SunLine Fuel Cell Buses & Hydrogen Onsite Generation Refueling Station

FINAL REPORT

PILOT COMMERCIAL DEPLOYMENT PROJECT

ACKNOWLEDGEMENTS

This report was prepared in fulfillment of California Air Resources Board Grant G14-LCTI-11 for the project titled "Air Quality Improvement Program and Low Carbon Transportation Greenhouse Gas Reduction Fund Investments Zero-Emission Truck and Bus Pilot Commercial Deployment Project: *SunLine Fuel Cell Buses & Hydrogen Onsite Regeneration Fueling Station Pilot Commercial Deployment Project*." The project was made possible through the support of key individuals and organizations, and SunLine Transit Agency (SunLine) would like to thank all those who provided support to aid in the success of the project. SunLine would like to especially thank California Air Resource Board (CARB) staff for their support and guidance throughout the process, along with project partner organizations:

This project was supported by the "California Climate Investments" (CCI) program.

ABBREVIATIONS

Abbreviation	Explanation
AQIP	Air Quality Innovation Program
BEB	Battery Electric Bus
BOP	Balance of Plant
CAC	Criteria Air Contaminants
CARB	California Air Resources Board
CCI	California Climate Investments
CI	Carbon Intensity
CNG	Compressed Natural Gas
CSD	Compression, Storage, and Dispensing
CVWD	Coachella Valley Water District
DGE	Diesel Gallon Equivalent
EER	Energy Efficiency Ratio
ELY	Electrolyzer
ESDs	Electrostatic Shutdown Systems
FCEBs	Fuel Cell Buses
FTA	Federal Transit Authority
GHG	Greenhouse Gas
H2	Hydrogen
HAZOP	Hazard and Operability Study
HVAC	Heating, Ventilation, and Air Conditioning
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
KPI	Key Performance Indicator
LCFS	Low Carbon Fuel Standard
LCT	Low Carbon Transportation
MV	Medium Voltage
NOx	Nitrogen Oxides
O&M	Operation and Maintenance
OEM	Original Equipment Manufacturer
PEM	Proton Exchange Membrane
PM10	Particulate Matter
REC	Renewable Energy Credit
RNG	Renewable Natural Gas
ROG	Reactive Organic Gases
SMR	Steam Methane Reformer
WER	Weighted Emissions Reduction

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EXECUTIVE SUMMARY

The *SunLine Fuel Cell Buses & Hydrogen Onsite Regeneration Fueling Station Pilot Commercial Deployment Project* was a four-year project that deployed five new 40-foot fuel cell electric transit buses (FCEBs) in daily service in the Coachella Valley, and included an upgrade to SunLine's existing hydrogen refueling station. The station upgrade included adding a proton exchange membrane (PEM) electrolyzer hydrogen production plant, supporting compression and storage equipment, and two 350-bar fueling dispensers, with a total fueling capacity of 900 kg/day.

Operating data for the buses and station was collected and analyzed for one year. While an independent firm, Ricardo Strategic Consulting, was selected by California Air Resources Board (CARB) to independently quantify the emissions reduction benefits and performance of the buses and station, SunLine commissioned project partner Zen Clean Energy Solutions (Zen) to collect and analyze data on their behalf. A summary of which is included with this report.

Dates: February 9, 2017 – December 31, 2020

Grantee: SunLine Transit Agency (SunLine) – bus and refueling station operations

Partners: New Flyer Industries – fuel cell electric bus supplier
Nel Hydrogen Inc. – hydrogen refueling station and PEM electrolyzer supplier
Zen Clean Energy Solutions – Project management, data analysis

Grant Amount:
CARB Contribution: $12,586,791
Matching Funds: $6,166,424
Project Total: $18,753,215

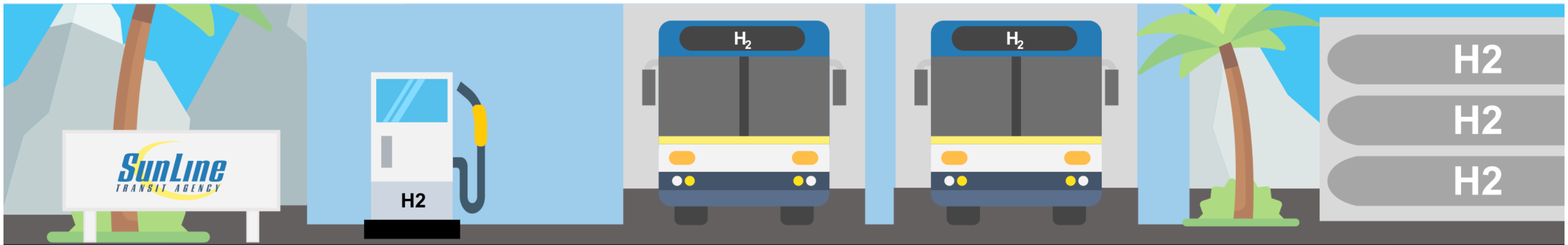
Vehicles/Equipment Funded:
Five New Flyer Xcelsior® XHE40 Buses

- Hydrogen-powered 40' fuel cell electric buses (FCEBs)
- Powered by Ballard FCveloCity-HD 85 kW modules
- Based on standard Xcelsior® CHARGE electric propulsion system

Nel Hydrogen Production and Refueling Station

- Supplied as complete turnkey solution, with 900 kg/day capacity
- M400 series modular PEM electrolyzer
- H2Station® modules deliver 350 bar hydrogen

SunLine is a zero-emission bus technology leader and shares knowledge with other transit agencies through the West Coast Center of Excellence in Zero Emission Technology. Outreach has been an important part of this project. As of December 2020, SunLine has a total of 17 FCEBs plus 4 BEBs in operation. Key project performance metrics are highlighted in the following infographic.

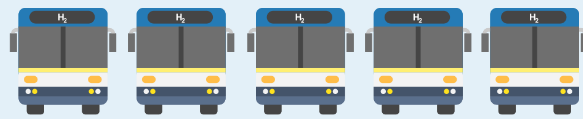


PROJECT SCOPE

ELECTROLYZER & H2 STATION

900 kg-H_2/day

FUEL CELL ELECTRIC BUSES



Five - 40' Transit Buses

FUNDING & PROJECT PARNTERS

CARB:	$12.6 M
Matched:	$6.2 M
Total:	$18.8 M

OUTREACH ACTIVITES

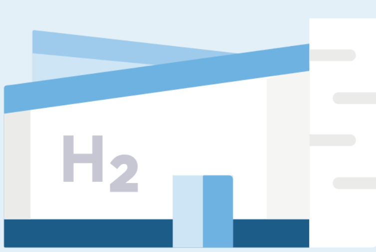
39 Outreach Activities = **11** Tours/Meetings to transit agencies, **22** Tours/Meetings to other companies, **6** Speaking Events/ Media Outreach

KEY OUTCOMES

H2 PRODUCTION

64,038

kg-H_2 produced



5 FCEBs

151,254

miles driven

22,012

kg-H_2 consumed

GHG ABATEMENT

296

tonnes-CO2e

Abated

PROJECT DESCRIPTION

The *SunLine Fuel Cell Buses & Hydrogen Onsite Regeneration Fueling Station Pilot Commercial Deployment Project* was a four-year project to deploy five new 40-foot fuel cell electric transit buses (FCEBs) in daily service in the Coachella Valley and to upgrade SunLine's existing hydrogen refueling station to incorporate an on-site proton exchange membrane (PEM) electrolyzer hydrogen production plant. The station upgrades also included adding new compression and storage equipment coupled with two new 350-bar fueling dispensers, adding a total fueling capacity of 900 kg/day to the site. The hydrogen production plant is powered with 100% renewable power, using a combination of on-site solar and renewable energy credit (REC) purchases.

This project was one of 8 Zero-Emission Truck and Bus Pilot Commercial Deployment Projects supported by the "California Climate Investments" (CCI) program and is part of the broader Clean Transportation Investments funding portfolio, which includes Air Quality Improvement Program (AQIP) and Low Carbon Transportation (LCT) Greenhouse Gas Reduction Fund Investments. The project received $12,586,791 in funding from California Air Resources Board (CARB) through LCT Investments, as well as $2,750,000 funding for the rolling stock from the Federal Transit Authority (FTA) which is considered cash match for the project. An additional $500,000 in infrastructure funding from the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), which was associated with 5 separate FCEBs purchased by SunLine, was added to the project to support the additional capacity needed to fuel these additional buses with the new station upgrades.

The project ran from February 2017 through to the end of December 2020. The first six months of the project were focused on negotiations and contracting with project partners, and some significant changes were made to the project team during this period. This included a change to both the hydrogen refueling station provider and the fuel cell modules supplier for integration into the New Flyer buses, which ended up being Nel Hydrogen Inc. and Ballard Power Systems, respectively. These changes to the project team were driven by a combination of commercial and technology factors. The project team ultimately consisted of SunLine Transit Agency as the project prime and operator of the buses and station, New Flyer Industries as the bus original equipment manufacturer (OEM), and Nel Hydrogen Inc. as the turnkey provider of the hydrogen production and refueling station upgrades. Zen Clean Energy Solutions was engaged by SunLine as an owner's representative to provide project management and administration services as well as data collection and analysis services.

