CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Hydrogen Station Equipment Performance Implementation and Station Testing

Contract 600-15-003

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Prepared by: California department of Food and Agriculture division of Measurement Standards

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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 ARFVTP, a project must be consistent with the Energy Commission's ARFVTP Investment Plan. The Energy Commission issued Contract Number 600-15-003 *Implementation Program for the Hydrogen Station Equipment Performance Device* with the California Department of Food and Agriculture Division of Measurement Standards to support the deployment of the Hydrogen Station Equipment Performance device to assess the performance of dispensers used in hydrogen refueling stations. This involves testing the safe and effective refueling of fuel cell electric vehicles (FCEVs), which requires conformance to the Society of Automotive Engineers International's J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles and related standards. The expanded use of alternative fuels such as hydrogen for zero-emission FCEVs will reduce the emissions of greenhouse gases and other criteria climate pollutants and the state's dependence on petroleum-based transportation fuels.

ABSTRACT

The continued adoption of hydrogen as a transportation fuel relies on consistent and reliable fueling of fuel cell electric vehicles. Consistent and reliable fueling is obtained through an important key aspect, which is compliance with standards such as the Society of Automotive Engineers International *J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles*. The Hydrogen Stations Equipment Performance device is a mobile test device used to test a refueling station and assure that hydrogen-fueling system performs in accordance with regulatory standards.

The overall goal of this Interagency Agreement is to help fund and to follow a standardized Implementation Program (referred to as the *California Hydrogen Station Equipment Performance (HyStEP) Implementation Program)* deploying the testing device to achieve consistent and accurate testing and to evaluate Society of Automotive Engineer standard J2601 compliance within hydrogen refueling stations, as they operate, in California.

Keywords: California Department of Food and Agriculture Division of Measurement Standards, fuel cell electric vehicles, hydrogen station equipment performance device, Society of Automotive Engineers International J2601

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EXECUTIVE SUMMARY

The Hydrogen Station Equipment Performance Implementation and Station Testing contract 600-15-003 with the California Department of Food and Agriculture began on October 2, 2015 and ended on October 1, 2017. The tasks began with transporting the Hydrogen Station Equipment Performance device from the National Renewable Energy Laboratory (NREL) in Golden Colorado to Los Angeles, California on December 14, 2015 for the initial testing and evaluation with the hydrogen refueling station located on the California State University, Los Angeles campus. California Air Resources Board staff analyzed the data and debriefed the technical teams at POWERTECH and the National Renewable Energy Laboratory at 5151 State University Drive, Los Angeles, California –the location of the initial testing of the station with public hydrogen refueling protocols.

In January 2016, the California Air Resources Board (CARB) team transported the Hydrogen Station Equipment Performance device to the South Coast Air Quality Management District hydrogen refueling station located at 21865 East Copley Drive in Diamond Bar, California and began the second test in a series of tests at various refueling facilities. The CARB team installed software in the Hydrogen Station Equipment Performance device between May 24 and May 27, 2016. In June 2016, the CARB team performed data analysis and data interpretation, and communicated with representatives of the technical staffs from automakers, Sandia National Laboratory, POWERTECH Labs Inc., and NREL about the compliance with public fueling protocols at the Diamond Bar hydrogen refueling station.

From December 2015 to August 2017, the CARB staff used the Hydrogen Station Equipment Performance device to test 11 hydrogen-refueling stations according to the American National Standards Institute/CSA Group Hydrogen Gas Vehicle 4.3 testing method, a method used to validate a hydrogen refueling station's compliance with the Society of Automotive Engineers J2601 fueling protocol standard. The tests were performed by simulating vehicle fills using each of the three test tanks located inside the Hydrogen Station Equipment Performance device. The continued use of the Hydrogen Station Equipment Performance device to validate hydrogen refueling station compliance with public standards continues beyond the publication of this Final Report.

CHAPTER 1:
Overview

The U.S. Department of Energy (DOE) funded the building of the HyStEP device which was built at POWERTECH Laboratories1, and underwent calibration and validation testing at the National Renewable Energy Laboratory (NREL) facility in Golden, Colorado. The California Air Resources Board (CARB) staff active in HyStEP use was trained in the application of the Society of Automotive Engineers (SAE) International *J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles* and the Canadian Standards Association (CSA) Group *Hydrogen Gas Vehicle 4.3 Fuel Dispensing for Hydrogen Gas Powered Vehicles*. In addition to the HyStEP application of fueling protocols and dispensing, the training at NREL included operations, maintenance, and safe transport of the HyStEP device.

