CHBC Hydrogen Fuel Cell Electric Bus Workshop

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Hosted at CalEPA

Acknowledgements

Planning Committee

This workshop was planned by the members of the Public Transport Sector Action Group within the CHBC, under its leadership by Lauren Skiver, General Manager of SunLine Transit, and Nicolas Pocard, Director of Marketing at Ballard Power Systems.

Workshop Sponsors

We thank the following organizations for their financial contribution, without which this workshop would not have been possible to develop and execute.

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This Workshop Report is a summary compiled by CHBC staff. Staff seeks to represent the discussions as complete and accurate as possible; however, staff cannot and does not take responsibility for a fully accurate representation of the discussions at the workshop.

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Welcome and Overview of the Workshop

Jeff Serfass, Executive Director, California Hydrogen Business Council

The Hydrogen Fuel Cell Electric Bus Workshop was the product of the California Hydrogen Business Council's Public Transport Sector Action Group, which was the result of a 2016 meeting between a dozen transit agencies at SunLine Transit Agency's headquarters in Thousand Palms, California. The 2016 meeting also saw the formation of the Zero Emission Bus Resource Alliance (ZEBRA). The purpose of this workshop was to inform government stakeholders of the progress of the bus market sector and to increase the adoption of Fuel Cell Electric Buses (FCEB). This workshop covered the status of the technology, discussed three market barriers to FCEBs, and ways to address these barriers. This report is one of the products resulting from this workshop designed to advance the sector.

Current Deployment Status, System Performance, Fueling Options

Nicolas Pocard, Director of Marketing, Ballard Power Systems; CHBC Co-Chair, Public Transportation SAG

The vision of the California Hydrogen Business Council is to see at least 100 FCEBs operating in California by 2025, with 20 FCEBs operated by five transit agencies each with required fueling infrastructure, and to increase the bus market sector's outreach efforts. At the time of this workshop, six U.S. transit agencies (three in California) operated 23 FCEBs (20 in California). The U.S. is also home to two FCEB manufacturers, ElDorado and New Flyer. A major advantage of FCEBs is that they offer the possibility for a 1:1 replacement of conventional combustion engine buses, without any compromise in operation at almost twice the fuel economy.

Zero Emission Bus technologies have seen increased momentum in the US, with most of the activity in California. The Los Angeles Metro Area plans to be 100 percent electric by 2030, with other transit agencies making similar commitments, but focused on Battery Electric Buses (BEBs). There are 300 BEBs in operation and ordered in the U.S., compared to 60 FCEBs in operation and ordered. FCEBs have a range of 200 plus miles and development of smaller buses has begun.

For worldwide adoption of FCEBs, buses need to be rolled out in larger clusters to gain production cost benefits and prove scalability of hydrogen infrastructure. Asia made strong commitments to FCEBs, with over 800 planned in Japan, South Korea, and China in the next years. China has 10 OEMs committed to FCEB development and had experience with large BEB fleet rollout, but are starting to see issues related to BEBs, e.g. battery degradation and limited operability. Despite the issues, China will see 500 ZEBs in operation by 2020.

FCEBs have met most of the Department of Energy's 2016 performance targets; AC Transit has FCEBs that have been in operation for 20,000 to over 25,000 hours. At scale, FCEBs are predicted to cost less than $900,000 per unit. The FCEB industry has performed to targets and the improvements have been significant, leading to industry maturation with more OEMs and suppliers allowing for a robust supply chain. Commercial solutions to deliver hydrogen to transit agencies as gaseous or liquid, as well as onsite production with storage and dispensing exist, but the cost of hydrogen is still high, at $8 to $14 per kg. The high cost was due mainly to high infrastructure CAPEX cost and the commercial model for transit agencies represented a challenge.

Further challenges remain for FCEB adoption, including awareness of the technology option, while total cost of ownership is high (but predicted to be lower), and hydrogen infrastructure is complex and expensive at small scale.

Transit Operators Share Experiences, Including Cost, and Fueling Challenges

Salvador Llamas, Director of Maintenance, AC Transit

Starting in 2006, AC Transit tested three Van Hool/UTC FCEBs for three years and conducted advanced demonstrations afterward. In 2010, AC Transit deployed 12 next generation Van Hool buses and collaborated with the NREL to analyze the data; US Hybrid and Clear Edge operated the buses. The biggest challenge for those FCEBs to overcome was how the fuel cell would interact with the bus's electric system and power management system.