Prior to the above-mentioned hydrogen fueling station upgrade, SunLine had been operating a steam methane reformer (SMR) running on renewable natural gas (RNG) to provide fuel for their fleet of FCEBs. The reformer was coupled with a tube trailer for hydrogen storage, and a 350 bar dispenser that is located outside the fence line next to SunLine's public-access compressed natural gas (CNG) dispenser. The SMR system was used to produce fuel for SunLine's 17 FCEB fleet during the first year the five new New Flyer buses purchased under this project operated (December 2018 – December 2019). This system, combined with delivered hydrogen supplied by an industrial gas supplier, was used to provide backup fuel as needed once the new electrolyzer production plant went into service in December 2019. The SMR reached the end of life during the project and was retired in January 2020, leaving delivered hydrogen as the only backup option. In parallel to this project, SunLine designed and constructed a new CNG fueling station that serves the balance of their fleet. The two new hydrogen dispensers were ultimately integrated into the fueling islands built under the CNG station scope. This required significant coordination on construction activities, and an integrated safety system design. To minimize disruptions, the new hydrogen station was first operated with a single dispenser in a temporary location away from the CNG station construction. In September/October 2020, the second dispenser was placed in the permanent location in one of the three new fueling islands. Once operation of the second station module and dispenser was proven to be stable and reliable, the temporary dispenser was relocated to a second of the three new fueling islands in November / December 2020.

The FCEBs were placed in operation in January 2019 in a staged manner as they became available for service. SunLine started providing data to Ricardo in May 2019 once shakedown testing was complete. Data collection for the new electrolyzer and hydrogen station modules and dispensers commenced in December 2019. All data collection continued until November 30, 2020. This met the requirement for a minimum of 1 year data collection as part of the project.

It should be noted that COVID-19 impacted the project in several ways. In terms of transit operations, the decline in ridership and need to provide extra safety and cleaning measures is continuing to impact SunLine's operations. Transit is considered an essential service, so the new hydrogen fuel cell buses and the hydrogen fuelling station continued to operate throughout the reporting period, but at lower utilization than would normally be expected.

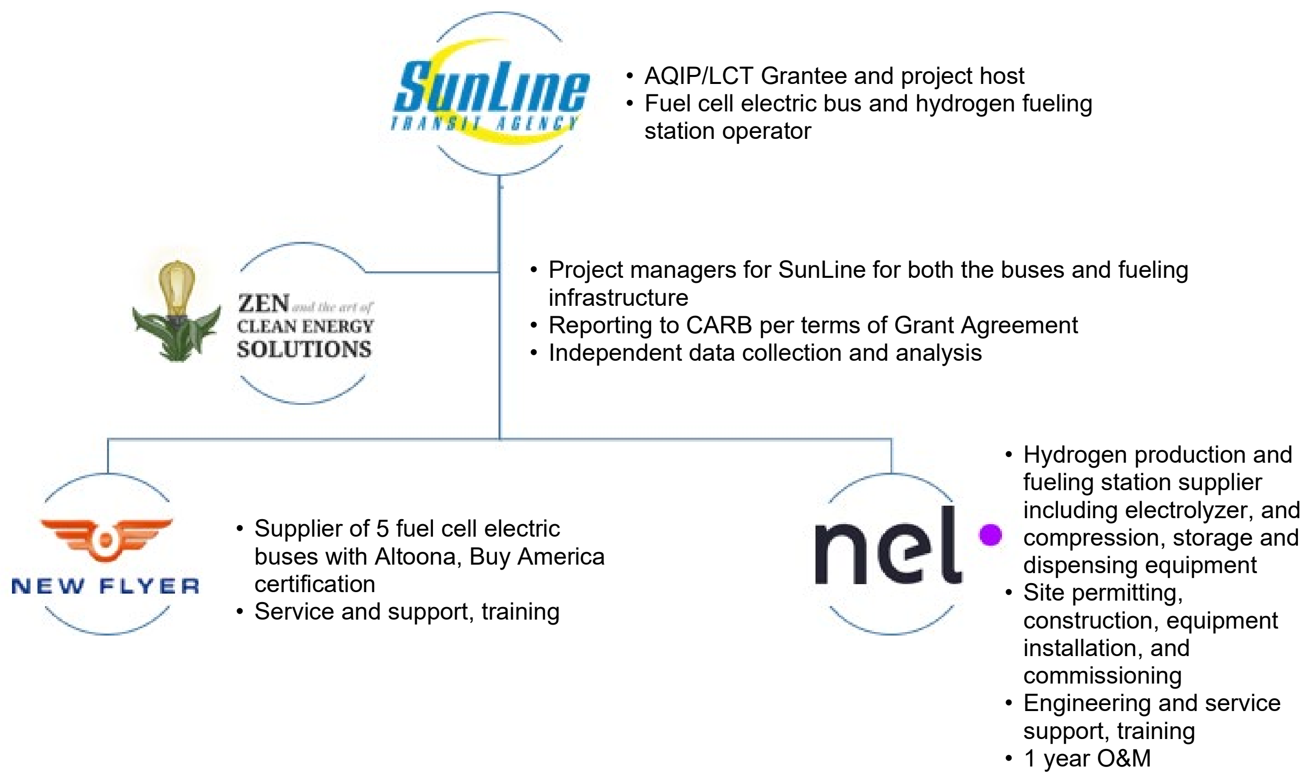
In addition to the impacts on fleet operation, travel restrictions and limited site access slowed the CNG station construction and associated installation of the permanent hydrogen dispensers. It also impacted station preventative and corrective maintenance activities on several occasions due to delays in parts procurement and travel restrictions for trained service personnel.

Scope and Objectives

- SunLine Transit Agency deployed five New Flyer XHE40 fuel cell electric buses in regular revenue service on two regular service routes in the Coachella Valley. The buses incorporated Ballard fuel cell FCveloCity-HD 85 kW modules.

- SunLine upgraded their existing fueling station to include:
    - A new electrolyzer and new compression, storage, and dispensing (CSD) equipment supplied by Nel Hydrogen Inc. as a turnkey system.
    - An increased station production of 900 kg/day and two 350 bar dispensers.
    - A new high voltage power line to provide sufficient grid connected capacity to run the electrolyzer.
    - Connection of on-site solar electricity production to the electrolyzer balance-of-plant to offset grid electrical requirements.
- SunLine collected data using CARB (Ricardo) specified equipment and reporting standards to capture the first year of bus and station operation:
    - Data was collected on 2 baseline CNG buses in addition to the 5 new FCEBs.
    - Zen conducted independent data collection and analysis on SunLine's behalf, included herein.

Project Team



SunLine Transit Agency

SunLine Transit Agency is a transit agency providing bus service in the Coachella Valley. SunLine is a world leader in the deployment of zero-emission bus technology with seventeen fuel cell buses and three battery electric buses currently in operation. In this project, SunLine acted as:

- The LCT Grantee and project host
- The fuel cell electric bus and hydrogen fueling station operator

New Flyer Industries

New Flyer is the largest transit bus manufacturer in North America. New Flyer was the fuel cell electric bus OEM for this project, responsible for supplying:

- 5 XHE40 Xcelsior™ fuel cell electric buses with Altoona, Buy America certification
- Bus service and support through the project, operator training

Nel Hydrogen Inc.

Nel Hydrogen Inc. (Nel) is the US subsidiary of Nel ASA, a global, dedicated hydrogen company, delivering solutions to produce, store and distribute hydrogen from renewable energy. Nel was responsible for delivering a 900 kg/day hydrogen refueling station, including electrolyzer, compression, storage and dispensing. Nel's scope included:

- Site construction, equipment installation, and commissioning
- Engineering and service support, operation and maintenance (O&M) training
- 1-year O&M on the station

Zen and the Art of Clean Energy Solutions Inc.

Zen Clean Energy Solutions is a project management firm with more than 60 years of combined experience in the clean energy sector, focused on hydrogen and fuel cell commercialization. In this project, Zen provided:

- Project management support to SunLine for both the fuel cell electric buses and fueling infrastructure
- Reporting services to CARB per the terms of the Grant Agreement
- Independent data collection and analysis services

Methodology

At the outset of the project, SunLine organized a kick-off meeting with project partners to ensure scope, deliverables, schedule, budget, and roles and responsibilities were clearly defined. Following the kick-off meeting, a detailed Project Management Plan was developed that included the above elements, along with describing methods for control and tracking throughout the project. A risk analysis was also conducted and was updated and managed throughout the project. The team held regular meetings throughout the project timeframe. The structure and participants of the meeting varied throughout the project timeframe on an as-needed basis to streamline communications.

Key Outcomes

Key project outcomes include the following:

- Five new New Flyer Xcelsior® XHE40 buses were successfully deployed at SunLine Transit during the timeframe of the project and will continue operating throughout their useful life.
  - The buses operated for over one year in regular revenue service.
  - The buses cumulatively traveled over 150,000 miles and consumed over 22,000 kg of on-site produced hydrogen.
  - SunLine's maintenance staff was trained by New Flyer personnel and are capable of routine maintenance on the new buses.
  - SunLine's fleet of FCEBs was expanded to seventeen x 40' buses as of the time of this report submission, five of which were directly support by this project and all of which rely on the new hydrogen production and fueling station.
- SunLine Transit's hydrogen fueling infrastructure was upgraded to include a Nel M400 PEM electrolyzer and two new 350 bar dispensing stations capable of generating and dispensing 900 kg-H2/day. The station will continue to be operated through to the end of its useful life.
  - The station generated and dispensed over 64,000 kg of hydrogen to the SunLine bus fleet over a 1-year period including over 22,000 kg to the five FCEBs funded by the LCT Program.
  - The station was integrated with SunLine's existing hydrogen infrastructure by connecting the low-pressure storage array to an existing tube trailer and 350 bar hydrogen dispenser, providing redundancy and backup for fueling operations.
  - SunLine's on-site solar arrays were connected to the station and demonstrated an ability to reduce grid electricity costs by over $2,800 per month. Further expansion of on-site solar will lead to further cost reductions beyond the timeframe of the project.
  - The new hydrogen dispensers were successfully integrated into SunLine's new CNG station fueling islands, with an integrated site safety strategy.
- The buses and station operated for over a year in regular transit service, and data was collected and analyzed to determine project performance and outcomes.

