CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Battery Dominant Fuel Cell Hybrid Bus for the SunLine Transit Agency

Prepared for: California Energy Commission

Prepared by: CALSTART, Inc.

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued PON-13-604 to fund projects that will improve air quality, reduce petroleum consumption and decrease greenhouse gas emissions. In response to PON-13-604, CALSTART submitted an application which was proposed for funding in the CEC's Notice of Proposed Awards dated July 3, 2014 and the agreement ARV-14-025 was executed on January 9, 2015.

ABSTRACT

The California Energy Commission issued Program Opportunity Notice-13-604 to leverage Clean Transportation Program funds to bring federal cost-sharing projects to California that will improve air quality, reduce petroleum consumption and decrease greenhouse gas emissions. In response to the solicitation, CALSTART submitted an application based on a project that received a Federal Transit Administration grant to fabricate and operate a Battery Dominant Fuel Cell Hybrid Bus. The Integrated Product Team for this project consisted of BAE Systems, US Hybrid and ElDorado National-California, SunLine Transit Agency and CALSTART. The Integrated Product Team, led by BAE Systems, designed and fabricated the bus and SunLine Transit Agency put the bus in service. The intent of this project was to produce a zero-emission bus that was substantially lower in price yet provided performance equivalent to a standard 40 foot transit bus. The Integrated Product Team successfully achieved their goals and the bus is operating at SunLine Transit Agency in the Coachella Valley in California.

Keywords: Fuel Cell, Hybrid, Transit Bus, Range Extender

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EXECUTIVE SUMMARY

The Battery-Dominant Fuel Cell Hybrid Bus project addressed the cost reduction of zero emission transit bus technologies and met the performance requirements of the Federal Transit Administration National Fuel Cell Bus Program for Fuel Cell Electric Buses. This project reduced the size and cost of the fuel cell power plant in the bus by 70 percent leading to cost-effective fuel cell electric bus availability to California's transit bus fleets within 2 to 4 years.

The initial work included studies on the system design for the Battery-Dominant Fuel Cell Hybrid Bus. The design requirements were finalized at a Kick-off Meeting and Critical Project Review on March 25, 2016 after which material procurement was initiated by BAE Systems and ElDorado National – California. US Hybrid fabricated the fuel cell engine. In May 2017, BAE verified the fuel cell engine using hardware in-the-loop lab performance tests. After final acceptance tests, the fuel cell engine was shipped to ElDorado National – California for Vehicle System Integration, in June 2017.

At ElDorado National – California, the bus moved to Assembly Line 3 for installation of subsystems and the Vehicle Identification Number. Assembly Line 3 is used by ElDorado National – California to complete the bus build with the typical transit bus components. By August 2017, the team completed installation of the propulsion system in the bus. This included vehicle driving tests.

During September 2017, over 300 miles of drive testing was completed under a variety of drive cycles that included "stop and go", "highway" driving, and testing on grades. In early October 2017, acceptance testing was completed, followed by delivery to SunLine Transit Agency on October 18, 2017. SunLine Transit Agency completed installation of SunLine Transit Agency's unique equipment and the exterior "wrap" displaying the vehicle livery including logos of the team members in the project. In February 2018, the Battery-Dominant Fuel Cell Hybrid bus was unveiled at an event at the SunLine Transit Agency headquarters.

Various problems contributed to considerable vehicle down time over the next few months. The Integrated Product Team identified various issues that needed resolution – these included faults with the fuel cell system and with the battery energy storage system. US Hybrid diagnosed and solved a supplier process problem. BAE Systems decided to remove and replace the battery system with a newer more reliable and supportable battery system.

The bus was put in service on November 16, 2018 and ran well. The amount of hydrogen used in-service is consistently in the 8.5 miles per kilogram compared to the typical 5.4 miles per kilogram. Some days the vehicle achieved over 200 miles in-service. The bus met the system design requirements. Operations averaged 2,520 miles per month. The results validated the Battery-Dominant Fuel Cell Hybrid Bus configuration as lower in capital expenses and lower in operations expenses. The 80 kilowatt fuel cell pricing is at least 70 percent less than the original 150 kW American Fuel Cell Bus fuel cell.