The HyStEP device includes three Type IV 70 mega Pascal2 (MPa) hydrogen storage tanks equipped with temperature and pressure sensors. The device performs hydrogen fill simulations for small, medium, and large compressed storage tanks similar to those used in many light duty fuel cell electric vehicles (FCEVs).

HyStEP uses the test procedures set forth in CSA Hydrogen Gas Vehicles 4.3 to evaluate hydrogen refueling dispenser performance by connecting to dispensers installed in the field. HyStEP collects a variety of communication and refueling data that, when analyzed by experts, is used to evaluate and validate numerous refueling parameters to determine conformance with SAE International J2601. CARB presents the test conditions, data, and observations to automakers so they can evaluate hydrogen refueling station performance without having to perform the protocol tests with vehicles. HyStEP equipment is enclosed in a utility trailer platform and is towed by a vehicle operated by CARB engineers. Figure 1 shows the HyStEP side and rear views and device display panel. The device is the property of the U.S. Department of Energy and is on temporary loan to CARB.

Figure 1: Side and Rear Views and the Display of the HyStEP Device

Source: California Air Resources Board

[1] POWERTECH is a manufacturer with a product line ranging from surge protection to power management.
[2] A pascal (Pa) is the SI derived unit of pressure used to quantify internal pressure, stress, Young's modulus and ultimate tensile strength, or one newton per square meter. A mega Pascal is 1,000,000 Pa.

CHAPTER 2:
Station Evaluation and Testing

Under Contract 600- 15-003, the HyStEP device was used to evaluate and test the hydrogen refueling stations listed in Table 1.

Table 1: Hydrogen Stations Tested Using HyStEP under Contract 600-15-003

Dates (to/from)	Address of HyStEP Testing
12/14/2015 to 12/16/2015, 2/26/2016 to 2/26/2016, 5/24/2016 to 5/26/2016	5151 State University Dr., Los Angeles, CA 90032
1/19/2016 to 1/22/2016	21865 E. Copley Dr., Diamond Bar, CA 91765
3/14/2016 to 3/16/2016	150 S. La Cumbre Rd., Santa Barbara, CA 93105
5/19/2016 to 5/20/2016	20731 Lake Forest Dr., Lake Forest, CA 92630
6/14/2016 to 6/17/2018, 8/2/2016 to 8/4/2016	8095 Lincoln Ave., Riverside, CA 92504
8/16/2016 to 8/18/2016	5314 Topanga Canyon Rd., Woodland Hills, CA 91364
8/30/2016 to 9/1/2016, 11/1/2016 to 11/3/2016	3731 E. La Palma Ave., Anaheim, CA 92806
10/6/2016 to 10/6/2016, 11/14/2016 to 11/18/2016, 3/20/2017 to 3/24/2017, 8/17/2017 to 8/17/2017	17287 Skyline Blvd., Woodside, CA 94062
6/12/2017 to 6/15/2017	2451 Bishop Dr., San Ramon, CA 94583
6/27/2017 to 6/29/2017, 7/5/2017 to 7/6/2017	2051 W. 190th St., Torrance, CA 90501
7/24/2017 to 7/26/2017	41700 Grimmer Blvd., Fremont, CA 94538

Source: California Energy Commission Staff

The HyStEP was towed to California on December 14, 2015, for initial testing and evaluation using the hydrogen refueling station located on the California State University, Los Angeles (CSULA) campus at 5151 State University Drive. The initial test lasted three days, until December 17, 2015 after which the CARB staff analyzed the data generated by HyStEP and debriefed the NREL technical team about the data.

In January 2016, the CARB team transported the HyStEP device to the South Coast Air Quality Management District hydrogen-refueling station located at 21865 East Copley Drive in Diamond Bar, California. CARB tested the Diamond Bar station, HyStEP, and fuel cell electric vehicles (FCEVs) that were modified and equipped for testing station-fueling performance between January 18 and January 23, 2016. The station data and automaker fueling data were compared with the data generated by HyStEP.