- Data was provided on a monthly basis to Ricardo starting in May 2019 and ending November 2020. Data analysis results will be published in a separate report. SunLine independently collected and assessed performance data, and results are included herein.
- Driver acceptance has been high, with driver feedback that the new buses are "the best they have ever driven."
- Data from the LCT FCEBs were compared to data collected from two baseline CNG buses operating on similar routes as the LCT FCEBs. Using the actual operation of the FCEBs and the calculated fuel economy of the CNG buses, the following results were determined:
  - Fuel consumption: 19,085 gasoline gallon equivalents (GGE) were avoided by using FCEBs instead of CNG buses
  - GHG Emissions: 162.4 tonnes-CO2e/year saved
  - CAC Emissions: Weighted Emissions Reduction (WER) of 0.348
  - Cost: $1.55/mi more than the baseline
- Over 296 tonnes-CO2e of greenhouse gas emissions were avoided directly as a result of the project compared to a diesel baseline.

- SunLine profiled the project and shared lessons learned through a total of 39 distinct outreach activities throughout the project timeframe, including tours, conference presentation, and media events.

Equipment Specifications

New Flyer Xcelsior® XHE40 Buses

High level description:

- Hydrogen-powered 40' fuel cell electric buses (FCEBs)
- Powered by Ballard FCveloCity-HD 85 kW modules
- Based on standard Xcelsior® CHARGE electric propulsion system
- 37.5 kg hydrogen storage onboard

Figure 1 – New Flyer XHE40 FCEB, photo courtesy of New Flyer

Table 1 – New Flyer XHE40 Technical Specification[1]

Parameter	Value
MEASUREMENTS	
Length	41' 0" (12.50m) over bumpers 40' 2" (12.24m) over body
Width	102" (2.6m)
Roof Height	11' 1" (3.3m) over charging rails
Step Height	14" (356mm)
Front step height (kneeled)	10" (254mm)
Interior height -floor to ceiling	79" (2m) over front and rear axle 95" (2.4m) mid-coach
Tire Size	305/70R22.5
Wheelbase	283.75" (7.2m)
PROPULSION	
Motor	Siemens ELFA2 Electric Drive System Optional High Gradeability Motor
PASSENGER CAPACITY (*Based on 150kWh ESS configuration)	
Seats	Up to 40*
Standees	Up to 43*
ACCESIBILITY	
Doors	2
Wheelchair Accessibility	32" (813mm) wide, 1:6 slope Flip out NFIL ramp, front door
Wheelchair Locations	2 – front location, rear location also available (other options available)
WEIGHT	
Curb Weight	31,500 lb (13,835 kg)
APPROACH ANGLE	
Approach/departure/breakover angles	9°/9°/9°
TURNING RADIUS (body, with aluminum wheels; *varies with wheel type)	
Turning radius	44' (13.4m) *
MAIN COMPONENTS	
Floor	Marine Grade Plywood Floor Optional Composite Floor Composite Rear Interior Step Tarabus, Altro, RCA Floor Covering
Electrical System	Parker Vansco

[1] Source: New Flyer, https://www.newflyer.com/site-content/uploads/2022/05/Xcelsior-CHARGE-H2.pdf

Parameter	Value
Cooling System	Electric cooling fans
HVAC	Thermo King RLFE
Axles	MAN HY-1350 rear disc brakes, single reduction axle
ENERGY STORAGE SYSTEM	
Fuel Cell	Ballard
Equivalent Battery Energy	700 kWh
Hydrogen Storage Volume	37.5 kg

Nel Hydrogen Production and Fueling Station

A schematic of the hydrogen production and fueling station upgrade scope and how it connects with the previous hydrogen station equipment can be seen below in Figure 2, with some photos of the actual station shown in Figure 3. Nel provided the station upgrade as a turnkey solution that included site design, construction, equipment supply, installation and commissioning, and one-year complete O&M support.

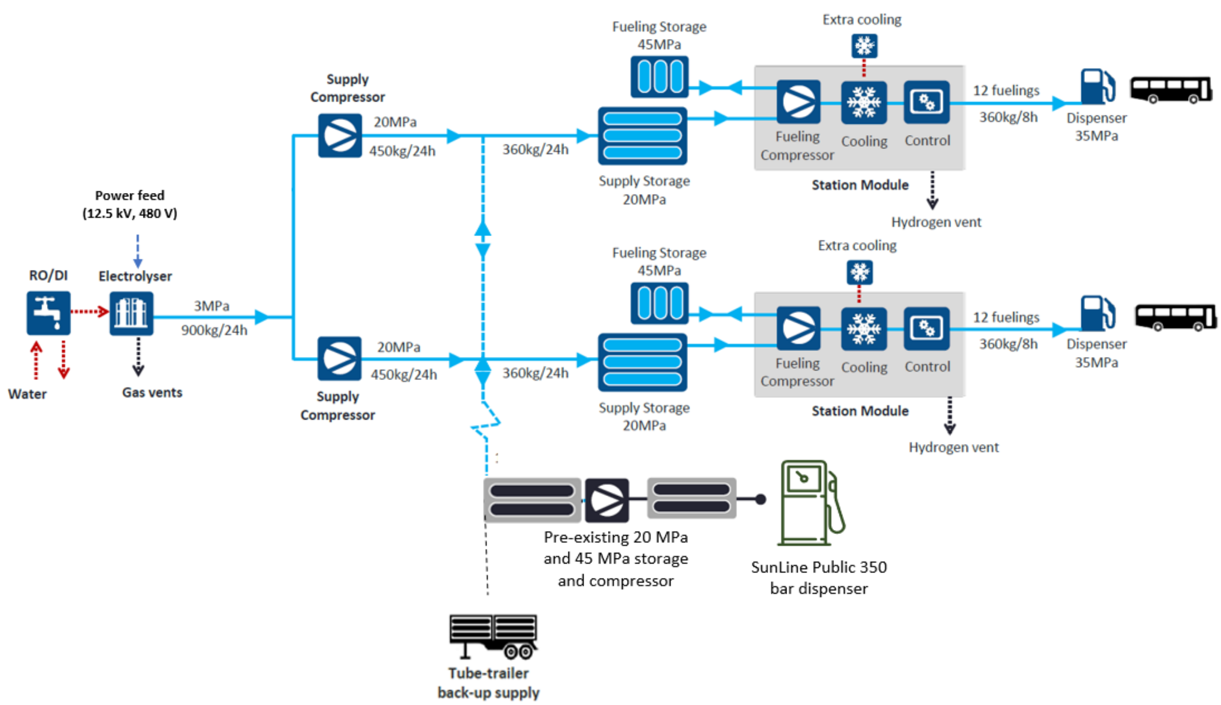


Figure 2 – Schematic of Hydrogen Production and Fueling Station

Figure 3 – Station photos. On left, hydrogen dispenser integrated into new CNG island. On right, panorama of full station.

A summary of important station specifications is shown in Table 2.

Table 2 – Hydrogen production and fueling station specifications

Parameter	Value	Unit	Comments
ELECTROLYZER			
Maximum Hydrogen Production Rate	902	kg/day	
Production Capacity Dynamic Range	10-100%	% of flow range	
Power Consumption per kg of H2 produced	60.3	kWh/kg	
Hydrogen purity	99.9995%	%	
Delivery Pressure	3	MPa	At outlet of electrolyzer
Building Dimensions	60' x 60'	WxD	
Stack Dimensions	508 x 508 x 887	WxDxH	
Feed Water Consumption per kg of H2 produced	14.32	L/Kg	
Rated Stack Power	250	kW	
Number of stacks	8	stacks	
Electrolysis type / principle	PEM	Such as PEM, Alkaline	
Output Temperature	10	°C	At outlet of electrolyzer
DISPENSER			
# of dispensers	2	Dispensers	
Pressure	35	MPa	Currently 2 in operation
Quantity per fueling	30	kg	Delivered pressure
Fueling time per fueling	15	Minutes	This is design fill size - will vary based on size of tank and fuel

Parameter	Value	Unit	Comments
			remaining on bus at time of fill.
STORAGE			
Low pressure storage capacity	323	kg	
Low pressure storage pressure	200	bar	
High pressure storage capacity	425	kg	
High pressure storage pressure	450	bar	

The efficiency of the electrolyzer depends on several varying factors. For example, cooling requires much more energy in a hotter location or in the summer months vs the winter. Also, there are efficiency advantages to operating continuously at lower loads as compared to cycling the system on and off at full load. Thus, 60.3 kWh/kg is an estimate for an average system operating over an entire year. Efficiency can decay over time depending on several factors.

