

**Appendix J**  
**Zero Emission Bay Area (ZEBA)**  
**Fuel Cell Electric Bus Demonstration Program**

## I. INTRODUCTION

The CARB's 2000 Fleet Rule for Transit Agencies (Transit Fleet Rule)<sup>1</sup> has been the primary reason for demonstrations of Fuel Cell Electric Buses (FCEBs) in the state of California. This rule set more stringent emission standards for new urban bus engines and promoted advances in the cleanest technologies, specifically zero-emission buses (ZEBs). In 2006, CARB amended the transit rule and added a requirement for an advanced zero-emission bus demonstration for the larger California agencies.<sup>2</sup>

As a result, the five largest transit agencies in the San Francisco Bay Area formed the ZEBA demonstration group, including Alameda-Contra Costa Transit District (AC Transit), Golden Gate Transit (GGT), Santa Clara Valley Transportation Authority (VTA), San Mateo County Transit District (SamTrans), and the San Francisco Municipal Transportation Agency (SFMTA). AC Transit is leading the project by purchasing the buses; providing facilities to house, maintain, and fuel them; and serving as the primary operator. The other transit agencies in the ZEBA demonstration group will contribute funding, participate in training activities, and periodically operate buses as part of the demonstration.

The ZEBA demonstration group is supported through funding and planning by the Metropolitan Transportation Commission (MTC), the Bay Area Air Quality Management District (BAAQMD), CARB, the California Energy Commission (CEC), and the Federal Transit Administration (FTA) (including early funding under the National Fuel Cell Bus Program). AC Transit was awarded a grant in the final round of the National Fuel Cell Bus Program funding. Managed through one of the non-profit consortia—the Center for Transportation and the Environment—the \$1.8 million award provides funds to support the continued operation of the FCEB fleet. The main goal of the ZEBA program is to demonstrate the performance of FCEBs can fulfill or exceed the operating requirements and standards of baseline diesel buses.

AC Transit's demonstration began in 2010 with 12 FCEBs. A total of 16 buses of this configuration were built by Van Hool: 12 for AC Transit and 4 that were operated by Connecticut Transit in Hartford with funding through the National Fuel Cell Bus Program. At the end of the Connecticut demonstration in 2013, one of the buses was transferred to AC Transit. That bus was put into service in late 2015, bringing the ZEBA fleet to 13 buses.

The ZEBA partners are collaborating with the U.S. Department of Energy (DOE) and DOE's National Renewable Energy Laboratory (NREL) to evaluate the buses in revenue

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<sup>1</sup> Cal. Code Regs., tit. 13, § 1956.3(b).

<sup>2</sup> See California Air Resources Board (CARB), Executive Order No. R-05-007 (July 28, 2006).

service. NREL published six reports on this demonstration in August 2011,<sup>3</sup> July 2012,<sup>4</sup> May 2014,<sup>5</sup> July 2015,<sup>6</sup> June 2016,<sup>7</sup> and September 2017.<sup>8</sup>

## II. ACCOMPLISHMENTS

Since its debut in 2010, the ZEBA program has achieved several milestones demonstrating the reliability of the technology and transit agency’s accomplishment on workforce training and service assurance.

The U.S. Department of Energy (DOE) and the Federal Transit Administration (FTA) established performance metrics and life expectancy for FCEBs. The DOE/FTA targets are presented in **Error! Reference source not found.**<sup>9</sup>

**Table 1: DOE/FTA Performance, Cost, and Durability Targets for FCEBs**

	Units	2016 Target	Ultimate Target
Bus lifetime	years/mile	12/500,000	12/500,000
Power plant lifetime	hours	18,000	25,000
Bus availability	%	85	90
Fuel fills	per day	1 (<10 min)	1 (<10 min)
Bus cost	\$	1,000,000	600,000
Power plant cost	\$	450,000	200,000
Hydrogen storage cost	\$	75,000	50,000

<sup>3</sup> National Renewable Energy Laboratory (NREL) (2011). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report. August 2011. Available: <https://www.nrel.gov/docs/fy11osti/52015.pdf>.

<sup>4</sup> National Renewable Energy Laboratory (NREL) (2012). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Second Results Report. July 2012. Available: <https://www.nrel.gov/docs/fy12osti/55367.pdf>.

