydrogen and fuel cell industry should continue to engage with EJ groups and provide them with the information needed to influence outcomes that support clean hydrogen and fuel cell technology.

One for One: Technology Platform Comparison

Moderated by Alan Mace, Ballard Power Systems

Al Cioffi, Business Development Manager, Plug Power

Hydrogen and fuel cells for material handling presents a commercially viable, zero emission technology. Small changes in energy costs pay huge vehicle and labor dividends with better productivity versus battery forklifts, which require operator downtime for charging and electrical infrastructure.

Plug Power has fueled over 17 million forklifts with over 13 million kilograms of hydrogen sold; each Plug Power hydrogen fuel cell forklift stores 1 kg of hydrogen on board. The materials handling sector is inherently labor intensive, with 77 percent of operational costs coming from labor and 11 percent from equipment costs. The remaining 23 percent of operational costs are from maintenance and insurance (11 percent) and energy costs (one percent).

At scale, capital costs of hydrogen infrastructure are lower than outfitting a warehouse with fast chargers for forklifts (200-300 vehicles). In addition to the scaling advantage of using hydrogen, valuable warehouse space required for charging (and in the case of lead acid, dedicated battery handling personnel) is not needed. Throughout the course of a shift, the voltage will drop in a battery forklift, slowing the vehicle down, while a fuel cell forklift maintains constant voltage throughout the shift; therefore, the operator never experiences power reduction.

By using a fuel cell forklift the operator realizes a myriad of savings: 4-6 percent battery labor savings, 6-15 percent labor and asset productivity increase, 10-30 percent annual added enterprise value and a payback time of 0.4-3 years.

When comparing forklifts with an internal combustion engine, a battery and a fuel cell, the fuel cell is the only technology that checks all the boxes of fast refueling, high performance, productivity, space utilization, total cost of ownership and zero emissions.

It is also worth considering that hydrogen will never be as expensive as it is now, the costs for production and distribution will come down as the technology becomes more mature and adopted broadly.

Tak Yokoo, Senior Executive Engineer, Advanced Fuel Cell Group, Toyota USA

Since launching the Environmental Challenge 2050, Toyota has accelerated its advancement of zero environmental impact with zero emission vehicles. While battery vehicles are more suitable for short range, low energy requirement, Toyota has made significant investments in fuel cell technology to address sectors beyond light duty transportation.

Toyota launched its first Class 8 fuel cell electric truck (FCET) in 2017, which has since moved 10,000 miles of freight. The FCET has a range of over 200 miles in port drayage operations. In July 2018, Toyota launched its second version of the Class 8 FCET with 300+ miles range and a sleeper cab. The truck can operate in dock, local and regional port drayage operation. The fuel cell system is designed to provide primary power to the electric motor for the majority of the duty cycle. The small 12kWh onboard battery gives the required power boost on steep grades.

Toyota continues its drive to commercialization through funding from the Air Resources Board Low Carbon Transportation Investments and AQIP Funding Plans to help cover the initial cost of the FCET developments.

The cost to operate a FCET is significantly higher than a diesel internal combustion engine (ICE) equivalent due to the cost of fuel. Given the promise of cheaper renewable hydrogen in the future, the cost of operating a fuel cell truck is projected to be lower than a conventional diesel truck, as repair and maintenance costs are low for a FCET.

Affordable hydrogen production hinges on standardized high-volume production combined with low cost renewables. The fuel requirement for the 70,000 registered cars in the Los Angeles regional area is equivalent to only 1,750 Class 8 trucks. There are 17,000 Class 8 trucks registered to perform port drayage service in the Los Angeles region. This translates into significant hydrogen demand for a large FCET fleet.

