CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Oakland Hydrogen Refueling Station

Prepared for: California Energy Commission

Prepared by: Alameda Contra Costa Transit District

AC TRANSIT

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation 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 executed contract 600-10-013 to expand Hydrogen Refueling Infrastructure. The contract was executed as 600-10-013 on February 28th, 2012.

ABSTRACT

This report describes the implementation and outcomes of a California Energy Commission grant to the Alameda-Contra Costa Transit District to help fund construction of a hydrogen fueling station at Alameda-Contra Costa Transit's Seminary Division 4 facility in Oakland. The hydrogen fueling station will distribute low-carbon, alternative fuel to be used by transit buses that serve the San Francisco Bay Area. The station is different from Alameda-Contra Costa Transit's existing hydrogen fueling station at its Emeryville facility in that the bus dispensers will be installed in-line with the diesel fueling island, there will be no public access light-duty fueling, and hydrogen will be available at 350 bar pressure only. Station construction is complete and operations began in December 2014. Overall, the project was a success as the station is currently running consistently at its full production capacity of 65 kilograms of hydrogen a day, which is a substantial portion of the 105 kilograms dispensed per day on average. This provides support to the current fleet of 13 fuel cell buses that are in daily operation.

Keywords: California Energy Commission, zero emission, bus, hydrogen, fuel cell, service, Oakland, fueling station, AC Transit, Van Hool, US Hybrid, UTC Power, ClearEdge Power, Siemens

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EXECUTIVE SUMMARY

This report describes the implementation and outcomes of a California Energy Commission grant to the Alameda-Contra Costa Transit District (AC Transit) to help fund construction of a hydrogen fueling station at Alameda-Contra Costa Transit's Seminary Division 4 facility in Oakland. The hydrogen fueling station will distribute low-carbon, alternative fuel to be used by transit buses that serve the San Francisco Bay Area. The station is different from AC Transit's existing hydrogen fueling station at its Emeryville facility in that the bus dispensers will be installed in-line with the diesel fueling island, there will be no public access light-duty fueling, and hydrogen will be available at 350 bar pressure only.

The station was designed and constructed to match the scope outlined in the grant agreement. Station construction is complete and operations began in December 2014. Alameda-Contra Costa Transit believes that the project substantially met the objectives of the agreement. The station is currently supporting the 13 fuel cell buses in daily operation with the capability to fuel more when Alameda-Contra Costa Transit expands its fuel cell bus fleet.

CHAPTER 1:
Project Background

This chapter discusses the background of the Alameda-Contra Costa Transit District (AC Transit) and the agency's current hydrogen fuel cell bus program and existing infrastructure.

Agency Information

AC Transit is one of the largest public transit operators in California, serving over 61 million passengers annually, with a fleet of more than 600 buses. AC Transit has been a strong advocate of fuel cell technology since 1999, successfully organizing a team of public and private partners to develop commercially viable, zero-emission solutions for heavy-duty transportation applications. This project has largely been motivated by community health improvements and quality-of-life benefits linked to zero tailpipe emissions and quiet electric-drive engines, and the global environmental benefits of utilizing sustainable sources of carbon-free renewable energy.

AC Transit's zero-emission fuel cell bus program was started by a mandate from the California Air Resources Board (CARB) in 2000. The first phase featured three first-generation fuel cell buses and two hydrogen stations. AC Transit installed an early generation electrolyzer at its Richmond Division 3 facility which operated from 2002 until 2008. A temporary onsite reformer with dispensing equipment was installed at the Seminary Division 4 facility in Oakland in partnership with Chevron which was in service from October 2005 until August 2010. The three first-generation fuel cell buses logged over 265,000 miles and carried more than 700,000 passengers from October 2005 until the last bus was retired in October 2010. Although those buses were 8,000 pounds heavier than a comparable diesel bus, they realized on average 60 percent better fuel economy.

AC Transit spearheaded the Zero Emission Bay Area (ZEBA) bus project in 2008 as a partnership with four transit partners in the region: Golden Gate Transit (GGT), San Mateo County Transit District (SamTrans), Santa Clara Valley Transportation Authority (VTA) and San Francisco Muni. This ongoing project includes deployment of 12 next-generation fuel cell buses owned and maintained by AC Transit with shared operations at GGT, VTA and Sam Trans. The objectives of this project are to evaluate the performance capabilities and operational readiness of a large fleet of fuel cell buses. The AC Transit fuel cell bus program is a whole hydrogen solution including, in addition to the 12-bus deployment, construction of two hydrogen stations capable of fueling the buses and passenger vehicles, upgrades to a fuel cell bus maintenance bay, installation of a 400 kW stationary fuel cell system and a 700kW solar system for power generation.

Current Hydrogen Fuel Cell Bus Fleet

The 12 next-generation fuel cell buses operate throughout the AC Transit service area. The buses have a fuel cell dominant hybrid-electric propulsion system in a series configuration. These second-generation fuel cell buses each weigh 5,000 pounds less than the first-generation buses and utilize more advanced systems. The bus manufacturer—Van Hool— fully integrated the hybrid design using a Siemens ELFA 2 hybrid system with two 85 kW AC

traction motors; US Hybrid[1] 120 kW PureMotion fuel cell power system; and an advanced lithium-based energy storage system by EnerDel. The first of the 12 buses entered service in August 2010 with all 12 in service by November 2011. Figure 1 shows one of the fuel cell buses. AC Transit constructed its first permanent fueling station at its Emeryville Division 2 facility and began fueling all the buses there in August of 2011.

Overall the fleet of fuel cell buses has performed better than initial expectations and continues to do so. As of the end of July 2016, the fuel cell buses have amassed over 1,600,000 miles and 195,000 hours on the fuel cell power systems, with an average speed of 8.5 mph, and have used over 250,000 kg of hydrogen. Availability for the buses is comparable to diesel buses running similar routes. The three oldest fuel cell power plants continue to accumulate significant hours of service without fuel cell stack maintenance or significant power degradation. One of the power plants has surpassed 20,000 hours of service, more than double 10,000-hour warranty, and all the power plants have surpassed their initial expected life of 5,000-10,000 hours.