<sup>5</sup> National Renewable Energy Laboratory (NREL) (2014). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Third Report. May 2014. Available: [https://www.afdc.energy.gov/uploads/publication/zeba\\_fcb\\_rpt3.pdf](https://www.afdc.energy.gov/uploads/publication/zeba_fcb_rpt3.pdf).

<sup>6</sup> National Renewable Energy Laboratory (NREL) (2015). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fourth Report. July 2015. Available: <https://www.nrel.gov/docs/fy15osti/63719.pdf>.

<sup>7</sup> National Renewable Energy Laboratory (NREL) (2016). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report. June 2016. Available: [https://www.afdc.energy.gov/uploads/publication/zeba\\_fcb\\_rpt5.pdf](https://www.afdc.energy.gov/uploads/publication/zeba_fcb_rpt5.pdf).

<sup>8</sup> National Renewable Energy Laboratory (NREL) (2017). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Sixth Report. September 2017. Available: [https://www.afdc.energy.gov/uploads/publication/zeba\\_fcb\\_rpt6.pdf](https://www.afdc.energy.gov/uploads/publication/zeba_fcb_rpt6.pdf).

<sup>9</sup> U.S. Department of Energy (U.S. DOE) (2012). Fuel Cell Technologies Program Record # 12012. March 2, 2012. Available: [https://www.hydrogen.energy.gov/pdfs/12012\\_fuel\\_cell\\_bus\\_targets.pdf](https://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf).

	<b>Units</b>	<b>2016 Target</b>	<b>Ultimate Target</b>
Road call frequency (bus/fuel cell system)	miles between road calls	3,500/15,000	4,000/20,000
Operation time	hours per day/ days per week	20/7	20/7
Scheduled and unscheduled maintenance cost	\$/mile	0.75	0.4
Range	miles	300	300
Fuel economy	miles per diesel gallon equivalent	8	8

Traditionally, a public transit bus life expectancy is measured in terms of the number of miles on its diesel engine. A diesel engine’s life expectancy is 6 years or 250,000 miles before overhaul. The life expectancy of a fuel cell power plant is measured in terms of hours. The ultimate DOE/FTA targets for a power plant is 25,000 hours. In July 2017, AC Transit’s FCEB#7 recorded its 25,000-hour milestone, it demonstrated the potential for fuel cells to meet the equivalent life cycle expectancy similar to a diesel engine.<sup>10</sup> In May 2018, the availability of the FCEBs was 88 percent, which is approaching the ultimate DOE/FTA target of 90 percent.

As of May 2018, the AC Transit FCEB fleet has made the following accomplishments:

- Bus availability is 88 percent
- 4 fuel cell power plants (FCPPs) (FCEBs#7, #12, #14 and #16) exceeded the 25,000-hour milestone (Table 1)<sup>11</sup>
- One FCPP (FCEB #7) has achieved well beyond 28,300 hours without any major failure. This is a record number of hours documented to date on a fuel cell in a transit application
- All of the FCPPs have surpassed 20,000 hours of operation with the exception of one bus (FCEB#13), which joined the AC Transit fleet in 2016
- The FCEB fleet has accrued more than 2.4 million miles (2,486,155 miles) and 297,095 hours on the fuel cell power systems since being placed into service

In addition, through enormous amount of effort, AC Transit and its project partners have developed an in-house training program for the technicians and operators. As of May

<sup>10</sup> California Air Resources Board (CARB) (2017). AC Transit's Fuel Cell Program Breaks 25,000 Hour Operating Record. July 12, 2017. Available: <https://ww2.arb.ca.gov/news/ac-transits-fuel-cell-program-breaks-25000-hour-operating-record>.

<sup>11</sup> AC Transit (2018). Zero Emission Bay Area (ZEBA) Summary Report. May 2018.

2018, the training program has amounted more than 14,000 hours, including training in hydrogen fuel cell and lithium ion battery safety, hands on technical experience, FCPP, and drive system.<sup>12</sup>

### **III. SIGNIFICANCE TO CALIFORNIA CLEAN TRANSIT**

The ZEBA demonstration program has provided over eight years' experience in operating FCEBs. It makes significant contributions to revolution of California's clean transits:

- (1) Improvement of FCEB technology. The manufacturers can use the lessons learned from the demonstration at AC Transit to improve the system, and components, increasing efficiency, reliability, and durability.
- (2) Sharing of trouble shooting experience. As an advanced technology demonstration program, AC Transit has experienced challenges and issues with FCEB operations, such as transition of maintenance to transit staff, availability of bus components that have a long lead time for delivery, and maintenance of fuel cell issues. Experiences and skills of identifying and addressing these issues can be shared with other transit agencies which already have or plan to have ZEBs.
- (3) Engagement of workforce training for zero-emission technologies. AC Transit and its project partners organized a comprehensive training program to ensure that the appropriate staff gained familiarity with hydrogen as a fuel and received detailed maintenance and operations information for the fuel cell electric bus. The agency developed training courses and videos to educate the public, transit staff, and first responders about fuel cell electric bus technology.<sup>13</sup> These training programs will now be expanded to include the other transit agencies.

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<sup>12</sup> AC Transit (2018). Zero Emission Bay Area (ZEBA) Summary Report. May 2018.

<sup>13</sup> U.S. Department of Transportation Federal Transit Administration (FTA) (2010). National Fuel Cell Bus Program: Accelerated Testing Evaluation Report #2. June 2010. Available: [http://www.actransit.org/wp-content/uploads/NREL\\_rept\\_JUN2010.pdf](http://www.actransit.org/wp-content/uploads/NREL_rept_JUN2010.pdf).

## Reference List J

The following documents are the technical, theoretical, or empirical studies, reports, or similar documents relied upon in proposing these regulatory amendments, identified as required by Government Code, section 11346.2, subdivision (b)(3). Additionally, each appendix references the documents upon which it relies, as required by Government Code, section 11346.2, subdivision (b)(3).

Note: Each “Explanatory Footnote” is a footnote containing explanatory discussion rather than referencing specific documents relied upon.

1. Explanatory Footnote.
2. California Air Resources Board (CARB) (2006). Executive Order No. R-05-007 (July 28, 2006).
3. National Renewable Energy Laboratory (NREL) (2011). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report. August 2011. Available: <https://www.nrel.gov/docs/fy11osti/52015.pdf>.
4. National Renewable Energy Laboratory (NREL) (2012). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Second Results Report. July 2012. Available: <https://www.nrel.gov/docs/fy12osti/55367.pdf>.
5. National Renewable Energy Laboratory (NREL) (2014). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Third Report. May 2014. Available: [https://www.afdc.energy.gov/uploads/publication/zeba\\_fcb\\_rpt3.pdf](https://www.afdc.energy.gov/uploads/publication/zeba_fcb_rpt3.pdf).
6. National Renewable Energy Laboratory (NREL) (2015). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fourth Report. July 2015. Available: <https://www.nrel.gov/docs/fy15osti/63719.pdf>.
7. National Renewable Energy Laboratory (NREL) (2016). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report. June 2016. Available: [https://www.afdc.energy.gov/uploads/publication/zeba\\_fcb\\_rpt5.pdf](https://www.afdc.energy.gov/uploads/publication/zeba_fcb_rpt5.pdf).
8. National Renewable Energy Laboratory (NREL) (2017). Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Sixth Report. September 2017. Available: [https://www.afdc.energy.gov/uploads/publication/zeba\\_fcb\\_rpt6.pdf](https://www.afdc.energy.gov/uploads/publication/zeba_fcb_rpt6.pdf).
9. U.S. Department of Energy (U.S. DOE) (2012). Fuel Cell Technologies Program Record # 12012. March 2, 2012. Available: [https://www.hydrogen.energy.gov/pdfs/12012\\_fuel\\_cell\\_bus\\_targets.pdf](https://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf).

10. California Air Resources Board (CARB) (2017). AC Transit's Fuel Cell Program Breaks 25,000 Hour Operating Record. July 12, 2017. Available: <https://ww2.arb.ca.gov/news/ac-transits-fuel-cell-program-breaks-25000-hour-operating-record>.
11. AC Transit (2018). Zero Emission Bay Area (ZEBA) Summary Report. May 2018.
12. AC Transit (2018). Zero Emission Bay Area (ZEBA) Summary Report. May 2018.
13. U.S. Department of Transportation Federal Transit Administration (FTA) (2010). National Fuel Cell Bus Program: Accelerated Testing Evaluation Report #2. June 2010. Available: [http://www.actransit.org/wp-content/uploads/NREL\\_rept\\_JUN2010.pdf](http://www.actransit.org/wp-content/uploads/NREL_rept_JUN2010.pdf).