OEM Perspective

Moderated by Nico Bouwkamp, Technical Program Manager – California Fuel Cell Partnership

California has established aggressive emissions reductions goals and is in the process of developing sector-targeted regulations to accomplish those goals. Within the next three years, the California Air Resources Board

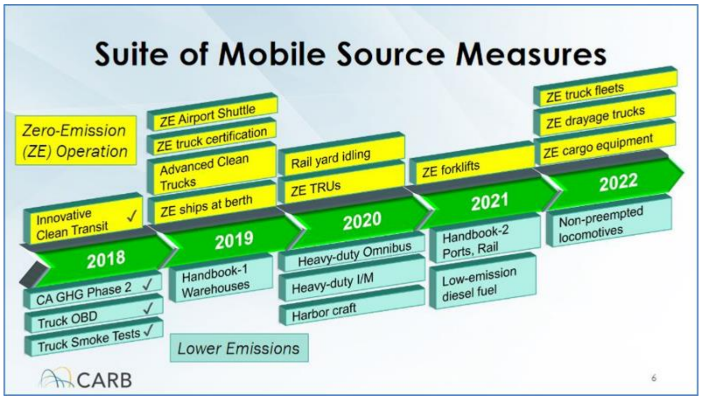

Figure 1 - [ARB Mobile Source Measures Timeline](#) – Bouwkamp April, 2019 Presentation

will implement mobile source measures on heavy duty Class 7 and 8 trucks, with the goal of accelerating deployment of zero emission truck fleets, drayage trucks, cargo equipment and ships-at-berth.

ARB is in the early stages of developing a new Advanced Clean Truck Regulation, requiring nine percent of Class 7 and 8 truck sales be zero emission by 2027, 11 percent in 2028, 13 percent in 2029, and 15 percent in 2030.

For the hydrogen and fuel cell industry specifically, the light duty vehicle sector and the heavy duty vehicle sector are symbiotic in their development and deployment. The light duty sector needs the heavy duty to drive the cost of hydrogen fuel down through high volume production. The heavy duty sector needs the light duty sector to drive down the costs of components like the fuel cells, as well as bring the technology to the forefront of public awareness.

Mark Freymueller, Vice President, Commercial Vehicle Eco--Friendly Business Development Team, Hyundai Motor Company

Japan and Korea are implementing aggressive plans to become hydrogen societies, starting with a ban of internal combustion engines within their respective borders. In light of this ban, Hyundai is advancing its fuel cell technology across all transportation sectors, including light, medium, heavy duty, cargo handling, rail and vessels. Hyundai plans to produce 700,000 fuel cell systems by 2030, including 500,000 FCEVs, and is manufacturing Class 2 through 8 trucks and buses. Their Class 8 truck, Xcient, has a 250-mile range, capable of hauling similar payloads to diesel trucks and refuels in 15 minutes.

The Xcient will be Hyundai's first FCET fleet deployment beginning this year in Switzerland with up to 1,600 trucks in operation by 2025. Hyundai is in the process of implementing a hydrogen infrastructure strategy with a variety of partners, starting small and "snowballing" to larger deployments.

Hyundai will develop different strategies to deploy their fuel cell equipment on a case-by-case basis centered around a jurisdiction's specific requirements. Every country has different customers, renewable energy portfolios and transportation costs.

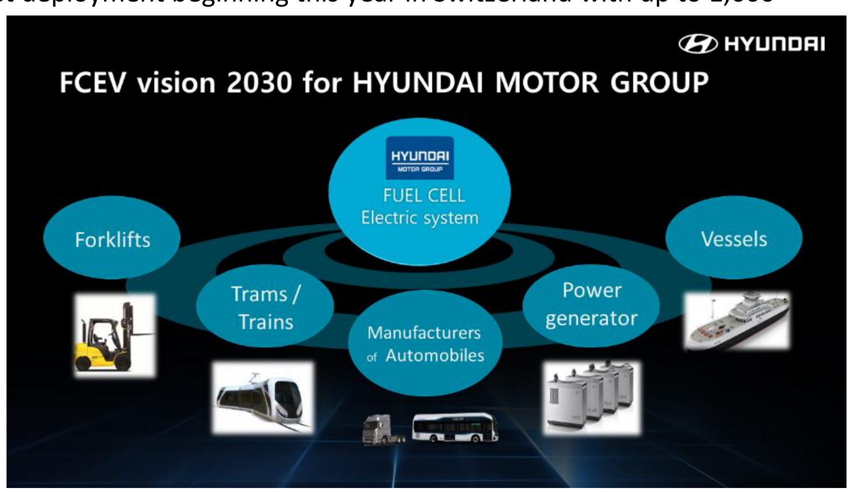

Figure 2 - [Hyundai Freymueller, April 2019](#)

Jesse Schneider, Executive Vice President, Nikola Motor Corporation

Nikola Motors is creating buzz in the zero emission heavy duty truck sector. The upstart Class 8 truck manufacturer has received 13,000 FCET orders, with 800 coming from Anheuser-Busch alone, which would replace their entire fleet. Nikola has partnered with Nel to develop a network of 700 hydrogen refueling stations by 2028, the first of which will be built in southern California and produce 8 tons of hydrogen per day.