AC Transit and its transit agency and manufacturer partners continue to run a full-service schedule for the buses and have expanded training of staff and operators. The buses operate on at least 10 different AC Transit routes regularly including one busy route with a 2.5-mile-long 5 percent grade. The buses continue to receive favorable comments from both drivers and passengers and have carried over 4 million passengers in revenue service.

Figure 1: 2010 Van Hool A300L Hydrogen Fuel Cell Bus

Source: AC Transit

1 The original fuel cell manufacturer was UTC Power, a subsidiary of UTC Industries. In December 2012, ClearEdge Power purchased UTC Power from UTC Industries. In August 2013, US Hybrid took over the mobile fuel cell contracts and technology from ClearEdge Power.

Emeryville Refueling Station

AC Transit's Emeryville Division 2 hydrogen station, constructed by WL Butler with storage and dispensing equipment from Linde LLC and an electrolyzer from Proton, was completed in July 2011 and fully commissioned by the end of August 2011. This station, shown in Figure 2, is a combined facility for buses and light-duty fuel cell electric vehicles. Funding from the state of California made the light-duty fuel cell vehicle fueling access possible.

Overall, this station has the rapid fueling capacity for 12 buses consecutively with more than 30 kilograms of hydrogen each, and 20 or more light-duty vehicles per day. The station includes a Proton C30 65 kilogram/day electrolyzer that produces renewable hydrogen using solar power offsets from more than 700 kW of solar installed at AC Transit's facilities. The station also features the latest advancement in compression and dispensing technology, enabling refueling of buses at rates up to 5 kilograms/minute—a time comparable to refueling diesel buses. Light-duty vehicles with three to seven kilograms of storage can refuel within three to four minutes.

Hydrogen from the electrolyzer is supplemented with commercially supplied liquid hydrogen delivered by truck to the holding tanks. More than 182,000 kg of fuel have been dispensed from this station through September 2015. The electrolyzer can produce at most 65kg of hydrogen in a 24-hour period, and any amount above that will come from the commercial supply. If there are four buses per day running out of Emeryville, and each bus can receive at most 40kg per fueling, then at most 41 percent of the hydrogen will have been produced on-site by the electrolyzer.

Figure 2: Emeryville Facility

Source: AC Transit

Oakland Seminary Refueling Station

Initial Planning

Once AC Transit determined it was going to advance to a larger fleet of fuel cell buses, a study was done to consider the possible scenarios to allow AC Transit to continue operating the hydrogen fueling systems at Seminary. Alternatives considered included modifying the existing temporary Chevron facilities and building all new facilities in another location on the existing property.

The study recommended building new facilities that included a hydrogen generating and compression area south of the existing bus wash, a canopy extension and two new fueling dispensers on the end of the existing fueling islands. The existing block facility housing the equipment would be used for current and supplemental hydrogen storage. This alternative creates a new station that will be representative of future transit fueling systems that dispense multiple fuels using the same staff and facilities. It allows hydrogen fueling to become 'conventional' in the sense that it will be just another fuel in the overall transit strategy and allows growth for the hydrogen fueling component which reduces overall emissions significantly.

Another consideration for the Seminary Station was the partnerships with other Zero Emission Bay Area agencies. The existing Emeryville facility was most conveniently located for GGT to run a bus in service. The Seminary facility is more conveniently located to the peninsula and the southern San Francisco Bay area to allow VTA and SamTrans to operate buses in service.

The CEC Grant Agreement

The goal of the Agreement is to build a hydrogen fueling station at AC Transit's Seminary Division 4 facility in Oakland that will distribute low-carbon, alternative fuel to be used by transit buses that serve the San Francisco Bay Area. The primary differences between the new Seminary Station and the existing Emeryville Station are:

- Bus dispensers will be installed in-line with the diesel fueling island
- No public access light-duty fueling
- Hydrogen will be available at 350 bar pressure only
- The on-site electrolyzer will be powered by a solid oxide fuel cell fueled with directed biogas

Objectives of the Project

The objectives of this project are to:

1. Build a state-of-the-art hydrogen bus fueling station with a capacity of 360 Kg hydrogen per day and a green-powered, locally distributed power system for transit fleet applications, and demonstrate their suitability to the transit industry in support of fuel cell bus operations.
2. Displace an estimated 175,000 gallons of diesel annually.

AC Transit is currently on track to meet all the objectives stated above. The current fleet of 13 fuel cell buses traveled a total of 461,229 miles in FY2017, which displaced approximately 107,780 gallons of diesel (using National Renewable Energy Laboratory estimate of 4.28 miles per gallon of diesel). With ten additional fuel cell buses arriving in 2018 that will also use the station, the total gallons of diesel displaced will average over 190,000 gallons of diesel annually.