During the Diamond Bar testing, a HyStEP fueling receptacle, which is a small part inside the device, malfunctioned. The HyStEP was transported to California State University in Los Angeles for installation of the replacement part. A complete systems integrity check was performed. HyStEP became operational after the repair by the end of February 2016.

HyStEP was then transported to Santa Barbara and deployed to perform additional automaker testing which included HyStEP comparisons at the hydrogen refueling station located at 150 South La Cumbre Road, in Santa Barbara, California from March 13 to March 18, 2016. Following the Santa Barbara station, HyStEP was deployed to the station located at 20731 Lake Forest Drive in Lake Forest, California from May 18 to May 21, 2016.

New software was installed in HyStEP between May 24 and May 27, 2016 and this activity repaired minor software bugs and improved the communication with hydrogen dispensers installed at stations during testing. Following the software installation, HyStEP was towed to CSULA for post installation system checks and additional testing of the CSULA hydrogen refueling station upgrade.

June 2016 was dedicated to data analysis, interpretation, and communication with technical staff from automakers, Sandia National Laboratory, POWERTECH Labs Inc., NREL, and the HyStEP team. Upon review of test data and the HyStEP performance results, the CARB HyStEP team conducted testing at three stations at 8095 Lincoln Avenue, Riverside; 5314 Topanga Canyon Road, Woodland Hills; and 3731 East La Palma Avenue, Anaheim, during August 2016.

In October 2016, the HyStEP tested a station at 17287 Skyline Boulevard, Woodside (San Mateo County). After reviewing the performance results at Anaheim and Woodside, the research team concluded that the stations did not meet the requirements of SAE International J2601. The data acquired from HyStEP testing allowed the developers to fine-tune their stations based on the results. After station modifications and improvements, the HyStEP retested the stations at Woodside and Anaheim in November 2016. After review of the test date, the team concluded that HyStEP would need to be redeployed at the Woodside station.

In March 2017, the research team redeployed HyStEP at the Woodside hydrogen refueling station to evaluate station modifications and improvements to address earlier performance issues. In August 2017, the HyStEP team returned to Woodside to conduct additional tests that were not completed in June 2017 due to technical issues.

The HyStEP team evaluated the hydrogen refueling station at 2451 Bishop Drive, San Ramon (Contra Costa County), in June 2017 with good results for the station. Likewise, the upgrades to the hydrogen refueling station at 2051 West 190th Street, Torrance (Los Angeles County), to a full retail station design were also tested in June 2017. In July 2017, the HyStEP team returned to Torrance to assess the second bank of dispensers at the Torrance hydrogen refueling station. In the same month, the team was deployed to the hydrogen refueling station

at 41700 Grimmer Boulevard, Fremont (Alameda County), to test the newly commissioned station.

Following the agreement term, HySTEP continues to be invaluable to the evaluation and testing of hydrogen refueling stations in California.

CHAPTER 3:
Test Data

The technical staff from the California Air Resources Board prepared the tabulated results of dispenser performance presented in this report. Through August 17, 2017, the hydrogen station equipment performance device and technical team was deployed to test 11 existing hydrogen refueling stations in California. Several stations were required to be retested because of technical issues. The following summary is being provided courtesy of CARB. Test note: The hydrogen station equipment performance device operators save matrix tests that contain useful data, illuminate technical/performance issues, or show station progress or a combination of these.

Station test data and results are considered confidential business information and are not included in this report.

A summary of station tests and dates is included in Table 2. The total "# of Test Days" required for each location varied from one day to about two weeks, due to additional work or adjustments required to pass all tests. General fault tests are intended to determine if the dispenser will react properly to exceeding the limits. Communication system and fueling protocol testing compares the field results against a table of data to evaluate if a dispenser can properly fuel a vehicle using the Society of Automotive Engineers International J2601 Table Based Fueling Protocol.[3]

[3] American National Standards Institute/ Canadian Standards Association Hydrogen Gas Vehicle 4.3-2016 (https://store.csagroup.org/ccrz__ProductDetails?viewState=DetailView&cartID=&sku=ANSI/CSA HGV 4.3-2016&isCSRFlow=true&portalUser=&store=&cclcl=en_US).