Nikola has developed the Hydrogen Station Testing Apparatus to test and validate the network of hydrogen stations it plans to build over the next decade. The company will also partner with solar and wind developers to provide cheap, renewable electricity for onsite hydrogen production.

Reports from the Field: Operator Experiences

Moderated by Lisa Mirisola, Program Supervisor, South Coast Air Quality Management District

Tony Williamson, Director, Compliance & Sustainability, Total Transportation Services Incorporated

Total Transportation Services Inc. (TTSI) is testing a variety of FCETs in their operations, with plans to add seven more FCETs by the end of this year for a total of 10. TTSI is also testing battery electric trucks (BET) and CNG trucks.

The fleet operates 20 hours per day Monday-Thursday and eight hours per day Friday-Saturday. TTSI's drivers say that the FCETs provide a better operator experience, with reduced noise, vibration, and no diesel fumes.

Two mobile refuelers with 300 kg are fueling the FCETs from a facility near the Port of Long Beach. TTSI is exploring the installation of a hydrogen station in the inland empire to operate the trucks between the ports and interior South Coast basin. The BET can be charged to 20-90 percent capacity, but has an operation cycle of four hours. This is due to the tractor weight of 24,000 lbs., which is limiting the payload the truck can transport, even with the 2,000 lbs. weight exemption for zero emission trucks.

Once FCETs are commercially available, TTSI plans to deploy as many as they can into their fleet, with a total of 225 trucks in the fleet today. TTSI will be doing more miles running into the inland empire as they become more confident in the FCET's reliability.

Fast Refueling: Hydrogen Infrastructure

Moderated by Greg Kleen, Fuel Cell Technology Manager, U.S. DOE Fuel Cell Technologies Office

Rob Del Core, Managing Director, Hydrogenics USA Inc.

Hydrogenics and Air Liquide have partnered to build large scale renewable hydrogen production facilities. Air Liquide will utilize Hydrogenics' module electrolyzers that can be combined to scale-up hydrogen production; their 5 MW electrolyzer can produce 4,000 kg of hydrogen per day and supply the hydrogen required for 100 FCETs. The modularized electrolyzers can be scaled to 40 MW to produce 17,000 kg of hydrogen per day.

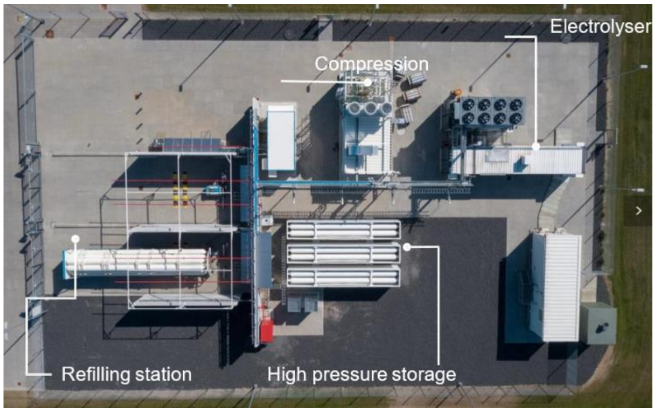

Figure 3 - Hydrogenics Station Footprint

Hydrogenics has built its HyBalance facility in Denmark, producing hydrogen for refueling stations and industrial customers. The facility uses 55 kWh of electricity to produce 1 kg of hydrogen; at $0.05/kWh the hydrogen cost is $2.75/kg, at $0.03/kWh the hydrogen cost drops to $1.65/kg. For large scale hydrogen production, 72 MWh of renewable electricity to a 3 MW electrolyzer can produce 1,350 kg of hydrogen, which is enough for 45 fuel cell buses.

The current barriers for hydrogen are not technologic, but commercial. Large scale hydrogen production is needed to support a fleet of hydrogen trucks, as is committed funding (public or private) to be able to provide a bundled fuel and fleet solution.