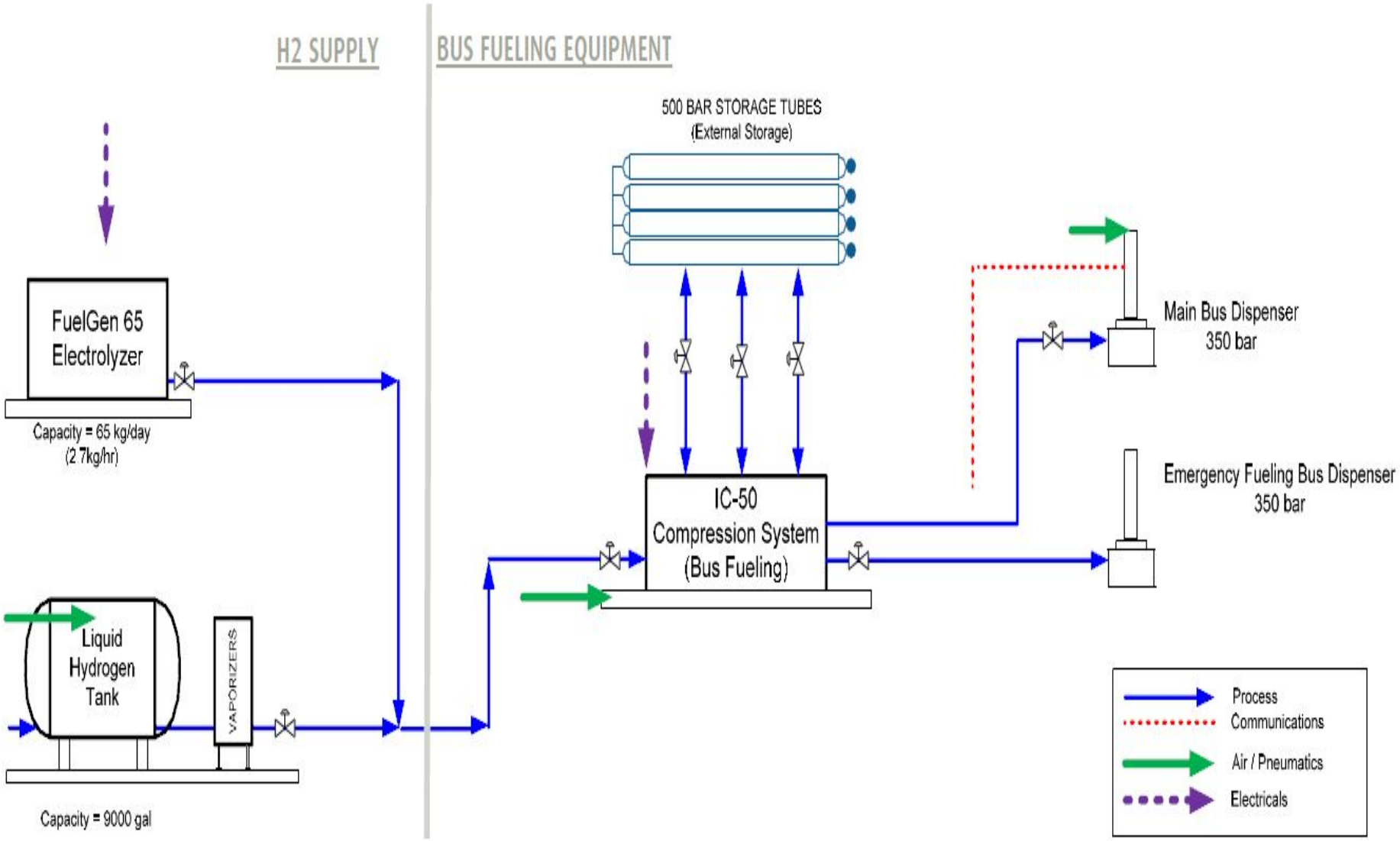
The full budget for the station is $16,323,159, which includes the installation of the stationary fuel cell power system. Funding has been provided by the CEC, CARB, FTA, Zero Emission Bus program partner agencies (VTA, SamTrans, GGT), PG&E (through an SGIP rebate), and AC Transit.

Station Operations

While the operating division will initially support three fuel cell buses, the station has been designed to refuel up to 12 buses, and as many as 24 buses in a 24-hour period to accommodate future growth. This will provide AC Transit with the flexibility to move buses between divisions and to expand its fleet with the least impact on its fueling infrastructure. The station is now completed and operating, and is the single largest hydrogen fueling station for transit buses in the United States.

The station equipment includes an IC50 compressor and fuel dispensers manufactured by Linde LLC. The IC50 is an ionic compressor that uses a special ionic liquid instead of a metal piston to compress the hydrogen. As shown in Figure 3, the compressor feeds gas at 500 bar into high pressure storage tubes with 360 kg of capacity. These are used to feed the two dispensers installed at the fueling island which fuel the buses at 350 bar. The hydrogen for the station will come from two sources. The station installed an on-site electrolyzer in 2016 that can produce up to 65 kg of hydrogen per day, and the remainder is from liquid hydrogen that is delivered to the site by Linde and kept in a large low-pressure storage tank. Construction of the electrolyzer was made possible by funds from the American Recovery and Reinvestment Act Transit Investments for Greenhouse Gas and Energy Reduction grant program, and a regional consortium of transit agencies including San Mateo County Transit District and Santa Clara Valley Transportation Authority.

Figure 3: Station Block Diagram



Source: AC Transit

The fueling station along with the entire maintenance facility is powered by a 420 kW Bloom Energy stationary fuel cell system, which was completed in March 2013. Directed biogas – collected from landfills – feeds the fuel cell, which in turn supplies clean electricity to the entire facility. Electricity from the stationary fuel cell will also power an electrolyzer to produce carbon-neutral hydrogen. The electrolyzer is now installed as a follow-on to the fueling station and has begun regular operations as of January 2017.

The current fleet of Van Hool fuel cell buses have 40 kg of hydrogen storage on-board, so fully fueling all twelve buses would be at most 480 kg per day. The 360 kg of high-pressure storage at Seminary can fully fuel just over 8 buses but in practice can fuel the full 12 bus fleet fleet given that buses will generally not be empty when they are refueled. Also, assuming that hydrogen fuelings will not happen all at once but will be staggered over time as the buses return from service, the compressor will continuously work to recharge the high-pressure storage and the station can in practice fuel upwards of 20-24 buses per day. Even higher numbers of buses can be refueled with a better compressor or more high-pressure storage, or both, although at a certain point the fuel supply storage/delivery must be upgraded also.

CHAPTER 2:
Seminary Station Construction

This chapter discusses the details of the project covered by the agreement – the Oakland Seminary hydrogen fuel cell bus refueling station.

Station Construction

Engineering Design

On May 8, 2013, AC Transit awarded a contract to Engineering, Procurement, and Construction, Inc. of Lakewood, Colorado, for engineering design and construction management services for the project. Engineering, Procurement, and Construction, Inc. completed engineering design of the station on September 27, 2013. Figure 4 shows the exit of the diesel fueling island before construction.