The project findings and conclusions led to encouraging transit properties to consider Battery Dominant Fuel Cell Hybrid Bus designs and encouraging the battery-dominant fuel cell propulsion configuration for medium- and heavy-duty truck powertrains.

CHAPTER 1:
Project Purpose and Approach

The Battery-Dominant Fuel Cell Hybrid Bus (BD-FCHB) offers an attractive, effective method of achieving the CEC's objective of helping to attain the state's climate change goals. A major roadblock to large scale Fuel Cell Bus (FCB) use is cost. Cost reduction is necessary to support commercialization of the technology and its affordable commercial use. The project associated with this Agreement addresses that problem.

The goals of this project are to:

- Fabricate and demonstrate a BD-FCHB that meets or exceeds the performance requirements of the Federal Transit Administration (FTA) National Fuel Cell Bus Program (NFCBP),
- Significantly reduce the size and cost of the fuel cell power plant by 70 percent,
- Optimize fuel cell application for transit applications,
- Further develop the supply chain to support fuel cell transit bus growth,
- Spur commercialization of BD-FCHB technology,
- Help California achieve its climate change, air quality, and emissions reduction goals, and
- Move fuel cell technology on transit buses toward commercialization so they are a viable cost-effective option to California transit bus fleets within 2-4 years.

The approach by the Team of CALSTART, SunLine Transit Agency (SunLine), BAE Systems, US Hybrid, and ElDorado National – California (ENC) is to perform a set of tasks that result in fabrication and operation of the BD-FCHB. The project work is funded by the FTA and CEC funds. The tasks for this project include:

Task 1 - Administration

Task 2 - Project Kick-Off

Task 3 - Bus Design Updates

Task 4 - Procure/Fab/Build Battery Dominant Fuel Cell Hybrid Bus

Task 5 - Integration/Lab test of Power Train

Task 6 - Vehicle System Integration, Test, Delivery

Task 7 - Fleet Operations

Task 8 - FTA Final Report

CHAPTER 2:
Project Activities

The team, led by BAE Systems, including SunLine, US Hybrid, CALSTART, and ENC held an on-line meeting to review a final detailed schedule for fabrication and demonstration of the BD-FCHB plus technical details that needed resolution. This meeting, on March 8, 2016, served to prepare for the Critical Project Review (CPR) on March 25, 2016, at the bus manufacturing facility, ENC. Multiple representatives from the technical team attended as well as the Commission Agreement Manager (CAM). The CAM and CALSTART personnel discussed the project's administrative and technical aspects, i.e., system design, architecture, load, mechanical structure, engine / roof, cooling, weight, and design and development and test and validation.

During the CPR, a tour of the ENC bus manufacturing floor which included inspection of similar bus designs and a ride over the ENC test track was included. Following the CPR, the team continued engineering activities including working on the fuel cell and DC-DC Converter for future delivery to BAE Systems for laboratory integration. BAE Systems and ENC executed procurement of all vehicle related material.

In May 2017, the System Integration Lab (SIL) completed integration and performance tests including acceleration, vehicle power demand, battery current, gradeability, hillhold, skidding, creep torque testing, and braking. The US Hybrid FCE was then shipped from the BAE Systems SIL after completion of integration in a hardware in-the-loop lab set-up returning to US Hybrid for Final Acceptance test and was received for integration on May 30, 2017 as shown in Figure 1.

Figure 1: FCe80 Fuel Cell Engine on a Stand at US Hybrid Facility

Source: US Hybrid, Inc.