Dave Edwards, Director and Advocate for Hydrogen Energy, Air Liquide

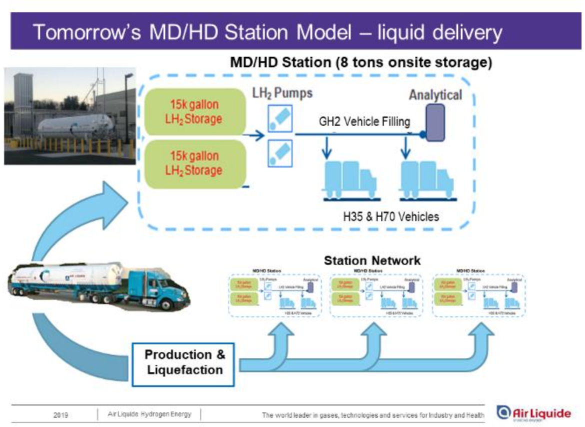

Figure 4 - Air Liquide Liquid H2Model

Hydrogen and fuel cell technology has proven its potential through demonstration projects; now is the time to scale up and enable mass deployment. The Hydrogen Council's 2050 Vision places trucks and mid-sized cars as high priorities for the hydrogen economy. Medium and heavy duty provide totally different vehicle and user expectations from quantity of fill and number of vehicles per day.

Air Liquide has a "hub-and-spoke model" for hydrogen production and distribution. Hydrogen production is followed by hydrogen liquefaction, and the liquid hydrogen is trucked to a distribution hub where the liquid hydrogen is vaporized into gaseous hydrogen at 450 bar and delivered to stations. The future of medium and heavy duty hydrogen fueling will require onsite liquid hydrogen to handle future throughput requirements. High throughput will also require high flow nozzles and standardization.

A liquid hydrogen delivery tanker can move up to 3.5 tons of hydrogen.

For hydrogen to be widely adopted, collaboration is key between vehicle OEMs, station designers, station owners, hydrogen suppliers, regulatory agencies, technology developers and government.

Steve Szymanski, Director of Business Development, Projects and Government, Nel

Nikola has an ambitious plan for FCETs and a network of fueling and service stations. Nikola's hydrogen stations will produce 8 tons per day from onsite electrolysis, which can be scaled-up to 32 tons per day.

Shell will use Nel electrolyzers to produce hydrogen onsite to test FCETs in the Los Angeles area. Nel, together with Air Liquide, Hyundai, Nikola Motor and Shell, have signed a Memorandum of Understanding (MOU) for hydrogen fueling components. The purpose of the MOU is to develop a standard for fueling heavy duty vehicles with high flow fueling hardware.

Lessons learned from hydrogen at bus depots can be applied to heavy duty trucks. 1,000 transit buses consume the same amount of hydrogen (25,000 kg/day) as 500 Class 8 FCETs or 40,000 light duty FCEVs.

Heavy duty vehicles are responsible for 47% of CO2 emissions from land based mobility and 8% of global CO2 emissions. Freight activity is expected to double by 2050; hydrogen is the most promising solution to reduce emissions across all transportation sectors.

Outcomes

Cory Shumaker facilitated a discussion at the end of the workshop to gain conclusions, identify issues and comments that would help shape the workshop results and future actions. These outcomes include:

- Next time, bring in government speakers to address policies.
- Are changes in CNG terminals necessary to work on hydrogen trucks? Brian answered that NFPA (National Fire Protection Association) has regulations and no changes are necessary unless major hydrogen system requirements are required.
- We need input from suppliers of the hydrogen infrastructure with gaps identified.
- CARB needs to help standardize the fueling system for heavy duty trucks.
- The California Fuel Cell Partnership is working on a heavy duty fact sheet and determining which actions are the highest priority to move the sector forward.
- Is 700 bar (10,000 psi) the best solution for stored hydrogen onboard? This is the pressure standard for light duty vehicles but the public transit industry is focused on 350 bar.
- An action plan is needed for MD/HD FCETs.
- Policy needs to be designed for MD and HD along with standards
- How do hydrogen producers access cheap renewable power down to $0.03 per kWh?
- This workshop was missing energy company and utility perspectives.