The original warranty for FCEBs was for 4,000 hours of operation per bus; later it raised to 20,000 hours and AC Transit currently has reached the milestone of over 25,000 hours of operation. Transit operators needed to learn how to maintain an FCEB system and train mechanics how to do so. FCEBs are now equipped to receive firmware updates that change the way the bus operates. AC Transit plans to collaborate with other technology providers to continue FCEB performance improvements and have become better at predictive maintenance, specifically the internal assessment of the time that specific components tend to fail. AC Transit plans to purchase 10 new New Flyer FCEBs and 5 BEBs.

Bill Habibe, Manager, Transit Technical Services, Orange County Transit Authority

The Orange County Transit Authority (OCTA) operates 530 buses, with 14-year life expectancy or 700,000 miles (50,000 miles/year). Each bus operated up to 12,000 miles per year. The University of California Irvine has a hydrogen fueling station that can service a bus with 40kg of hydrogen fuel. In 2016, OCTA buses were available 91 percent and in 2017, the buses were available 98 percent. The main reasons for unavailability of the bus caused by the fuel cell were the fuel cell cooling system and electric drive issues. Only one bus did not perform similar to a conventional bus. OCTA plans to purchase 10 more FCEBs and a fueling station is under construction.

Tommy Edwards, Chief Operating Officer, SunLine Transit

SunLine Transit is a small agency that consists of nine municipalities, organized as a joint power authority, covering 11,000 square miles. In 1990, SunLine used rehabbed buses that did not perform well in extreme heat. In 1993, SunLine decided to transition to clean technology and replaced the entire fleet overnight to CNG. SunLine's board continued to advance clean tech in their fleet in 1996 by focusing on zero emission transportation.

SunLine's previous experience with high-pressure gases (CNG) helped with its early adoption of FCEBs. FCEB deployment began in 2000 and SunLine is set to have 19 buses by 2019/2020. SunLine has integrated FCEBs into their normal operations and have transitioned with the same drivers. SunLine partnered with CALSTART, CTE, CARB, AQMD, and the FTA on their FCEB project. SunLine will get a new refueling station.

During the Q&A it was discussed that FCEBs have a fuel efficiency of about 9 miles per kg, with a total range of 380 miles, a major challenge for BEBs to replicate. FCEB deployment between different agencies have produced different maintenance numbers for the same bus models. To learn from different experiences, agencies should:

- Share lessons from FCEB deployment
- Provide a 5-week training program followed by 5 weeks of work on FCEBS to apply their training
- Technician training should focus on fuel cells
- Establish an information exchange for hydrogen applications

There is a missing comparative discussion on the challenges of BEBs infrastructure. Agencies need to understand the challenges from BEB and FCEB infrastructure by relying on advisers, not manufacturers of the buses. Large scale adoption of BEBs will see considerable charging and electrical infrastructure challenges. AC Transit can support its FCEB fleet by two fueling stations, provided by Linde, and additional FCEBs can be added with no or very minor changes to those stations. The next transit agencies to take on hydrogen are Los Angeles Metro and the Central Valley.

Adoptions Barriers - Awareness: Improving Transit Agency Awareness about FCEBs

Jaimie Levin, Senior Program Manager and Director of West Coast Operations, Center for Transportation and the Environment (CTE)

There is always something new to learn about FCEBs. Transit agencies believe in FCEB's capabilities and now operate from Reno to Oakland; the technology has proven itself. However, 30% of the cost of operation is supported by revenue from the fare box and transit agencies received subsidies. AC Transit has 545 buses that must meet "pull out" requirements every morning; the transit agency have to be able to afford the total cost of ownership. Transit agencies are risk adverse since they need to meet bus schedules to keep customers satisfied. The biggest challenge for FCEB adoption by transit agencies is the large cost of a new fleet.

CARB is looking to adopt a 2040 target for all vehicles and fleets to be zero emission. Transit agencies are in opposition to the potential 2040 target due to the cost concerns. Policy makers are asking for electric vehicles and heavy-duty vehicles with all electric drive by 2030. Infrastructure is a challenge for BEBs and FCEBs. The challenge is overall total cost of ownership (TCO). Agencies will not buy technology if the TCO forces them to reduce service.