Budget and Schedule

The original project budget was $17,801,410 as shown in the table below. The CARB funding amount for the project is $12,586,791. From the outset, SunLine planned to allocate FTA funding of $2,750,000 toward the five buses as cash match for the project. The main sources of in-kind match for the project were expected to be bus and station operating costs for the 1-year demonstration period in the amount of $2,318,771 and SunLine labour to administer the project in the amount of $145,848.

Table 3 – Project budget from proposal and original grant agreement

Costs	CARB Grant Cash	Application Match Funding Cash	Application Match Funding In Kind	Total
1. Pilot Commercial Deployment Funds	$ 12,586,791	$ 2,750,000	$ 2,318,771	$ 17,655,562
2. Administrative Funds	$ -	$ -	$ 145,848	$ 145,848
Total	$ 12,586,791	$ 2,750,000	$ 2,464,619	$ 17,801,410

The project experienced cost over-runs, and SunLine had to find additional sources of funds to cover these additional costs. One major unanticipated project cost was the need to bring a new power line to the site to provide the capacity needed by the electrolyzer. This new 12.4kV, 2.4 MW power line cost close to $1 million. SunLine had to use other capital funds to pay for this construction, and these costs count toward cash match to the project. The connection to Coachella Valley Water District (CVWD) water and sewer was close to $275,000 and also had not been included in the original budget. This cost as well as some higher than anticipated electricity commissioning costs were paid with CARB funds that were re-allocated from the original bus budget, as some bus price reductions were achieved as a result of a bulk procurement with other agencies buying FCEBs from New Flyer at the same time. Additional costs were also incurred to build the hydrogen production and fueling station and ensure sufficient capacity for SunLine's full fleet of 17 fuel cell buses. An additional $500,000 of HVIP infrastructure funds that were available from a parallel procurement of five ElDorado fuel cell buses were leveraged for this incremental cost. The final budget identified in Amendment 3 of the grant funding agreement between CARB and SunLine, as well as the final actual project budget, as shown in Table 4.

The final project cost was $18,753,214. The CARB funds did not change throughout the project; all additional costs were covered through cash and in-kind match sources. The final match funding was $6,166,424, equivalent to 33% of total project costs.

The project ran from February 2017 until December 2020, with final reporting extending until March 2021. The project was initially going to be completed in December 2019, but CARB requested a one-year, no-cost project extension in order to provide more time for data collection and analysis in light of the delays in getting the equipment into regular service. Figure 4 shows the project schedule along with key milestone dates that were achieved.

Table 4 – Final budget from Amendment 3 of grant agreement

Task	CARB Grant Funds ($ Thousand)					Match Funds ($ Thousand)			Grant + Match
	SunLine	New Flyer	Nel	Zen	Total	Cash	In-Kind	Total	
BUDGET AMOUNTS UPDATED TO REFLECT AMENDMENT 3 WITH CARB									
1. Administrative and Project Management	$0	$0	$159.5	$120.1	$279.6	$0	$145.8	$145.8	$425.4
2. Bus Acquisition, Delivery, and Commissioning	$0	$3,150	$0	$0	$3,150	$2,750	$0	$2,750	$5,900
3. Upgrade Existing Hydrogen Infrastructure	$344.8	$0	$8,812.4	$0	$9,157.2	$0	$500	$500	$9,657.2
4. Operation of and data collection from buses & HRS	$0	$0	$0	$0	$0	$0	$2,319	$2,318.8	$2,318.8
Total	$344.8	$3,150	$8,971.9	$120.1	$12,586.8	$2,750	$2,964.6	$5,714.6	$18,301.4

Table 5 – Final project cumulative actual costs

Task	CARB Grant Funds ($ Thousand)					Match Funds ($ Thousand)			Grant + Match
	SunLine	New Flyer	Nel	Zen	Total	Cash	In-Kind	Total	
CUMULATIVE EXPENSES TO DATE									
1. Administrative and Project Management	$0	$0	$159.5	$120.1	$279.6	$279.1	$149.4	$428.5	$708
2. Bus Acquisition, Delivery, and Commissioning	$0	$3,150	$0	$0	$3,150	$2,750	$0	$2,750	$5,900
3. Upgrade Existing Hydrogen Infrastructure	$344.8	$0	$8,812.4	$0	$9,157.2	$1,251.1	$541.6	$541.6	$10,950
4. Operation of and data collection from buses & HRS	$0	$0	$0	$0	$0	$26.4	$1,168.8	$1,168.8	$1,195.2
Total	$344.8	$3,150	$8,971.9	$120.1	$12,586.8	$4,306.6	$2,964.6	$6,166.4	$18,753.2

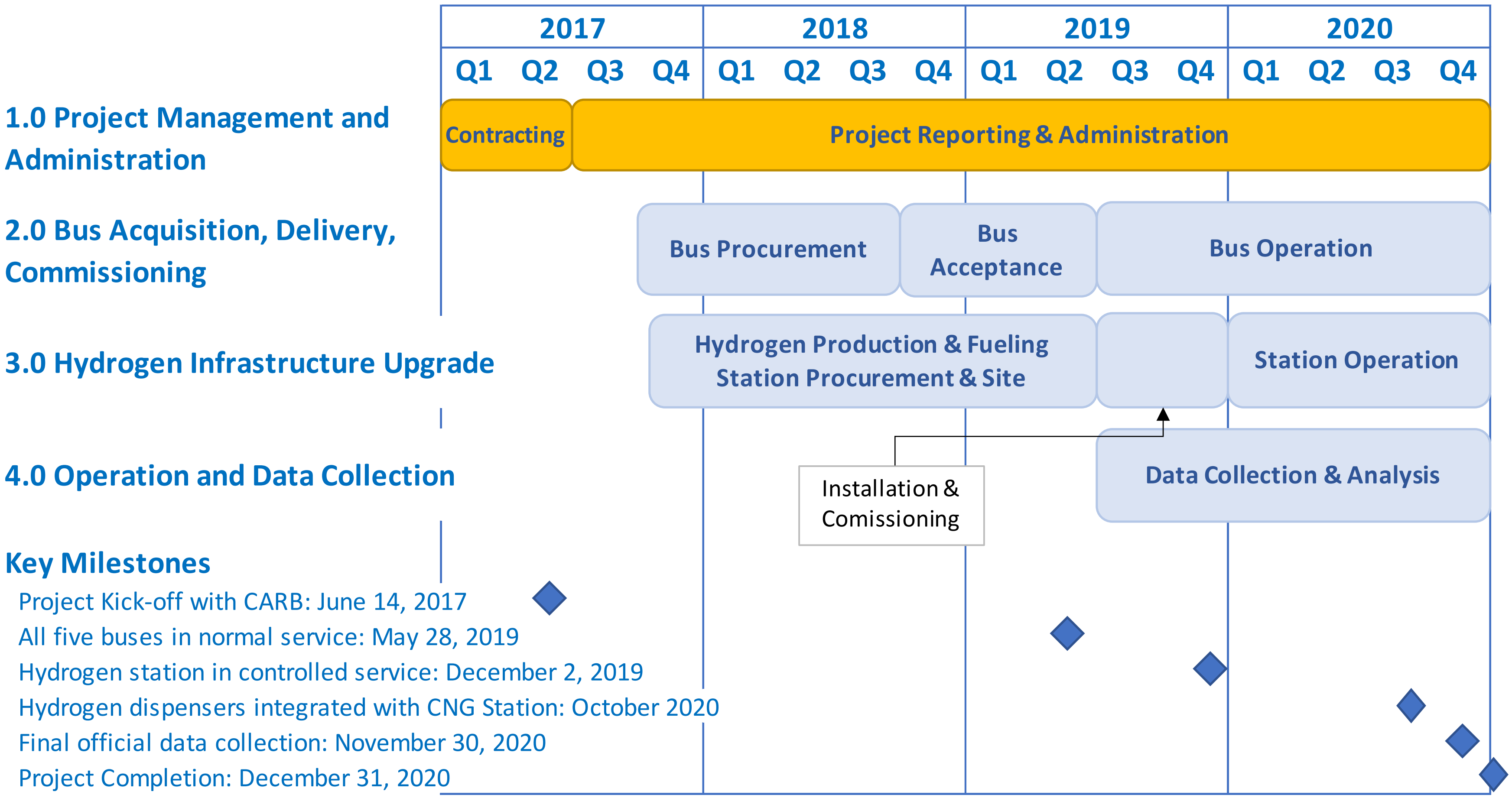


Figure 4 – Project Schedule and Key Milestones

DATA COLLECTION AND RESULTS

CARB contracted Ricardo Strategic Consulting (Ricardo) to conduct third-party data collection and analysis related to the performance of the five FCEBs and 900 kg-H2/day electrolyzer funded by the LCT Program. Ricardo will complete a comprehensive report detailing their findings in early summer 2021.

The results shown in this report were generated internally by SunLine with support from Zen Clean Energy Solutions. The data was compiled throughout the project as a way for SunLine to track performance and inform internal decision making. The future report to be delivered by Ricardo will be reviewed by SunLine. It will incorporate the data shown in this document as well as additional sources of data collected independently by Ricardo including direct measurement of bus performance using on-bus data loggers.