Figure 4: Fueling Island Before Construction

Source: AC Transit

Equipment

Linde LLC was awarded a contract in July 2009 through a negotiated agreement to supply equipment for both the Emeryville and Seminary stations. The Seminary Station, like the Emeryville Station, will utilize Linde's proprietary ionic liquid compression system. The primary supply of hydrogen will be liquid hydrogen delivered by Linde and stored on site in a 9,000-gallon container. The liquid fuel will be vaporized, pressurized, and stored at 450-bar pressure in American Society of Mechanical Engineers tubes, with a storage capacity of 360 kilograms. A third of the fuel supply is derived from the electrolysis of water using a Proton Exchange

Membrane electrolyzer powered by renewable electricity generated from biogas-fed stationary solid-oxide fuel cells. The renewable fuel supply allows the station to meet the requirements of SB 1505 requiring a minimum of 33 percent renewable hydrogen dispensed. Two Linde dispensers will be installed at the operating division's fueling island, in line with existing diesel dispensers. This will enable AC Transit to fuel and service the hydrogen buses in the same way as a standard diesel bus.

Schedule

The original schedule and the actual dates are shown below in Table 1.

Table 1: High-Level Schedule

Milestone	Original	Actual
Agreement Signed	3/29/2012	3/29/2012
Complete Final Design	10/31/2012	11/23/2013
Obtain all Necessary Permits	10/31/2012	5/31/2014
Accept Delivery of Hydrogen Equipment	6/30/2013	5/31/2014
Complete Construction	9/30/2013	7/2/2014
Operational date	12/31/2013	11/30/2015

Source: AC Transit

Emeryville Leak Delays

In May of 2012, a hydrogen gas leak at AC Transit's existing Emeryville fueling station led to a nine-month shutdown while an investigation of the incident occurred. Scientists from the Sandia National Lab worked with AC Transit to determine the cause of the incident (Harris & San Marchi, Oct 2012). The Sandia report ultimately determined that a metal incompatible with hydrogen service was used in valves that broke and caused the leak. Linde replaced the valves, and after coordination with the Emeryville Fire Department and creation of an enhanced risk management plan, the station reopened in February of 2013. The nine-month shutdown due to the incident investigation caused a similar delay in the Seminary station project. There were no injuries or damage to other property other than the broken valve.

Because of the nine-month delay, AC Transit requested a one-year no-cost time extension to the CEC agreement to be able to complete the data collection portion by approximately October 2014. The CEC initially rejected the one-year time extension, but after a Critical Project Review meeting in October of 2013, the CEC granted AC Transit an extension until May 15, 2014 to complete the station and begin operations. Further delays were encountered, and AC Transit completed construction and commissioning of the station on December 7, 2014 and began initial data collection with three buses using the station. After the funding agreement expired, AC Transit continues to collect data to fulfill the requirements of the funding agreement at no further cost to the CEC.

Construction

AC Transit released an Invitation for Bids construction procurement for posting on November 11, 2013, with bids due back by December 22. The contract was awarded to Roebbelen Contracting Inc. of El Dorado Hills, California on January 8, 2014. Roebbelen had the winning low bid for the base scope and additive alternates #1 and #2 from three firms that bid on all items. The bid was structured this way to allow for AC Transit to award a base bid that fully

constructs the station based on the existing scope and within the existing budget but allows for AC Transit to include the additions if the base scope is below the budget.

Figure 5 shows the fueling island with the hydrogen dispensers installed and the additional canopy added to cover them. Figure 6 shows (from left to right) the delivered liquid hydrogen storage tank, the vaporizer tubes, and the IC 50 compressor. The high-pressure storage tubes are located to the right of the compressor. Figure 7 shows the station equipment plan view, in particular the location of the high-pressure storage tubes.

One interesting part of the construction is the use of Trenwa precast concrete trenches for the high-pressure tubing that connects the various station equipment together. The Seminary facility is located in the Hayward Fault zone and the integrity of high-pressure lines located sub-grade is a concern. The Trenwa trenches can be opened for service or inspection and provide room for movement in the case of earthquakes. The trench cover plates can be seen running across the foreground of the picture in Figure 6.