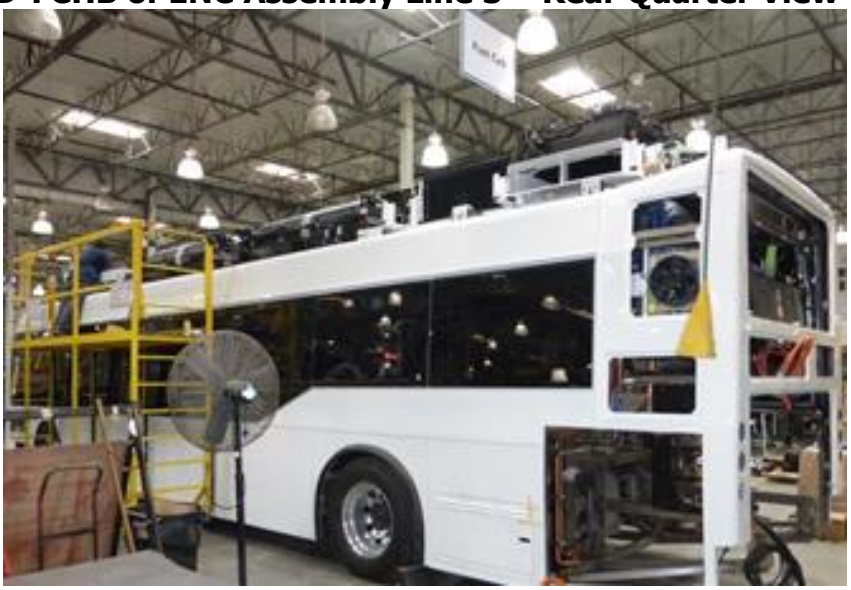
During that time-period, a meeting was held at ENC with the CEC staff who reviewed the ENC bus manufacturing operations and inspect the progress on the manufacture of the BD-FCHB. Also, in attendance for the visit were host ENC staff, two BAE Systems vehicle integration staff, and a CALSTART representative. As part of the visit, attendees rode on a bus (not the BD-FCHB) that was driven on the back lot at ENC where a partial course is laid out that represents a portion of the Altoona durability test track. Federally funded production transit vehicles must test a vehicle representing the production configuration at Altoona prior to procurement of more than 5 of the same configuration. Following that a review meeting was held with all attendees plus Tony Wayne, President of ENC.

In June 2017, work continued to near completion on the bus build-out. The team completed mounting of the fuel cell in the engine cradle and installation of the cradle into the bus. The roof covers were painted. The remaining steps in the BAE assembly line were completed including install of the low voltage (LV) wiring and LV power distribution unit, install of the ground straps and a few remaining high voltage cables. The bus then moved to the ENC's line 3 assembly later in June as shown in Figures 2 and 3. Figure 4 shows the vehicle identification number (VIN) that ENC applies as the Originator of the Vehicle. Assembly Line 3 is used by ENC to complete the bus build with the typical transit bus components.

Figure 2: BD-FCHB of ENC Assembly Line 3

Source: CALSTART, Inc.

Figure 3: BD-FCHB of ENC Assembly Line 3 – Rear Quarter View



Source: CALSTART, Inc.