Impact of Unforeseen Events

Several unforeseen circumstances impacted the operation of the five LCT FCEBs throughout the project demonstration period. COVID-19 has impacted almost every sector of the economy and public transit is no different. Since March 2020, SunLine has adjusted service to better serve the population during the global pandemic. Safety measures such as rear loading, increased frequency of cleaning, and the elimination of fare collection were quickly incorporated into regular operation. SunLine has also been operating on a Sunday service schedule every day of the week instead of regular operation and has been dispatching additional buses to double service to limit the number of passengers on each bus and aid social distancing. Weekend schedule operation, along with other factors, have reduced the operating miles of the FCEBs.

During the demonstration period, two major accidents also occurred which resulted in months of downtime for the buses involved. In both cases, the accidents had nothing to do with bus operation or technology type. In early October 2019, one of the FCEBs (FC14) was struck by a front-end loader while parked at the SunLine Thousand Palms facility. The front-end loader rolled through the fence from a neighbouring property and struck the motionless bus. This bus was out of service until May 2020, resulting in a seven-month period in which no data was collected and reducing the average mileage of the FCEBs. One of the baseline CNG Buses (622) was also damaged when it was stolen and driven off-road into the desert. This incident occurred in September 2020 and, as of the writing of this report, is still out of service.

Repeated protests during 2020 also resulted in limited runtime for the LCT FCEBs. Demonstrations in Southern California and throughout the country led in certain instances to destruction of property. Due to safety concerns, SunLine decided to limit deployment of the new FCEBs during nighttime hours when these demonstrations were taking place. Instead, older CNG vehicles were dispatched so that if any damage were incurred it would not be to the newer buses.

Station Performance

The H2 station dispensed 64,038 kg-H2 to SunLine's fleet of 17 FCEBs, including the five FCEBs funded by the LCT Program over the project period of Dec 01, 2019 – Nov. 28, 2020. An average of 172.2 kg-H2 was dispensed per day, with May 2020 and December 2019 having the most and least dispensed per day with values of 248 kg-H2/day and 112 kg-H2/day, respectively. The December 2019 low dispensed value resulted from that being the start-up month where the station was only partially available, with high early life downtime to be resolved through shakedown testing. The average hydrogen dispensed per day each month (Figure 5) varied depending on downtime of the H2 station and electrolyzer, maintenance, and external events such as COVID-19 and public protests described previously in the *Impact of Unforeseen Events* Section. The H2 station includes the compression, storage, and dispensing equipment of the hydrogen production and fueling facility, whereas the electrolyzer encompasses the cell stacks and hydrogen production unit.

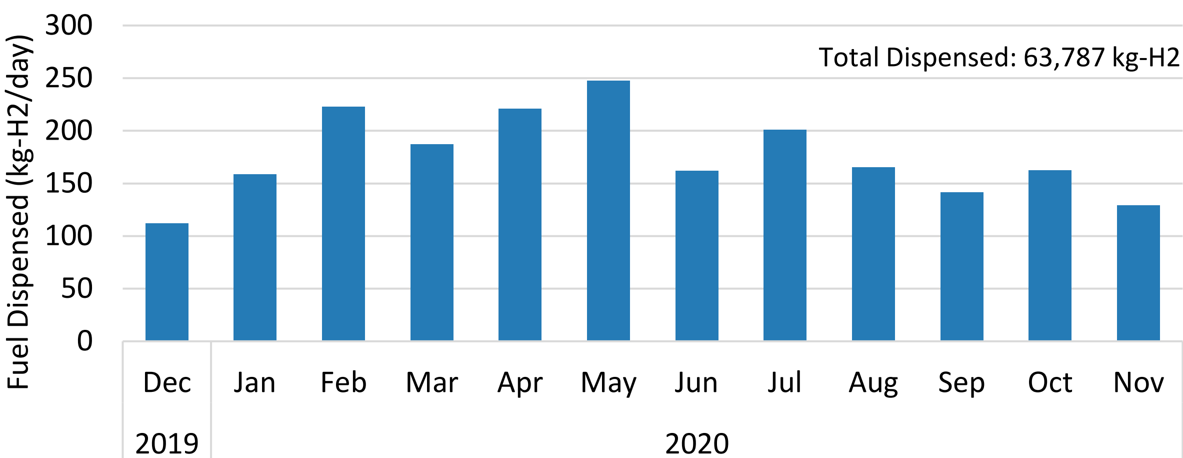


Figure 5 – Daily hydrogen dispensed from the H2 station per month

Fuel Cost

SunLine calculates the cost per kilogram of hydrogen dispensed on a monthly basis. The total cost of operating the station is accounted for including electric and water utility bills, and maintenance labor and materials. The dispensed cost is calculated by taking the total cost of production and dividing by the number of kilograms of hydrogen dispensed into buses as measured by SunLine's fuel management system. By far, the largest component of cost was electricity, as shown in Figure 6. Maintenance costs over the project period were negligible because the station was under warranty. The costs shown do not incorporate revenue from the sale of low carbon fuel standard credits.

The cost of dispensed fuel varied significantly throughout the project. In the best months, dispensed costs of <$8/kg were achieved. This matched the target cost modeled at the outset of the project and continues to be the upper threshold for the dispensed hydrogen cost target going forward. However, costs in some months have been unacceptably high at greater than $17/kg. At the time of report submission, a root cause analysis and joint effort between Nel and SunLine is underway to work on reducing dispensed fuel cost to the target value of <$8/kg. In February 2021, it was determined by the team that the high dispensed costs are likely a result of unexpected hydrogen venting losses in the system, traced primarily to the two hydrogen supply compressors between the electrolyzer and the low-pressure storage system which had been supplied by a third-party vendor. Premature packing failures were discovered, and the rod packing was replaced in both compressors. Early data shows that the system losses have been dramatically reduced, from approximately 50% loss through the system to <5%. Further work is needed to close out the root cause analysis, and to implement prevention and detection measures to ensure this does not happen again.

Figure 6 shows the monthly cost of dispensed hydrogen plotted with the amount of hydrogen dispensed in each month. Generally, the months with the lowest cost had higher throughput of hydrogen production and dispensing. Figure 7 shows the relationship between the monthly cost of dispensed hydrogen plotted with the average station downtime each month. There appears to be a strong correlation between hydrogen cost and station downtime; the months with the lowest costs had the least planned downtime. However, while November 2020 had low downtime, the cost of dispensed hydrogen was the highest to date in that month. This is now thought to be a result of the compressor packing failure described above. Station downtime does still impact dispensed hydrogen cost, as one known impact of downtime is that the electrolyzer vents hydrogen upon startup in order to reach target dewpoint before sending produced hydrogen to the storage system. The team continues to actively work to improve the station reliability and reduce downtime.