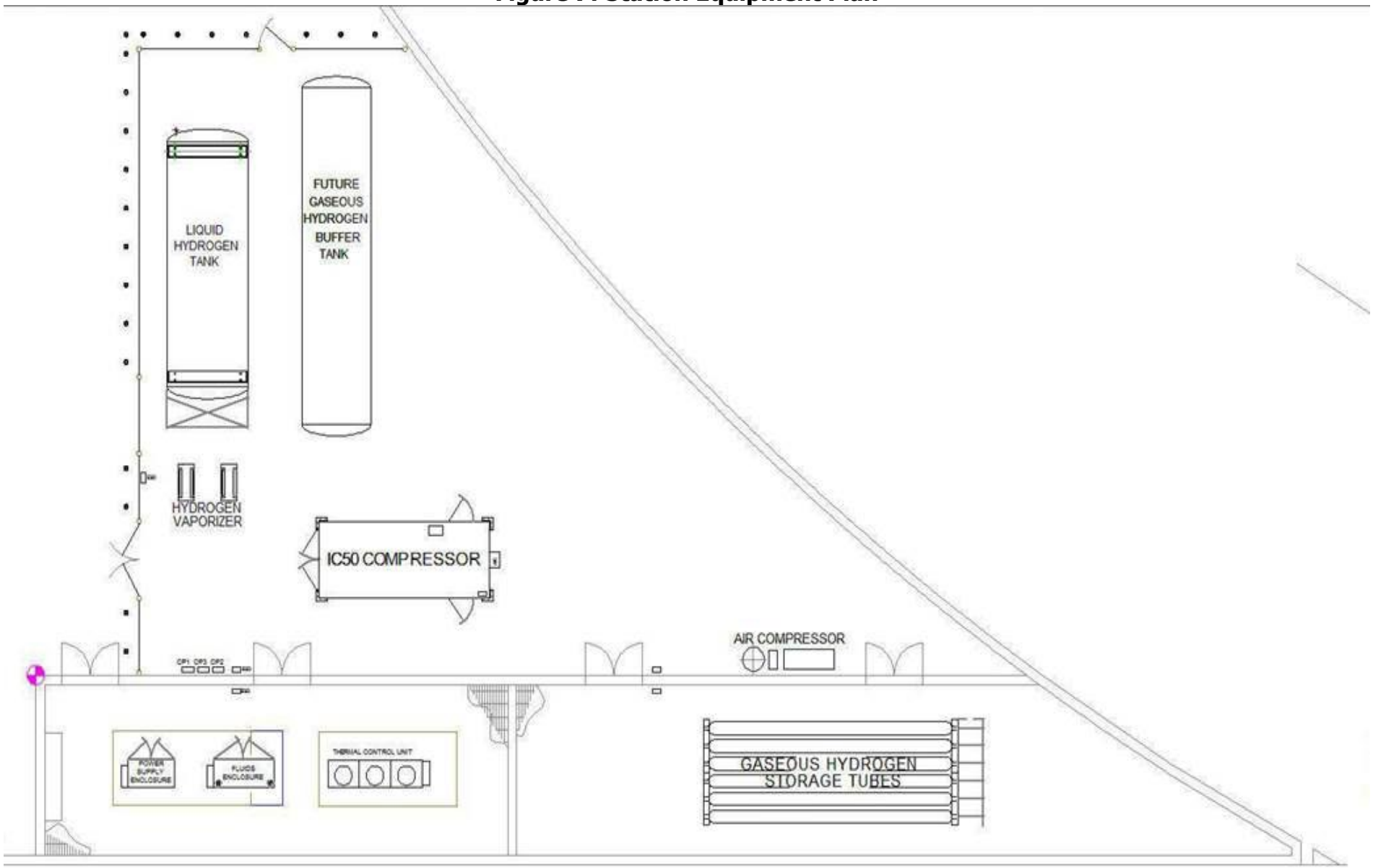
Figure 5: Fueling Island with Hydrogen Dispensers and Canopy

Source: AC Transit

Figure 6: Station Equipment

Source: AC Transit

Figure 7: Station Equipment Plan



Source: AC Transit

CHAPTER 3:
Project Assessment

This chapter discusses the public benefits of the Oakland Seminary hydrogen fuel cell bus refueling station. The station will be assessed based on whether it meets its objectives and can successfully fulfill the operating needs of AC Transit and the fuel cell bus fleet. An important consideration is the integration of the hydrogen fueling in the normal fuel island process for all buses.

The Seminary hydrogen station was completed and commissioned for operation on December 7, 2014. AC Transit began with three hydrogen fuel cell buses running in revenue service out of the Seminary facility and ramped up to eight buses by March 15, 2015. The majority of the fuel cell bus fleet was shifted to the Seminary station due to increased efficiency of operations there as planned by the station design. Staff was immediately able to see the efficiency gains from having the fuel cell buses come in after a shift and be maintained, washed, and fueled similarly to the other buses without any special detours in the bus yard.

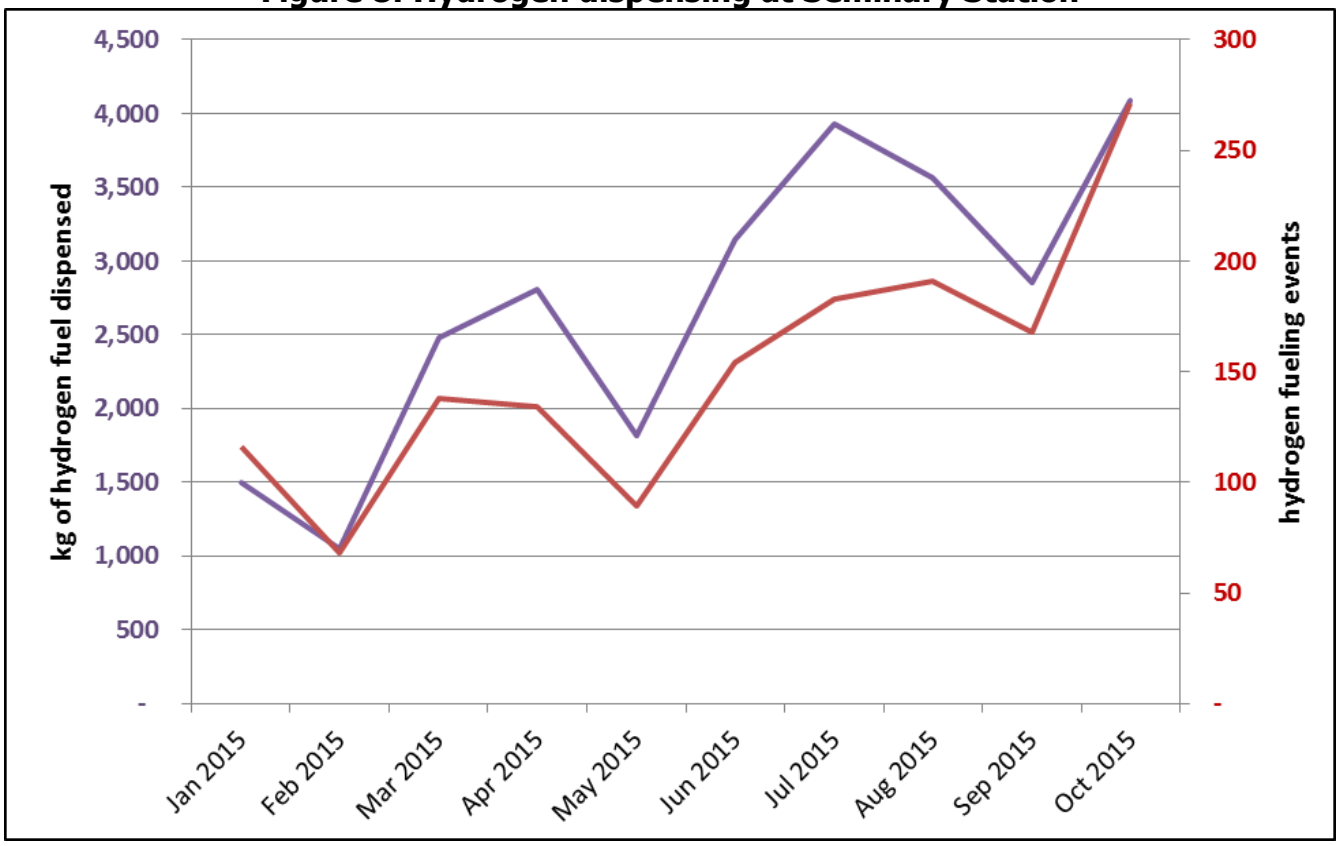
The increased operational efficiency is obvious when looking at the setup at the Emeryville bus yard and hydrogen refueling station. As shown in Figure 5, fuel cell buses returning to the Emeryville yard must go through the fueling island for non-fueling maintenance and checkup activities (normal bus routing shown in green arrows), then instead of parking must shuttle over to the hydrogen refueling station before parking. When the hydrogen fueling is done at the fueling island as at Seminary as shown in Figure 9, the extra time and personnel to shuttle each bus approximately 5-10 minutes to the fueling station are not needed. This efficiency is significant in a bus maintenance yard that services approximately 210 vehicles a day.