Figure 4: BD-FCHB VIN

Source: ElDorado National-California

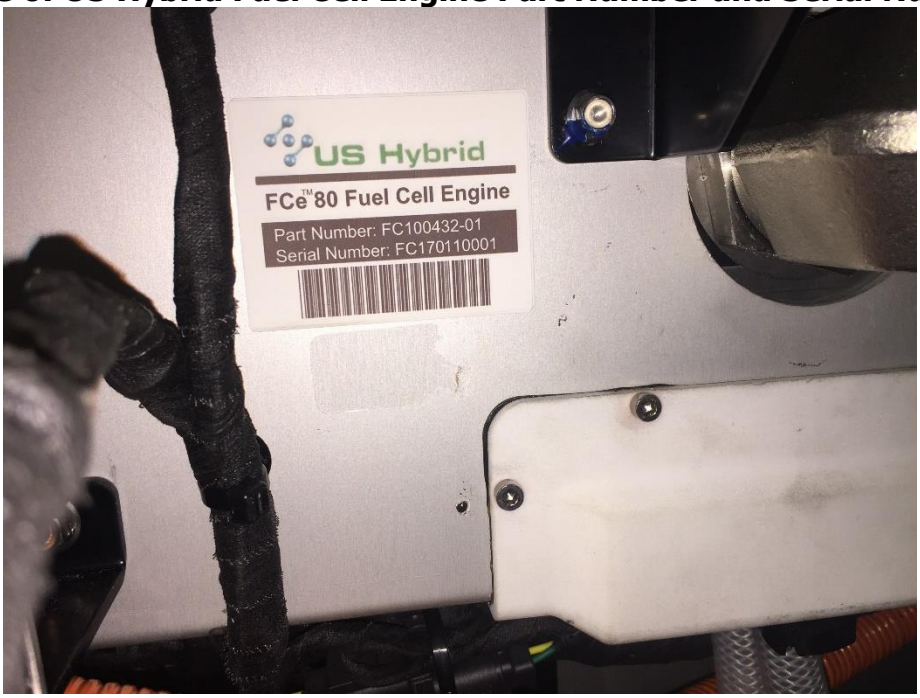
In July 2017, work continued to near completion on the bus build-out. The team completed mechanical integration of the bus. This included the mounting of the FCE cradle. However, while mechanical integration continued the FCE was removed and shipped to US Fuel Cell (a subsidiary of US Hybrid) for hardware upgrades as part of a continuous improvement effort to maintain field configuration of their fuel cell engines. BAE Systems started LV check-out on the bus after the July 4th holiday.

Figure 5 is a picture of the US Hybrid FCE in a shipping container. Figure 6 shows the FCE Part and Serial Number.

Figure 5: US Hybrid Fuel Cell Engine

Source: CALSTART, Inc.

Figure 6: US Hybrid Fuel Cell Engine Part Number and Serial Number



Source: US Hybrid, Inc.

By August 2017, the team completed vehicle integration of the bus. This included vehicle driving tests with the upgraded FCE which was reinstalled on the bus. Vehicle integration task was 95 percent complete including LV electrical integration testing and high voltage (HV) electrical integration testing.

In September 2017, work included vehicle driving tests with the upgraded FCE. Over 300 miles of drive testing was completed under a variety of drive cycles that included "stop and go", "highway" driving, and testing on grades. Testing also identified some areas that required replacement or upgrades. For example, the air compressor drive hardware on the FCE was replaced and ENC installed updates to bus Dynex Software based on results from bus testing.

SunLine's pre-acceptance of the BD-FCHB followed by final Acceptance testing in early October 2017. The bus was delivered to SunLine October 18, 2017. SunLine completed installation of SunLine unique equipment and the exterior "wrap" displaying the unique vehicle livery including logos of the team members in the project. Figure 7 shows the BD-FCHB at SunLine in the "wrap".

In December 2017, work continued to focus on Final Acceptance of the vehicle by SunLine. In early December, training on the vehicle was completed. There were updates provided by the IPT by the individual suppliers. For example, BAE Systems found a few lines and cables that needed better securing to prevent rubbing. Likewise, a water pump wire harness was chaffing at a point where it was in contact with the belly pan. Although not yet in revenue service, the bus was operated on SunLine routes on a daily basis. SunLine's experience with delivery of a new bus reveals that operations with the vehicle continues until a "Clean Point" occurs for data collection. This allows time for tuning the vehicle for smooth operation and removal of faults caused by minor out of spec occurrences.

Figure 7: Battery Dominant Fuel Cell Hybrid Bus at SunLine Transit Agency

Source: SunLine Transit Agency

In January 2018, Delivery and Final Acceptance documentation for the vehicle was forwarded to SunLine. In January, minor updates were provided to the IPT by the individual suppliers. Although not yet in revenue service, the bus was operated on SunLine routes on a daily basis. Prior to delivery, the bus had logged over 800 miles to demonstrate its performance characteristics. SunLine increased the daily hours of operation seeking to represent fully operational capability.