Table 2: Hydrogen Station Equipment Performance Device Testing Summary

Station Name	Address	Testing Dates		# of Test Days	# of the Hydrogen Station Equipment Performance Device Fills Recorded & Saved	General Fault Reported	General Fault Tests Recorded & Saved	Table Based Communi-cation Tests	Table Based Communi-cation Tests Recorded & Saved	Table Based Fueling Protocol, # of Graphs	Table Based Fueling Protocol Recorded & Saved	Total Tests Per Report
		Start	End									
CSULA	5151 State University Dr., Los Angeles, CA 90032	12/14/2015	12/16/2015	3	30	N/A	9	N/A	11	N/A	10	N/A
Diamond Bar	21865 E. Copley Dr., Diamond Bar, CA 91765	1/19/2016	1/22/2016	4	39	6	9	9	12	21	18	36
CSULA	5151 State University Dr., Los Angeles, CA 90032	2/26/2016	2/26/2016	1	6	N/A	0	N/A	6	N/A	0	N/A
Santa Barbara	150 S. La Cumbre Rd., Santa Barbara, CA 93105	3/14/2016	3/16/2016	3	31	8	6	11	8	16	17	35
Lake Forrest	20731 Lake Forest Dr., Lake Forest, CA 92630	5/19/2016	5/20/2016	2	23	N/A	9	N/A	6	N/A	8	N/A
CSULA	5151 State University Dr., Los Angeles, CA 90032	5/24/2016	5/26/2016	3	44	8	12	11	8	24	24	43
Riverside	8095 Lincoln Ave., Riverside, CA 92504	6/14/2016	6/17/2016	4	69	8	19	11	13	21	37	40
Riverside	8095 Lincoln Ave., Riverside, CA 92504	8/2/2016	8/4/2016	3	60	8	7	11	21	27	32	46
Woodland Hills	5314 Topanga Canyon Rd., Woodland Hills, CA 91364	8/16/2016	8/18/2016	3	46	8	6	11	16	25	24	44

Station Name	Address	Testing Dates		# of Test Days	# of the Hydrogen Station Equipment Performance Device Fills Recorded & Saved	General Fault Reported	General Fault Tests Recorded & Saved	Table Based Communi-cation Tests	Table Based Communi-cation Tests Recorded & Saved	Table Based Fueling Protocol, # of Graphs	Table Based Fueling Protocol Recorded & Saved	Total Tests Per Report
		Start	End									
Anaheim	3731 E. La Palma Ave., Anaheim, CA 92806	8/30/2016	9/1/2016	3	56	8	8	11	19	14	29	33
Woodside	17287 Skyline Blvd., Woodside, CA 94062	10/6/2016	10/6/2016	1	2	N/A	0	N/A	0	N/A	2	N/A
Anaheim	3731 E. La Palma Ave., Anaheim, CA 92806	11/1/2016	11/3/2016	3	28	8	5	11	7	18	16	37
Woodside	17287 Skyline Blvd., Woodside, CA 94062	11/14/2016	11/18/2016	5	58	8	12	11	18	28	28	47
Woodside	17287 Skyline Blvd., Woodside, CA 94062	3/20/2017	3/24/2017	5	38	1	3	1	6	14	29	16
San Ramon	2451 Bishop Dr., San Ramon, CA 94583	6/12/2017	6/15/2017	4	54	8	9	11	20	20	24	39
Torrance B	2051 W. 190th St., Torrance, CA 90501	6/27/2017	6/29/2017	3	56	8	9	11	22	20	25	39
Torrance A	2051 W. 190th St., Torrance, CA 90501	7/5/2017	7/6/2017	2	47	8	9	11	20	10	18	29
Fremont	41700 Grimmer Blvd., Fremont, CA 94538	7/24/2017	7/26/2017	3	47	8	9	11	22	18	18	37
Woodside	17287 Skyline Blvd., Woodside, CA 94062	8/17/2017	8/17/2017	1	8	0	0	1	1	5	7	6

Station Name	Address	Testing Dates		# of Test Days	# of the Hydrogen Station Equipment Performance Device Fills Recorded & Saved	General Fault Reported	General Fault Tests Recorded & Saved	Table Based Communi-cation Tests	Table Based Communi-cation Tests Recorded & Saved	Table Based Fueling Protocol, # of Graphs	Table Based Fueling Protocol Recorded & Saved	Total Tests Per Report
		Start	End									
Total				**59**	**742**	**103**	**141**	**143**	**236**	**281**	**366**	**527**