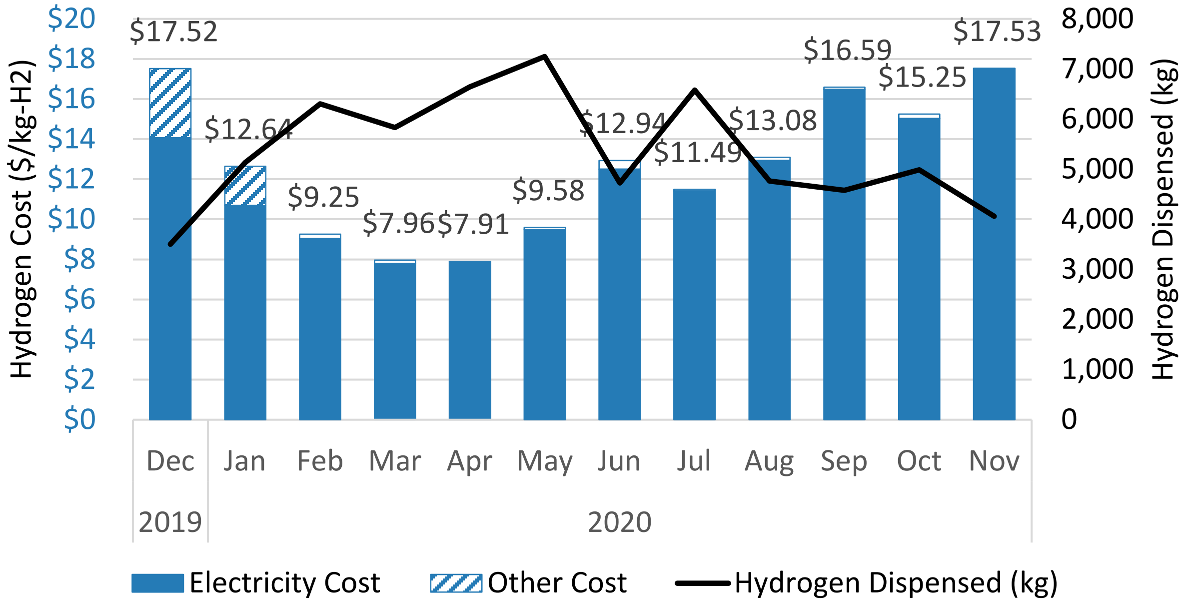


Figure 6 – Cost of hydrogen per month vs. hydrogen dispensed per month

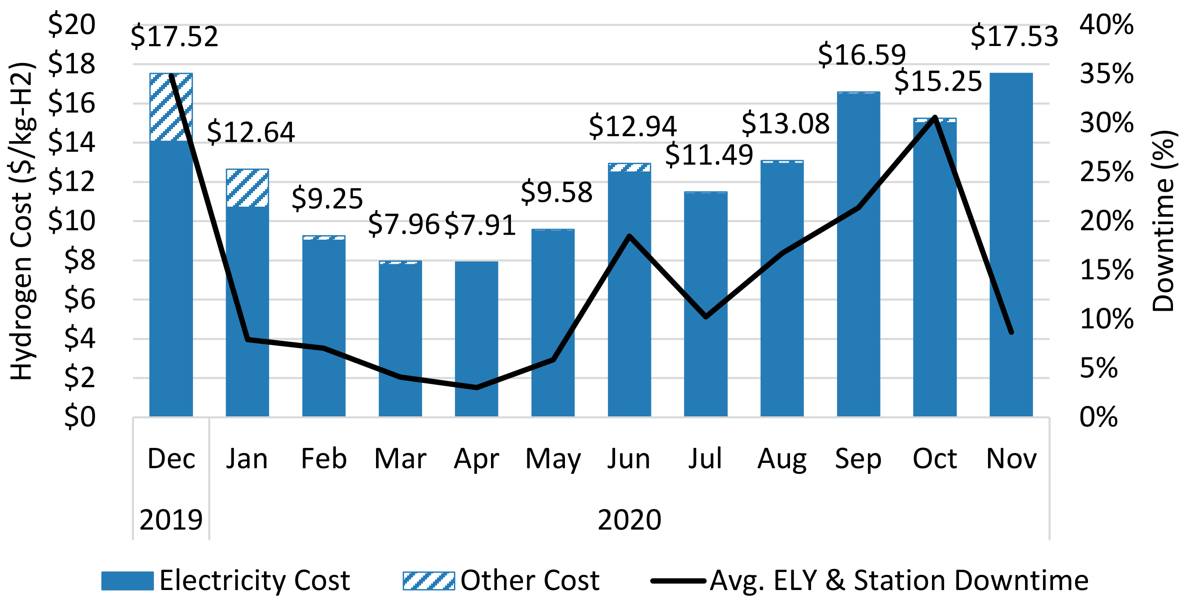


Figure 7 – Cost of hydrogen per month vs. average H2 station and ELY downtime per month

Downtime of the H2 station and the electrolyzer varied throughout the project, resulting in an average downtime of 20% and 9%, respectively, and a combined average downtime of 14%. Several downtime events resulted from increasing ambient temperature in Thousand Palms, as the cooling system struggled to operate normally. The average H2 station and electrolyzer downtime per month versus the highest ambient temperature is displayed in Figure 8 to illustrate the relationship between temperature and downtime.

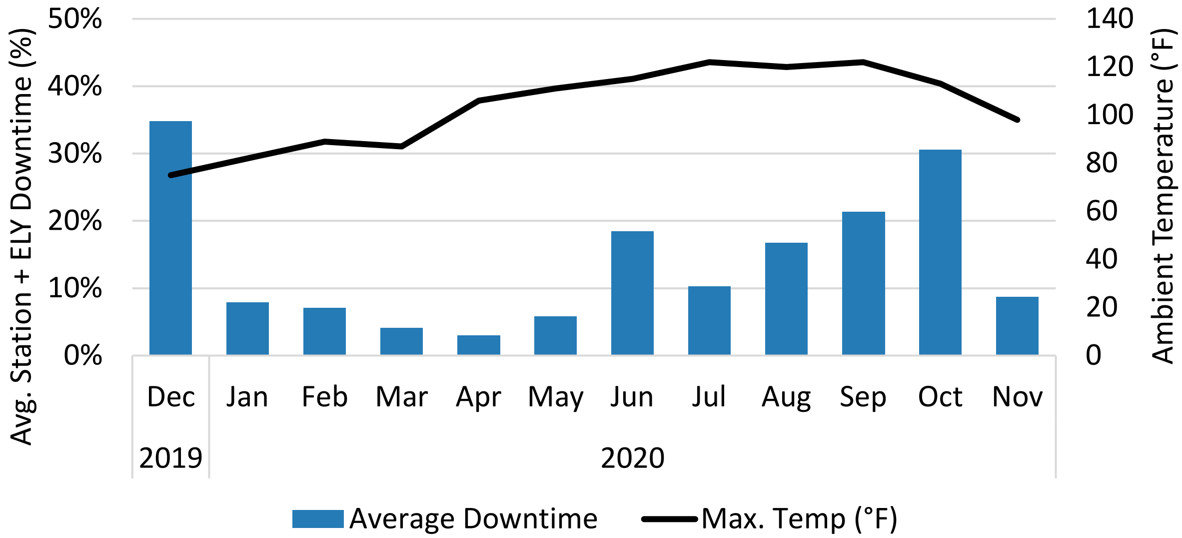


Figure 8 – H2 station availability per month vs. maximum monthly ambient temperature

December 2019 had the most downtime with a value of 35% averaged for the H2 station and electrolyzer. Most downtime in December can be attributed to startup issues as well as low CO2 compressor levels in the H2 station hydrogen pre-cooling system, resulting in numerous alarms and technicians on site having to manually cycle the compressor to regain CO2 levels after each fill. During site commissioning, it was discovered that a cooling system upgrade would be required in the system. One impact of the undersized cooling system was the inability to fully condense and recover the CO2 cooling medium in the H2 station. COVID-19 resulted in some delays to implement the upgrades, which were put in place in September 2020. In order to mitigate overheating during the early months of operation, the fill rate was reduced via a software fix described further below.

The downtime in October 2020 was high with a value of 31% due to planned downtime and maintenance occurring when the temporary dispensers were taken down and moved to their permanent positions.

A general increase in downtime began in May 2020 due to maintenance and repairs being delayed by external factors discussed in *Impact of Unforeseen Events* and as ambient temperatures reached over 100° until November 2020. The increased temperatures resulted in cooling restraints in the equipment related to the main station module compressor and oil cooling system. A heater failure in the electrolyzer hydrogen drying system in June 2020 and delayed shipping of replacement parts, caused the electrolyzer to shut down for 6 days, resulting in an average downtime of 18%.

To improve the dispenser fueling rate, the chilling system was replaced by adding pre-cooling to the hydrogen before entering the station modules when the permanent stations were constructed in mid-October. Prior to upgrading the cooling, the fill rate was reduced to ~ 1kg/min to avoid overheating during fueling. Once the additional cooling was added, the software was reset to the target fill rate of 2 kg/min, whereby a 30 kg full fill can be achieved in approximately 15 minutes. The fueling rates of the two systems is displayed in Figure 9. The results include fueling events for all buses in SunLine's fleet, not just the five LCT buses. Some of the older FCEBs fleet have on-board storage of 50 kg, compared to 37.5 kg for the LCT buses.

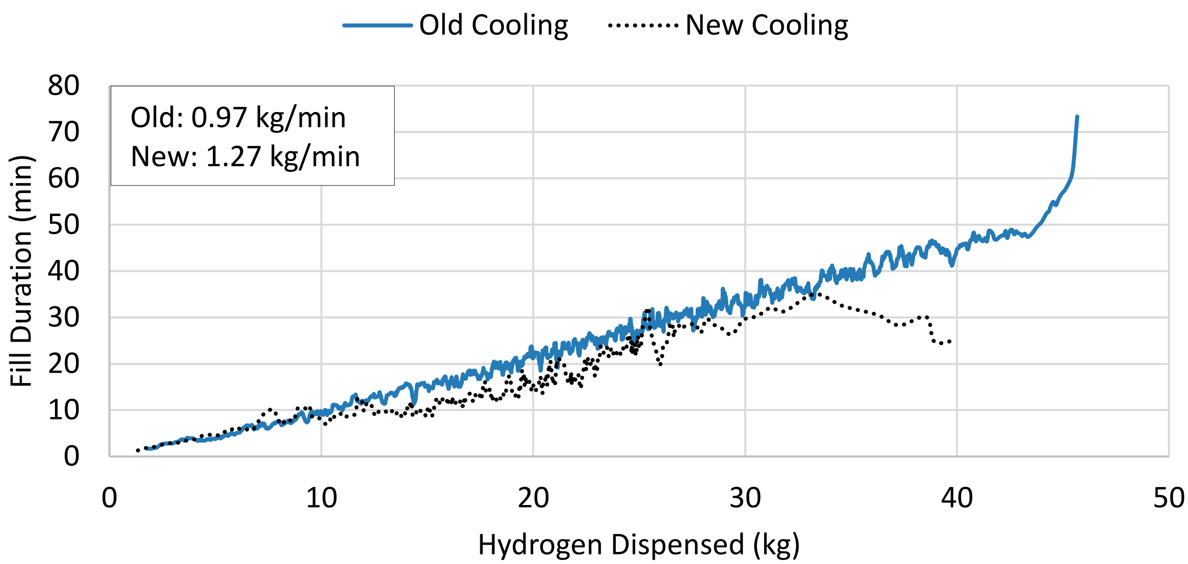


Figure 9 – Station fueling rate of old and new chiller system

The original cooling system prior to upgrade, in operation between December 1, 2019 to September 17, 2020, provided an average filling rate of 0.97 kg/min, whereas the upgraded system with increased cooling capacity achieved via the addition of a new chiller, in operation starting September 17, 2020, performed at rate of 1.27 kg/min. The fill rate was estimated to be ~2 kg/min during the majority of the filling event; however, the fill rate is decreased during the initial startup leak and pressure check (~15 seconds), intermediate leak check (~5 seconds), and is brought down to 0.9 kg/min for the last 20 bar of fueling pressure to allow for optimal state of charge. As such, the average filling rate of the new cooling system resulted in 1.27 kg/min for the total fueling time.