On February 2, 2018, the BD-FCHB was unveiled as FC7 at an event held at the SunLine Transit Agency headquarters in Thousand Palms. This new zero emission bus will have the capability to cover any route in SunLine's service territory – even with the air conditioner operating at maximum levels in the middle of the summer.

The unveiling event took place in front of the SunLine's headquarters building with speeches from a podium in front of the bus. After remarks by distinguished speakers, participants boarded the bus for a ride through SunLine's maintenance and fueling facilities followed by a ride on local streets to demonstrate the bus's performance as shown in Figure 8. In particular, the guests noted the quietness of the ride.

In February 2018, the bus for the most part did not perform in revenue service. Miles accrued were 348. BAE Systems continued to support data capturing. This includes the drivetrain interface between the fuel cell, batteries, and fuel delivery system. BAE Systems manually charged the ESS as required to facilitate successful performance during customer hosted engagements.

Figure 8: Tommy Edwards Presenting the Bus Attributes

Source: SunLine Transit Agency

Figure 9 shows a specification sheet for the bus.

Figure 9: Vehicle Specification Sheet

Source: SunLine Transit Agency

As noted previously Fleet Operations (Task 7) and data collection started in December 2017. Data for December 2017, January and February 2018 has been forwarded to the National Renewable Energy Laboratory (NREL). However, the bus was unavailable for fleet operations for most of the month of March.

As of February 26, 2018, the US Hybrid FCE was removed from the vehicle and shipped to US Hybrid fuel cell facilities for root cause analysis of lower than expected performance. It was returned on March 20th to the SunLine Facility.

After reinstallation of the FCE, the vehicle was taken out for a test drive on March 21. After approximately 1 hour on the road a battery module failed which later was confirmed to be caused by an overstressed battery fuse. On March 27, the battery module was confirmed to have failed and was replaced. After a subsequent 2-hour test drive the bus was declared ready for service. The next day on March 28, SunLine put the bus back into service on routes close to the agency headquarters. The FC7 had accumulated 2,180 miles.

Various problems contributed to considerable vehicle down time over the next few months. The IPT identified various issues that needed resolution – these included faults with the fuel cell system and with the battery ESS among other items. In May 2018, continuing issues with the XALT Xsyst7 batteries were deemed unacceptable to BAE Systems. BAE Systems decided to remove and replace the battery system with a newer more reliable and supportable battery system. This difficult decision involved a long, lead-time so the replacement plan was scheduled for the 3rd Quarter 2018. As a temporary measure a software workaround was uploaded by BAE Systems so the bus could be driven.

The bus continued to experience problems so in-service mileage was very low. In August 2018, the FCE experienced a field performance loss and was returned to US Hybrid. US Hybrid identified the root cause of the FCE performance issues as a failure of manifold coating causing corrosion and leakage of ions into the fuel cell poisoning the cell stack. The situation was diagnosed as a supplier process problem.

The team decision was to make hardware and software changes to accommodate the new battery pack and plan to install improved hardware sequentially – first the ESS then second the FCE – all in October 2018. The ESS was changed to the XALT XPAND XMP71P System. This involved disassembly of the Xsys7 and installation of the XMP71P ESS. Following integration of the XMP71P in the vehicle which included hardware and bracketry needed to accommodate the new battery system. The vehicle was test driven to assure it was performing as expected.

US Hybrid chose to revise the Cell Stack Assembly (CSA) design with non-metallic manifolds working with their supplier to assure the manifold coating process was accomplished as designed. Installation and integration of the FCE was accomplished at ENC following the ESS integration. This was followed by test drives to validate performance with BAE Systems. The vehicle was delivered to SunLine on November 16, 2018.