Source: California Air Resources Board

CHAPTER 4: Conclusions

Evaluations indicate that the HyStEP device test procedures and results are generally consistent with the station refueling protocol testing conducted by various auto manufacturers. The development of equipment and test procedures for evaluating hydrogen station performance in accordance with Society of Automotive Engineers International J2601 is ongoing with the test procedures in the Canadian Standards Association Hydrogen Gas Vehicle 4.3-2016. The HyStEP device deployment team continues to collaborate with U.S. DOE, Canadian Standards Association, original equipment manufacturers, and station developers to refine the test procedures and protocols necessary to fairly assess hydrogen station dispenser performance. Continued testing by the HyStEP device and comparison with manufacturer data will be needed to fully develop and validate a robust and reliable testing alternative to original equipment manufacturers for vehicles for the validation of station fueling protocol performance. Some of the benefits of using the HyStEP device follow.

The device:

1. Minimizes the need for auto manufacturers to send FCEVs to test each station, thus reducing the overall time required to validate the fill performance of a station.
2. Supports fine-tuning the performance of hydrogen refueling station equipment and supports increased understanding of the compression, storage, and dispensing technology.
3. Produces test results to support hydrogen refueling station certification, inspection, and standards development.

GLOSSARY

ALTERNATIVE AND RENEWABLE FUELS AND VEHICLE TECHNOLOGY PROGRAM (ARFVTP)—Now known as the Clean Transportation Program, created by Assembly Bill 118 (Nunez, Chapter 750, Statutes of 2007), with an annual budget of about $100 million. Supports projects that develop and improve alternative and renewable low-carbon fuels, improve alternative and renewable fuels for existing and developing engine technologies, and expand transit and transportation infrastructures. Also establishes workforce-training programs, conducts public education and promotion, and creates technology centers, among other tasks.

CALIFORNIA AIR RESOURCES BOARD (ARB)—The "clean air agency" in the government of California whose main goals include attaining and maintaining healthy air quality, protecting the public from exposure to toxic air contaminants, and providing innovative approaches for complying with air pollution rules and regulations.

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. The CEC's five major areas of responsibilities are:

- Forecasting future statewide energy needs.
- Licensing power plants sufficient to meet those needs.
- Promoting energy conservation and efficiency measures.
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels.
- Planning for and directing state response to energy emergencies.

Funding for the CEC's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account, and other sources.

CALIFORNIA STATE UNIVERSTIY, LOS ANGELES (CSULA) - Public university in the heart of Los Angeles and is dedicated to engagement, service, and the public good.[4]

CANADIAN STANDARDS ASSOCIATION (CSA) - Global organization dedicated to safety, social good and sustainability. We are a leader in Standards Development and in Testing, Inspection and Certification around the world including Canada, the U.S., Europe and Asia.[5]

HYDROGEN STATION EQUIPMENT PERFORMANCE (HyStEP) - The primary purpose of the HyStEP Device is to be used by a certification agency to measure the performance of hydrogen dispensers with respect to the required fueling protocol standard.[6]

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.

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[4] California State University, Los Angeles Webpage (http://www.calstatela.edu/).

[5] Canadian Standards Association (https://www.csagroup.org/)

[6] HyStEP Webpage and Information (https://h2tools.org/h2first/HyStEp)

HYDROGEN STATION EQUIPMENT PERFORMANCE (HyStEP) - HyStEP Device was developed to help reduce the time to commission a hydrogen station.

UNITED STATES DEPARTMENT OF ENERGY (U.S. DOE)—The federal department established by the Department of Energy Organization Act to consolidate the major federal energy functions into one cabinet-level department that would formulate a comprehensive, balanced national energy policy. DOE's main headquarters are in Washington, D.C.

NATIONAL RENEWABLE ENERGY LABORATORY (NREL)—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. Located in Golden, Colorado.

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)—A global association of more than 128,000 engineers and related technical experts in the aerospace, automotive, and commercial vehicle industries. The leader in connecting and educating mobility professionals to enable safe, clean, and accessible mobility solutions.[7]

[7] Society of Automotive Engineers (https://www.sae.org/about/)