Lawrence Livermore National Laboratory is looking at cryo-compression to double fuel economy for hydrogen. This could lead to well over 300-mile range, way beyond the BEBs, reaching 500 or more miles. Weight is a huge problem with BEBs; FCEBs are now 5,000 lbs. lighter than they were 14 years ago. The power density is going up and fuel cells are being packaged lighter and smaller. FCEB advantages include range with a potential 500-mile range, weight, and recharge times match CNG and diesel.

The top challenges facing FCEB adoption by the transit agency are hydrogen infrastructure and the unit cost of each bus. The price of hydrogen fuel remains too expensive and not economically comparable to diesel or CNG. It will take a high volume of fuel to reduce costs. Redundancy will be critical as the fleet size grows and the footprint of the infrastructure needs to be reduced. Renewable fuel will be required to push greenhouse gas reductions. FCEBs will surpass all other available alternative technologies.

The discussions from the Q&A covered that the range and refueling time are the difference between FCEBs and BEBs and cryo-compressed hydrogen could help. The annual cost to operate and maintain FCEB fleets needs further development to allow real decision making because those factors have significant impacts on transit agency boards. To make FCEBs more affordable and build out of hydrogen infrastructure, there needs to be more competition to drive costs down.

Adoption Barriers - Value Proposition: Reducing FCEB TCO compared to BEB and CNG

Nicolas Pocard, Director of Marketing, Ballard Power Systems

The total cost of ownership (TCO) for transit agencies is divided into 50% for operation and maintenance, of which 30% is fuel cost and 20% is maintenance (today at $1/mile, $0.5 by 2020) and the remaining 50% for the cost of the bus. Today the cost for a FCEB is $1.2 million, expected to go down to $800,000 by 2020.

Today, FCEBs cost $7.27/mile, compared to $5.70/mile for BEBs and $4.80/mile for diesel. If costs are to be reduced, there must be efforts to reduce capex, fuel, and maintenance. A major driver to reduce bus cost is volume; by 2020 the cost for an order of 100 buses could go down to $800,000/bus. For fuel, the range is $7-12/kg, the higher cost range includes hydrogen delivery to retail stations; the lower range is for onsite steam methane reforming (SMR).

Remaining challenges for FCEBs center around:

- Need to increase availability/uptime consistently to higher than 90%
- Improve fuel cell module total life cycle cost by increasing component life time and reducing cost for parts
- Reduce fuel cell drivetrain cost which makes up 40% of bus at this time, goal is less than 10%, the fuel cell power module is projected to see a cost reduction from 2012 to 2020 of 70%
- Current focus is to increase operating temperatures to improve vehicle efficiency and improving life cycle cost of module
- Goals for 2020 are to push fuel cost down to $0.8/mile and to reduce maintenance cost to below $0.5/mile
- A challenge remains with ARB's data which underestimates the cost of electrical infrastructure for larger scale BEB adoption
- **Action for industry is to deliver the data and numbers to make FCEV a success on paper and in reality**

During the Q&A, it was discussed that with CNG buses, components make up about 20% of the cost; for FCEB that number is 60%. Volume will help considerably with cost reduction, especially from activities in China. FCEB projects should target numbers of 20+ vehicles to see real cost reductions. However, natural gas is the preferred fuel today; there is no way to be lower cost per mile, in part due to subsidies of Natural Gas. One attendee mentioned that CNG engines were very polluting engines from 2009-2016, similar to the VW case, and should be paying a penalty for misleading the public and regulators.

Infrastructure comparisons between FCEBs and BEBs are difficult, e.g. demand charges are not part of the cost estimates for BEBs as it is hard to get a good idea of what the true cost of the BEB electrical infrastructure looks like.

Leslie Eudy, Senior Project Leader, National Renewable Energy Laboratory

NREL is a third party evaluator of FCEB data and has identified 4 challenges before widespread adoption of FCEBs, including:

1. Steep learning curve for operators not familiar with gaseous fuels, requires training and monitoring;
2. Lack of a robust supply chain for components with multiple suppliers and standardized components;
3. Lack of parts list for maintenance inventory;
4. Lack of support centers.