Further testing is required to validate fill performance with larger fills and under a wider range of ambient temperatures.

Bus Performance

The five LCT FCEBs travelled a total of 151,254 miles throughout the course of the project with an average of 30,251 miles/bus. The total distance travelled per LCT bus is shown in Figure 10.

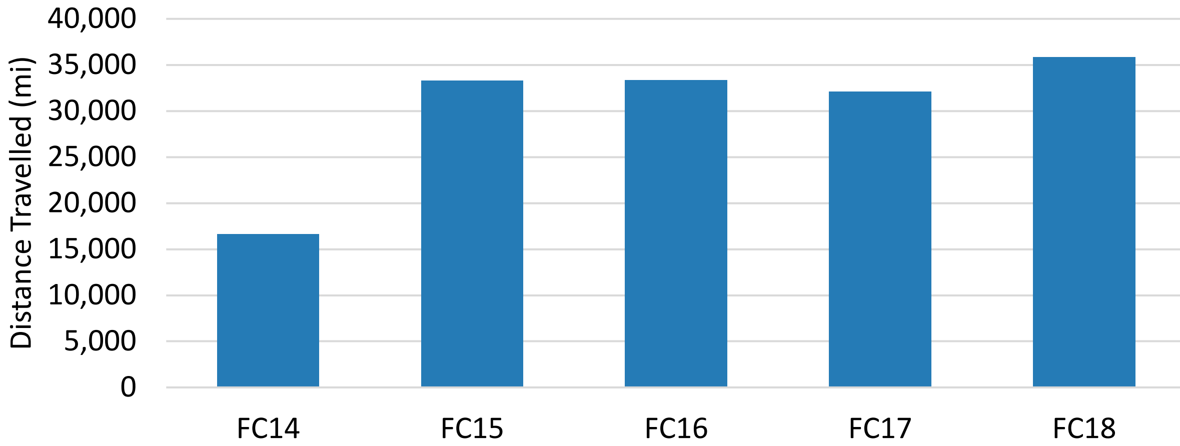


Figure 10 – Total distance travelled per LCT bus

In early October 2020, a front-end loader from a neighbouring cement plant rolled through the fence and into FC14, resulting in the bus being repaired and out of service until May 2020. As such, FC14 had a considerably lower distance travelled (16,666 miles) than the other four LCT buses (33,647 miles on average).

To compare the FCEBs to CNG buses, data from two baseline CNG buses operating on similar routes to the LCT buses was collected. The mileage of each CNG bus is displayed in Figure 11.

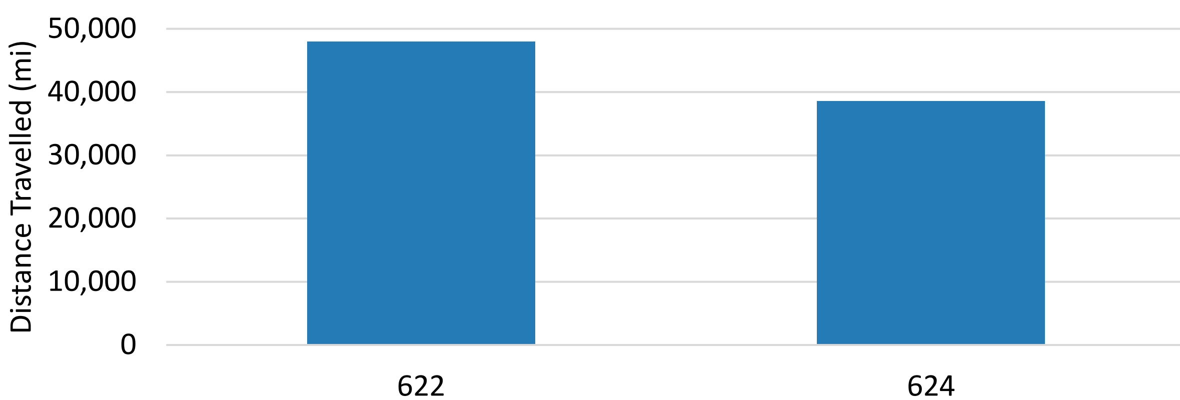


Figure 11 – Total distance travelled per equivalent CNG bus

Over the course of the project, the two CNG buses travelled a total and average of 86,541 miles and 43,271 miles/bus, respectively. Both buses experienced prolonged periods of downtime due to required maintenance. The engine of Bus 624 was rebuilt off-site at the Cummins repair facility, causing it to be out of service from Nov 15, 2019, to Jan 9, 2020, and was also sidelined in July 2020 for required maintenance. Bus 622 was sidelined from September 18, 2020, for the remaining duration of the project due to damages sustained while the bus was stolen. A comparison of the average mileage and fuel dispensed per bus for the FCEBs and CNG buses is provided in Figure 12.

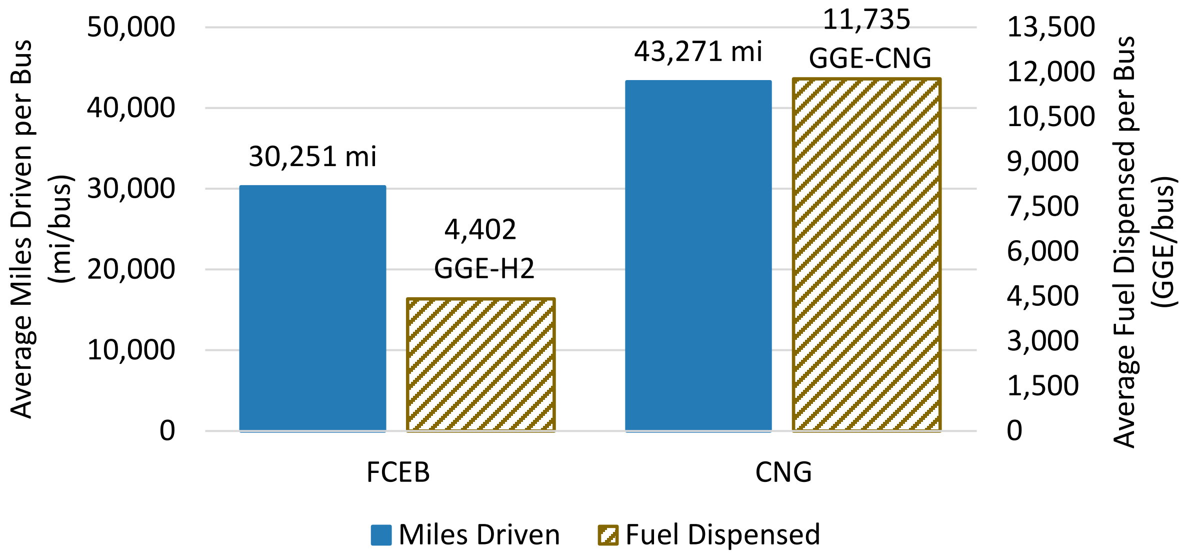


Figure 12 – Average mileage and fuel dispensed for LCT FCEBs and CNG buses

The CNG buses travelled an average of 13,020 miles and consumed 7,333 GGE-CNG more per bus than the LCT buses. The difference in mileage between bus technologies can be explained by FC 14 being out of service for 9 months and unforeseen events putting the buses at risk for which the FCEBs were pulled out of service but the CNG buses continued to operate. In addition, for the first several months of operation, SunLine had to run the FCEBs on shorter routes due to limitations in hydrogen availability from the SMR system that was used to produce fuel for the buses from the period they went into operation until December 2, 2019.

Fuel Economy

The average fuel economy for the entire project and range of monthly fuel economy for the LCT buses, other FCEBs in SunLine's fleet, and two CNG buses were calculated and displayed in Figure 13 to compare the latest FCEB technology to older generations and CNG buses. FCEB fuel economy is typically measured in miles per kg of hydrogen (mi/kg) since a kg is the standard unit of measurement for hydrogen in transportation applications. SunLine tracks CNG bus fuel economy in miles per gallon of gasoline-equivalent (mi/GGE). In terms of energy, one kilogram of hydrogen is approximately equal to one-gallon gasoline-equivalent (1 kg-H2 = 1.004 GGE[2]).