As planned for the station, one of the dispensers is the primary and normally handles all fueling of the fuel cell buses. The other dispenser functions as a backup, with only periodic use to ensure it is still functioning normally. Assuming AC Transit's fuel cell bus fleet grows both dispensers would eventually come into normal use and function as backups to each other.

Figure 8 shows the monthly totals for the kilograms of hydrogen fuel dispensed at 350 bar and the total fueling "events" where each event is a separate fueling, generally corresponding 1:1 with the number of buses fueled. Service with eight buses started in March 2015, and May 2015 shows a bit lower due to one bus being out of service due to an accident. There were issues with the compressor in September 2015, causing a drop in hydrogen fueling. The data is primarily from automatic monthly reports from the system monitoring station installed by Linde.

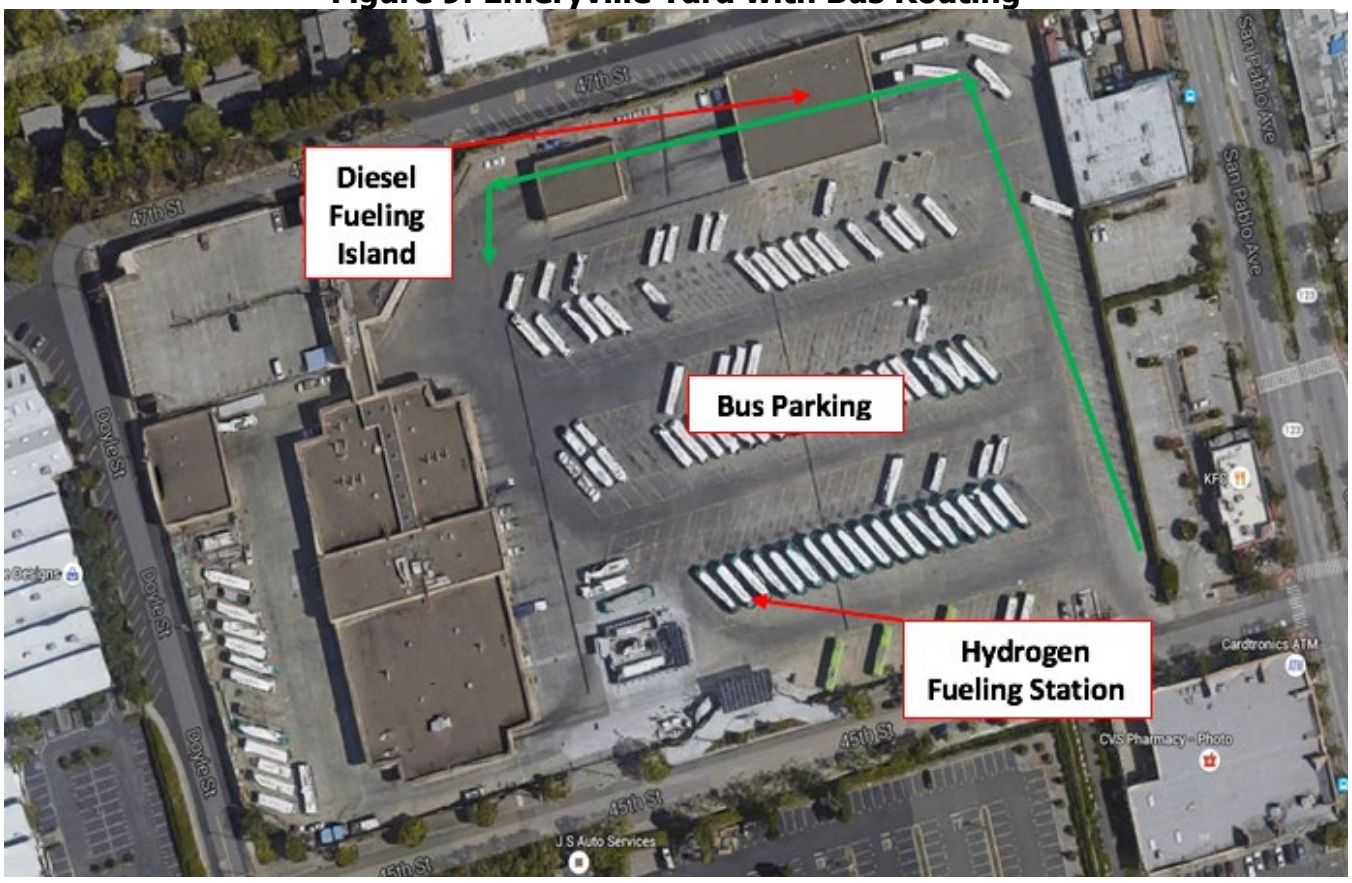
The chart in Figure 8 clearly shows the increasing service being run out of the Seminary station. As each bus has 40 kg of hydrogen storage on-board, the maximum monthly fueling amount with eight buses is 9600 kg. Based on National Renewable Energy Laboratory data (Eudy & Post, April 2015) the average miles per kg of the fuel cell bus fleet and the average monthly mileage, the buses use about 3,384 kg of fuel per month or about 35 percent of their fuel capacity. This roughly corresponds with the average amount of fuel dispensed over the July-October 2015 period.