The DOE developed targets for technology readiness and a report is schedule to be released. The cost for maintenance includes replacement parts and additional training. CNG and diesel are seeing linear increases over time for maintenance costs. With FCEBs, the training costs start high, decreases quickly but increase again once initial issues appear; once more experience is gained, the cost curve remains steady. FCEBs' fuel costs are very high, four to six times more than CNG, also due to lack of large-scale hydrogen production facilities. SunLine Transit has created a Center of Excellence for training but more experience and an inventory list of parts are needed.

Adoption Barriers - Hydrogen infrastructure: Partners and Project Readiness

Rob del Core, Director, Fuel Cell Power Systems Group, Hydrogenics USA

Hydrogenics is involved in several heavy-duty applications on rail, bus and truck, fueling stations and power-to-gas and has over 60 years of experience with electrolyzers. Hydrogenics has 11 of 13 FCEB fueling stations in Europe, with the technology being commercially available and deployed. To reduce cost there needs to be more volume; to reach that volume, 10 to 15 transit agencies must be represented. To improve the technology, experience must be gained by multiple transit agencies to build a pool of feedback. Agencies like the CEC, CARB, etc. make funding happen for initial projects but private capital is needed because it is faster to convert. The key challenge now is a need for guaranteed hydrogen offtake for fueling stations. Project partners include transit agencies, technology suppliers and private and government funders.

Steve Szymanski, Director of Business Development, Nel Hydrogen/Proton OnSite

Nel Hydrogen, a large electrolyzer production company, now owns Proton OnSite. The two companies manufacture 1kW to 2MW electrolyzers, and offer fueling station options for 35 MPa to 70 MPa, and have the capacity to produce 300 stations per year to support 200,000 FCEVs. Nel/Proton Onsite are the supplier for seven California Bay Area stations in 2018, with Shell and the CEC. They have also built a hydrogen station with pipelined hydrogen.

SunLine will have the world's largest electrolyzer. Transit operations create a steady demand for hydrogen at stations. Learning from CNG deployment will be important for hydrogen. "We can achieve diesel parity," with new business models.

Nitin Natesan, Business Development Manager, Linde North America

Linde has developed several bus fleet projects around the world. According to Linde's analysis, the environmental goals need to be utilizing existing financing for ZEBs for tank-to-wheel or well-to-wheel where possible. When making operational decisions, focus should be placed on the mileage/range requirements, number of buses needed, and a ramp up plan to include future fueling need and capacity of the fleet. The footprint and space of site determine the potential for onsite production. We need to know what is more important, CapEx or OpEx. The production form is dependent on needs, availability of gas in area, and environmental considerations.

Purpose built hydrogen production will be coming in the future and help bring price down. Hydrogen pipelines will cost $1 million - $2 million per mile. A robust supply chain can be optimized for the needs of the fleets. The NewBusFuel study offers a reference for different scenarios. The forklift fueling example at BMW shows how projects can be scaled up, 200 kg to 1,000 kg within a restraint footprint environment. Electricity rates in California is a challenge for electrolysis.

Information shared in the Q&A included question about the electricity requirement of the liquefaction process, which is 12 kWh/kg. The operator needs and to understand utility costs including negative pricing, low electricity rates for liquefaction would also benefit the cost of production for capacity of 250 tons/day. Maintenance costs for liquid hydrogen operations is similar to large scale SMR refinery. There won't be evaporative loses if there is a demand only, when the tank is sitting for days there will be boil-off losses.

Developing an Action Plan for FCEBs

Tommy Edwards, Chief Operating Officer, SunLine Transit, ZEBRA; Identify high-value targets for adoption

The Zero Emission Bus Resource Alliance (ZEBRA) formed to help with education and outreach efforts regarding FCEBs. It is a safe space for transit agencies, interested in becoming more tightknit and working together, to discuss FCEBs. ZEBRA is a self-funded, membership organization. The purpose of ZEBRA is to allow transit agencies to share experiences and coordinate the transition to ZEBs. ZEBRA consists of 22 transit agency CEO's, including some outside of California. ZEBRA received seed funding from the California Transit Agency, with CTE match funding. ZEBRA addresses education and outreach needs with peer-to-peer education

Leslie Goodbody, Air Resources Engineer, California Air Resources Board; Funding Sources for FCEB projects

The California Air Resources board released the AQIP funding plan before the start of the Fuel Cell Bus Workshop. Recent funding from CARB included 10 buses at OCTA, 10 buses at AC Transit with fueling upgrade, 5 buses and one fueling station at SunLine Transit. Funding for 2017-2018 will come from many sources:

1. Low Carbon Transportation (AB134) - $560 million
    a. $180 million Clean Truck and Bus Voucher (HVIP), plus $8 million from AQIP
        i. Buses from New Flyer and ElDorado are close to being included
        ii. The waitlist was at 135 buses
    b. $35 million for Zero Emission Bus purchases
    c. $300,000 Voucher and $315,000 in disadvantaged communities for FCEBs

    d. $100,000/bus for infrastructure for fleets of 5 buses or more
2. Carl Moyer Program offers $225 million
    a. Includes funding for transit and school buses to fund replacement of heavy-duty vehicles, cleaner than law currently requires.
    b. Funding for infrastructure is eligible up to 50%
3. VW mitigation for NOx reduction - $423 million
    a. CARB is the lead agency for the VW mitigation trust
    b. Public comments are accepted
    c. October 9 Workshop was planned to provide input on
        i. Principles for fund use
        ii. Potential mitigation
        iii. Process for administration
        iv. Benefits to disadvantaged communities
    d. There are many remaining needs, including transit, shuttle, school buses and the supporting infrastructure.

Oscar Pardinas, Regional Sales Manager, ElDorado National – California; Learning Lessons from BEB manufacturers - Soliciting FCEB projects directly with transit agencies

Transit agencies need to commit to a fleet when purchasing FCEBs, not just one bus. However, the awards for funding are too low to make this feasible. Agencies need to bring in universities to learn and apply knowledge for education and training. An APTA committee on FCEBs to help with education efforts is necessary; BEBs already self-promote. FCEBs are electric buses, if agencies look at TCO and the social goals for their community, it can be helpful to making a case for FCEBs.

Nico Bouwkamp, Technical Program Manager, California Fuel Cell Partnership; Fuel Cell Bus Roadmap and New Developments

To advance the transition to FCEBs, transit agencies will need more funding, champions, and a comprehensive plan. CaFCP developed a 2013 roadmap and its action plan looks at commercialization and the need to deploy thousands of units. The cost for 40 buses from a single supplier, necessary fueling infrastructure, and 12 years of operation, maintenance, training and education is about $50 million based on 2012 data.

Since then, the cost per bus has come down to $900,000 per bus at a 40 unit order, compared to the EU cost of $700,000. Japan and China will potentially lead the transition to FCEBs. The low costs in the EU are due to a more robust supply chain. SunLine Transit created the Center of Excellence as a workforce training program focused on maintaining and operating zero-emission buses in public fleets with public and private organizations, including transit agencies, colleges, private industry, and government agencies. AC Transit and OCTA are Center of Excellence collaborators.

The infrastructure for buses and trucks are very similar and the need to learn from synergies presents an opportunity. There are still many challenges to overcome:

1. Lack of cost information, we must make cost and data publically available and counter alternative BEB facts;

2. Decision makers have a knowledge gap, outreach and education must focus on insurance, lawyer education and staff training;
3. Need to address stakeholder current views on BEB range claims, charging infrastructure on a small scale, aversions to natural gas.

Focus should also be placed on technology readiness at the agencies and how much staff can address technology challenges. Transit agencies have the advantage of one fueling point.

Vision, Recap & Next Steps

Nicolas Pocard, Director of Marketing, Ballard Power Systems

FCEB technology is available and proven to operate like conventional buses. A major challenge moving forward will be bringing costs down. The industry has to offer a compelling TCO compared to other zero emission technologies at scale. There is now more funding available for FCEBs to bridge the gap to other low carbon transit options. We need to increase the volume of hydrogen production and add more agencies to the mix. There may be a good application in fuel cell school buses, using a fueling station that could serve other vehicles in the community. The North America Fuel Cell Conference will be in Canton Ohio on November 2-3 and discussions will continue.

Action Items from this workshop are:

- Develop approaches to increase awareness
- Develop new business model for H2 infrastructure
- Apply for available funding
- Create fuel cell group / committee in APTA
- Develop more champions in transit agencies
- Share experiences and case studies to educate others
- Highlight scalability of H2 infrastructure on footprint with BEB infrastructure
- Get some kind of a standard fire department public announcement and education
- Develop argument for where the battery bus makes sense and where the fuel cell bus makes sense. Identify the pros and cons of each

Develop guidelines to track the action items above.

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