SunLine's staff inspected the bus after delivery to assure it was ready for service. It was filled with hydrogen and put in the service fleet operations on November 16, 2018. The bus has been running well and has continued in service for the remainder of November. No problems were experienced. US Hybrid confirmed that the data was adequate. About 300 to 400 miles

per week are now executed on routes in-service. The data show that the kilogram (kg) of hydrogen used in-service is consistently in the 8.5 miles per kg. Some days the vehicle achieved close to or over 200 miles in-service.

BAE systems is still working on derating factors to accurately control the FCE. SunLine needs to understand this to add to the training of the operators and dispatchers so that they understand the impact on operations when fuel cell status lights are illuminated. BAE Systems and US Hybrid will collaborate on adding this information to the operator and maintenance staff training materials.

CHAPTER 3:
Analysis of Fleet Service Data

The maximum capacity of the fuel system on the BD-FCHB is 50 kg. The diesel gallon equivalent (dge) mileage is 5.81 miles per dge or 8.5 miles per kg of hydrogen. This means 23.5 kg of hydrogen displaces 34.4 gallons of diesel fuel. The duty cycle of the BD-FCB ranges from a short route of 71 miles to the longest route at SunLine of more than 200 miles on a daily basis.

A single BD-FCHB operating at SunLine would typically average a little over 3,000 (3,094 in test trials) miles per month. That corresponds to 37,128 miles annually. Using Altoona test data for a 2010 model compressed natural gas (CNG) bus for Manhattan Cycle (MAN), Orange County Cycle (OCC) and Urban Dynamometer Driving Cycle (UDDC) criteria pollutant and greenhouse gas (GHG) emissions are summarized in Table 1 on a per mile basis and as the annual reductions per bus. The reductions are shown in grams (g) per mile and pounds (lbs) per year for each cycle and an average annual reduction in pounds.

Table 1: Annual Expected Air Emission Reductions per Bus

	NOx	PM	NMHC	CO	GHG
MAN g/mile	0.7	0.009	0.05	13.4	2,900
OCC g/mile	2.5	0.016	0.03	6.9	2,000
UDDC g/mile	2.25	0.002	0.02	4.7	1,500
MAN lbs/yr	57.30	0.74	4.09	1,096.83	237,374.36
OCC lbs/yr	204.63	1.31	2.46	564.79	163,706.46
UDDC lbs/yr	184.17	0.00	1.64	384.71	122,779.84
Average lb/yr	148.7	0.682	2.72	682.11	174,620.22

Source: CALSTART, Inc.

Specific jobs resulting from this project would include workers at CALSTART, SunLine (although not funded by CEC funds the funds make the project possible), US Hybrid, and ENC. Estimated part-time equivalent positions is estimated at, respectively, 5, 10, 18 and 62. Plus five to six times for indirect community jobs for short periods of time for 375 supporting jobs for a total of 470 positions impacted by these funds. If SunLine or other transit agencies procure additional BD-FCH buses more jobs will be created in the state in proportion to the quantity of buses ordered.

Currently, SunLine produces its hydrogen for fuel cell buses using renewable natural gas (RNG) as feedstock for on-site steam methane reforming (SMR). Grid power for the SMR and

compression is augmented by on-site solar array and by wind-turbine power. Since SunLine's fleet of fuel cell buses is growing, SunLine has contracted for an electrolyzer that should more than quadruple the daily hydrogen production. Electrolyzers are devices that use an electric current to split a water molecule into hydrogen and oxygen. Electrolyzers using renewable electricity from wind or solar will produce renewable hydrogen. A new solar array and perhaps wind turbine are planned at SunLine to make hydrogen production 33 percent renewable.

Any Energy Efficiency Measures Used in the Facility that May Exceed Title 24 Standards in Part 6 of the California Code Regulations

Title 24 Part 6 requires that all lighting systems and HVAC systems in non-residential buildings require switching or control capabilities to turn off when unoccupied. Since these funds are for the fabrication and operation of a transit bus, Title 24 Standards in Part 6 of the California Code Regulations do not apply.