Figure 8: Hydrogen dispensing at Seminary Station



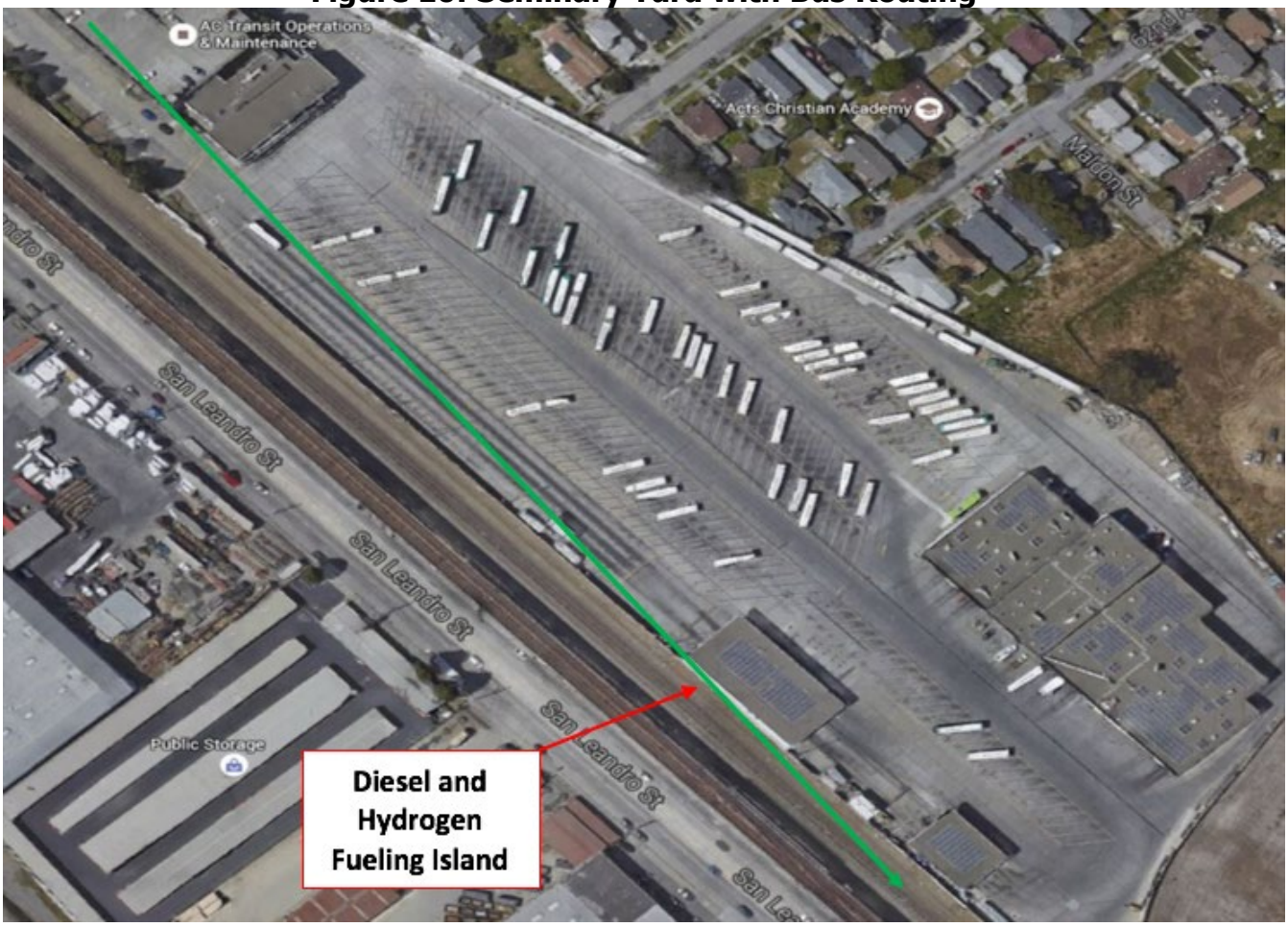
Source: AC Transit

Figure 9: Emeryville Yard with Bus Routing



Source: AC Transit

Figure 10: Seminary Yard with Bus Routing



Source: AC Transit

Objectives

The station meets or is on track to meet both main objectives as described in Chapter 1.

For Objective 1, the 360 kg of high-pressure storage fulfills the capability to fuel at least 360 kg of hydrogen per day. The current fleet of Van Hool fuel cell buses have 40 kg of hydrogen storage on-board, so fully fueling all twelve buses would be at most 480 kg per day. The 360 kg of high-pressure storage at Seminary can fully fuel just over 8 buses but in practice can fuel the full 12 bus fleet given that buses will generally not be empty when they are refueled. Also, assuming that hydrogen fuelings will not happen all at once but will be staggered over time as the buses return from service, the compressor will continuously work to recharge the high-pressure storage and the station can in practice fuel upwards of 20-24 buses per day. Even higher numbers of buses can be refueled with a better compressor or more high-pressure storage or both, although at a certain point the fuel supply storage/delivery must be upgraded also. These options can be further examined if and when the hydrogen fuel cell fleet is expanded.

For Objective 2, the station as designed can meet the goal if all 12 of the buses in the fuel cell fleet are fueled there. The 175,000 gallons of diesel fuel per year equates to about 762,767 miles per year at the 3.95 miles/DGE that the Van Hool diesel buses achieve (Eudy & Post, April 2015). Based on recent average mileage, eight fuel cell buses operating from Seminary would only achieve 229,348 miles per year, so overall the station is not meeting the objective of displacing 175,000 gallons of diesel per year based on an average miles per gallon of 3.95.