The project is a zero carbon intensity and bus produces zero greenhouse gas emissions.

The BD-FCHB meets or exceeds all but one of the SunLine's requirements. From Table 2, the ambient temperature range for normal operation was expected to be 10 to 115 degrees Fahrenheit (F). The actual range is expected to be 32 to 115 degrees F. A waiver is necessary from SunLine.

Table 2: Performance and Requirements Matrix

Performance Requirements	Expected	Actual
Normal Operation w/Ambient Temp Between	10-115°F	32-115°F
Normal Operation w/Humidity Between	5-100%	5-100%
Curb Weight Below	35,900 lbs	32,920 lbs
Top Speed	50 mph	51 mph
Gradeability on a 2.5% Ascending Grade	40 mph	> 40 mph
Gradeability on a 10% Ascending Grade	15 mph	Not Avail.
Acceleration	Not Avail.	Not Avail.
Internal and External Noise Targets	Not Avail.	Not Avail.
Operating Range	200 miles	215 miles

Source: BAE Systems

GLOSSARY

CALIFORNIA ENERGY COMMISSION (CEC) – The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy.

CALSTART – A nonprofit organization working nationally and internationally with businesses and governments to develop clean, efficient transportation solutions. CALSTART is a network that connects companies and government agencies and helps them do their jobs better. CALSTART is located in Pasadena, California.[1]

COMPRESSED NATURAL GAS (CNG) – Natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

DC-DC CONVERTER – An electronic circuit or electromechanical device that converts a source of direct current from one voltage level to another.

DIESEL GALLON-EQUIVALENT (DGE) – The amount of alternative fuel it takes to equal the energy content of one liquid gallon of diesel gasoline.

FEDERAL TRANSIT ADMINISTRATION (FTA) – provides financial and technical assistance to local public transit systems, including buses, subways, light rail, commuter rail, trolleys and ferries. FTA also oversees safety measures and helps develop next-generation technology research.[2]

FUEL CELL – A device or an electrochemical engine with no moving parts that converts the chemical energy of a fuel, such as hydrogen, and an oxidant, such as oxygen, directly into electricity. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes, thus producing electricity.

FUEL CELL ELECTRIC VEHICLE (FCEV) – A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.

GREENHOUSE GAS – Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs). (EPA)

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1 CALSTART (https://calstart.org/)
2 About Federal Transit Administration (https://www.transit.dot.gov/about-fta)

HYDROGEN (H2) – A colorless, odorless, highly flammable gas, the chemical element of atomic number 1.

KILOGRAM (kg) – The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1,000 cubic centimeters of water at the temperature of its maximum density.

KILOWATT (kW) – One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon a typical home, with central air conditioning and other equipment in use, might have a demand of four kW each hour.

NATIONAL FUEL CELL BUS PROGRAM – a cooperative initiative between government and industry to advance the commercialization of fuel cell technology in U.S. transit buses.[3]

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) – The National Renewable Energy Laboratory (NREL), located in Golden, Colorado, is the United States' primary laboratory for renewable energy and energy efficiency research and development. NREL is the only Federal laboratory dedicated to the research, development, commercialization, and deployment of renewable energy and energy efficiency technologies.

RENEWABLE NATURAL GAS (RNG) – Or biomethane, is a pipeline-quality gas that is fully interchangeable with conventional gas and thus can be used in natural gas vehicles. RNG is essentially biogas (the gaseous product of the decomposition of organic matter) that has been processed to purity standards. Like conventional natural gas, RNG can be used as a transportation fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG).[4]

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[3] About National Fuel Cell Bus Program (https://www.transit.dot.gov/research-innovation/about-national-fuel-cell-bus-program)

[4] U.S. Department of Energy (https://afdc.energy.gov/fuels/natural_gas_renewable.html)