AC Transit staff is unable to determine if a mistake was made in the initial calculations for this figure, but the station is still contributing a significant amount to the reduction of both fossil fuel use and emissions.

Despite not achieving the diesel fuel displacement, the reduction in GHG emissions comes closer to the objective. At an average of 19,112 miles per month and 3,087 kg of hydrogen used per month for eight fuel cell buses, the reduction in GHG emissions is about 33 percent from the diesel scenario using carbon intensity values based on the CARB Low Carbon Fuel Standards pathway values for diesel (ULSD001) and hydrogen production (HYGN005) that currently apply. Based on the current station operational averages approximately 460 MT GHG would be avoided per year for the buses operating from the station. As the on-site electrolyzer is now operating, the GHG reductions will be even greater as the well-to-wheel emissions for 33 percent of the hydrogen produced will be lower than the reformer-produced hydrogen currently in use.

Training

Training is conducted for two groups of employees - bus operators and maintenance technicians. Bus operators are trained in general defensive driving tactics for day to day road operations. In addition, bus operators are also trained to conduct pre-trip inspection and safety precautions specific to fuel cell buses such as start-up, shutdown and emergency shut down procedures.

Maintenance employees are given thorough operations and safety training which covers components of the hydrogen production and dispensing equipment, properties of hydrogen and safety precautions when working with or near the hydrogen equipment. The training is conducted in the classroom as well as in the field. Since the opening of the Seminary facility, 60 maintenance staff have been trained and training continues to be conducted.

Public Benefits

Environmental

The environmental benefits of the station are mainly due to the reduced emissions possible by the operation of hydrogen fuel cell buses. The buses themselves emit no CO2 or criteria pollutants; their only emission is H2O. This is especially beneficial to communities with high air pollution burdens. The full well-to-wheel emissions profile is also greatly reduced due to the "green" sources that AC Transit uses to supply power and fuel to the stations. As mentioned previously, the full Seminary facility including the station and electrolyzer is powered by a stationary fuel cell system. The stationary fuel cell system is fed by directed biogas at a supply contract guaranteed level of at least 75 percent. Biogas is recovered from landfills and is classified as a GHG-free source. AC Transit has designed the system to meet California's Senate Bill 1535 33 percent renewable hydrogen fuel mandate.

As stated in Objective 2 of the grant, the displacement of diesel fuel use has a direct impact on GHG emissions locally. As discussed above, the GHG emissions are approximately 33 percent reduced for the fuel cell buses versus diesel buses which translates in to approximately 460 MT GHG emissions avoided per year for operations of eight buses from the station.

A further environmental benefit to fuel cell buses is that the fuel cell power plant is essentially silent in normal operation in contrast to a diesel or even diesel-electric hybrid power plant. In surveys done by AC Transit, both drivers and passenger have commented favorably on how quiet the bus is in operation.

CHAPTER 4: Conclusions

This chapter discusses the conclusions and observations of staff from the process and results of constructing the Oakland Seminary hydrogen fuel cell bus refueling station.

AC Transit believes that the project was successful and has largely accomplished the goals and objectives set forth. As hydrogen fuel cell buses move further along the curve to commercial availability and more widespread use, proving their integration with the daily operations of regular diesel transit buses is a key milestone. The success of the project has also allowed AC Transit to further expand its hydrogen fuel cell bus fleet with another ten buses to be purchased in 2017 with funding from the California Air Resources Board.

Project Outcome

Scope and Schedule Adherence

The constructed scope of the project matches the scope agreed to in the grant contract and will ultimately match the scope envisioned for the full station project which includes the stationary fuel cell power supply and electrolyzer production of hydrogen. This is anticipated to be completed in early 2017.

Schedule adherence for the project was unfortunately not very good. The largest delay to the project was from the shutdown and investigation of the leak incident at the Emeryville station which caused the Seminary station work to be stopped until the investigations were completed. Delays were also encountered with permit approval from the Oakland Fire Department. Hydrogen refueling stations are a new phenomenon for most localities, and some time must be allowed for fire departments to become comfortable with the design and emergency response requirements. This includes plan review for permit issuance.

Future

With the facility completed and now running at full capacity, we expect to continue our lead as the transit agency with the largest hydrogen fuel cell fleet in the country. As federal, state and regional agencies continue to support zero emission transit facilities, we are pleased to be in the position to work with them towards the common goal of increasing sustainable transportation.

GLOSSARY

CALIFORNIA AIR RESOURCES BOARD (CARB)—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.

GREENHOUSE GAS (GHG)—Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (NOx), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

GOLDEN GATE TRANSIT (GGT)–A special district of the State of California which operates and maintains the Golden Gate Bridge and two unified public transit systems – Golden Gate Transit and Golden Gate Ferry – connecting the counties of Marin, Sonoma, San Francisco, and Contra Costa. The District provides these public services under authority of California State Law.[2]

SAN MATEO COUNTY TRANSIT DISTRICT (SAMTRANS)– The San Mateo County Transit District is the administrative body for the principal public transit and transportation programs in San Mateo County: SamTrans bus service, including Redi-Wheels paratransit service, Caltrain commuter rail and the San Mateo County Transportation Authority.[3]

SANTA CLARA VALLEY TRANSPORTATION AUTHORITY (VTA)–An independent special district that provides sustainable, accessible, community-focused transportation options that are innovative, environmentally responsible, and promote the vitality of our region. VTA provides bus, light rail, and paratransit services, as well as participates as a funding partner in regional rail service including Caltrain, Capital Corridor, and the Altamont Corridor Express.[4]

2 Golden Gate Transit is available at https://www.goldengate.org/district/about-the-district/

3 San Mateo County Transit District is available at https://www.smctd.com/

4 Santa Clara Valley Transportation Authority is available at https://www.vta.org/about

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