[2] California Air Resources Board. (2019). The LCFS Credit Price Calculator Version 1.3. Retrieved from https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard

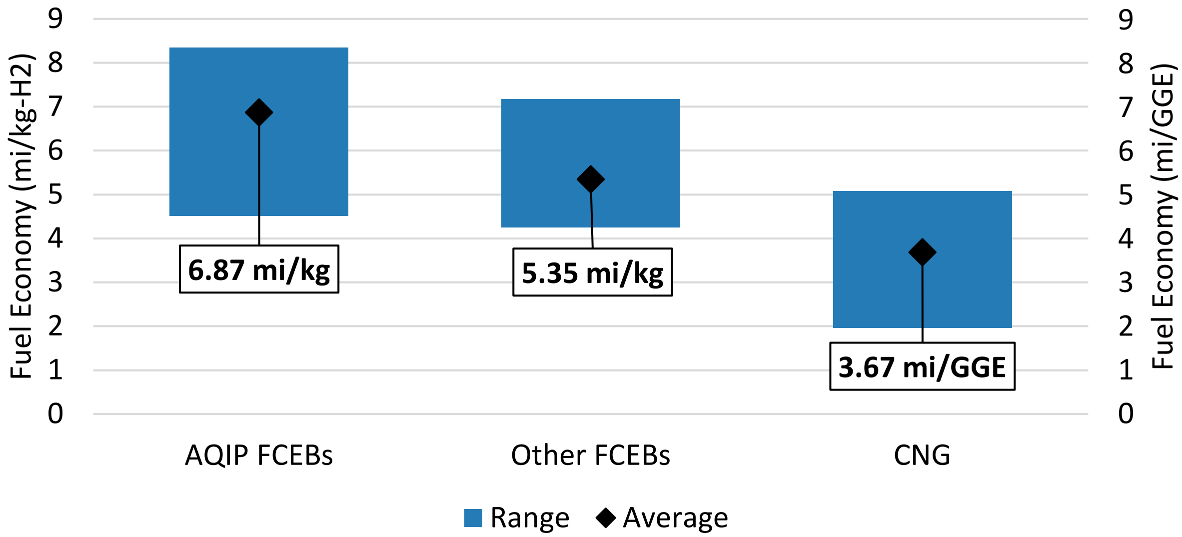


Figure 13 – Average and range of fuel economy for LCT FCEBs, other FCEBs, and CNG buses in SunLine's fleet

The LCT buses had the highest annual average fuel economy with a value of 6.87 mi/kg-H2, resulting in a fuel economy of 1.52 mi/kg-H2 and 3.2 mi/GGE-CNG greater than the other FCEBs in SunLine's fleet and the CNG buses, respectively. All bus technologies experienced a wide range in average fuel economy each month depending on the ambient temperature. The maximum average monthly fuel economy for the LCT buses was 16% and 64% greater than the maximum average monthly fuel economy of SunLine's other FCEBs and CNG buses, respectively. The relationship between the fuel economy of the LCT buses and ambient temperature was observed and is displayed in Figure 14.

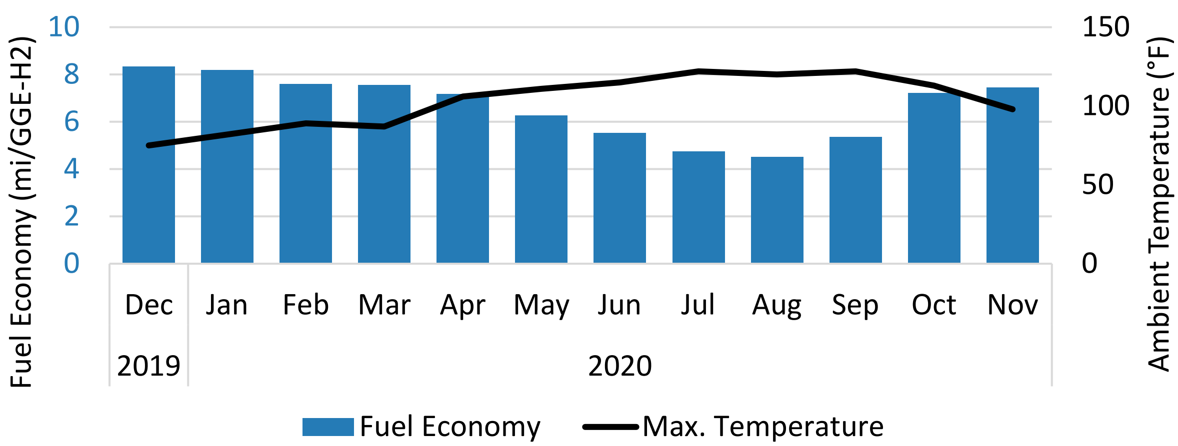


Figure 14 – Fuel economy of LCT FCEBs vs. maximum ambient temperature per month

The fuel economy ranged from 4.51 to 8.34 miles/kg-H2 and was observed to be lower when the ambient temperature increased. The reduced fuel economy occurring when ambient temperatures are high is in large part due to higher air conditioning loads and fuel cell system cooling loads, which increase the power demand from the vehicle.

A range for the cost of each technology on a per mile basis was calculated using the range of monthly fuel costs (Figure 7) and fuel economy (Figure 13) as displayed in Figure 15.

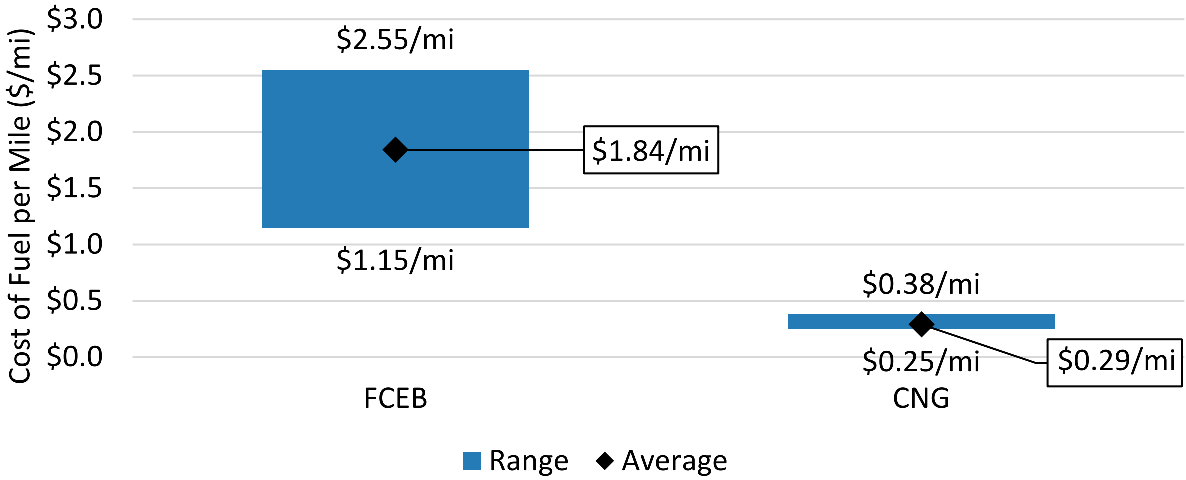


Figure 15 – Cost of fuel per mile for FCEB and CNG buses

The average cost of fuel per mile for the LCT FCEBs and CNG buses over the course of the project was $1.84/mi and $0.29/mile, respectively. The cost of hydrogen per mile had a larger variance than CNG as the cost of hydrogen was strongly dependent on station downtime and the venting losses that have been recently corrected. The lowest cost of hydrogen per mile was $1.15/mi and $2.55/mi at its highest. Going forward, the team will be working to bring the cost per mile of the hydrogen buses down.

Renewable Hydrogen Content

SunLine has contracted an independent broker to purchase RECs to offset emissions from the generation of hydrogen and register low carbon fuel standard (LCFS) credits with CARB. The broker began purchasing RECs in Q2 of 2020 and has been purchasing or will purchase RECs to offset 100% of the electricity used to generate hydrogen. Credits have not been purchased to offset electricity used by the balance-of-plant (BOP) of the electrolyzer system including equipment such as compressors, pumps, and controls.

Table 6 shows the electricity consumption used by the electrolyzer as well as the BOP and the RECs purchased to offset emissions.

Table 6 – Electricity and RECs summary

Month	Electrolyzer Electricity (kWh)	BOP Electricity (kWh)	RECs Purchased (kWh)	Electricity not offset (kWh)	Hydrogen Dispensed (kg)
Dec-19	271,200	49,000		320,200	3,138
Jan-20	331,200	50,000		381,200	5,545
Feb-20	422,400	62,000		484,400	6,235
Mar-20	309,600	48,000		357,600	6,555
Apr-20	384,000	61,000	384,000	61,000	6,191
May-20	501,600	93,000	501,600	93,000	6,934
Jun-20	393,600	73,000	393,600	73,000	5,660
Jul-20	518,400	100,000	518,400	100,000	5,623
Aug-20	367,200	94,000	367,200	94,000	5,774
Sep-20	511,200	96,000	511,200	96,000	3,970
Oct-20	492,000	84,000	492,000	84,000	4,545
Nov-20	480,000	59,000	480,000	59,000	3,617
Total	**4,982,400**	**869,000**	**3,648,000**	**2,203,400**	**63,787**

RECs were purchased to offset emissions for 73% of the electricity consumed in the production of hydrogen throughout this process, more than twice as much as the 33% renewable content requirement.

The hydrogen carbon intensity (CI) can be calculated using the following calculation:

$$H2\ CI = (kWh_{Not\ Offset}\ )(Grid\ CI)/(H2\ dispensed)$$

The California grid CI was assumed to be 82.92 g-CO2e/MJ.[3]

$$H2\ CI_{actual} = \left(\frac{2{,}203{,}400\ kWh}{year}\right)\left(\frac{3.6\ MJ}{kWh}\right)\left(\frac{82.92\ gCO2e}{MJ}\right)\left(\frac{year}{63{,}787\ kgH2}\right)\left(\frac{kgH2}{120\ MJ}\right) = \mathbf{85.9\ gCO2e/MJ}$$

Moving forward, SunLine will purchase offsets or use renewable electricity directly for 100% of the electricity used to generate hydrogen, exactly as was done from April through November. The CI for hydrogen produced over this period was calculated, which is a better indicator of the expected CI for future years of operation.

[3] CARB. (2020). Low Carbon Fuel Standard Annual Updates to Lookup Table Pathways. Retrieved from https://ww2.arb.ca.gov/sites/default/files/classic//fuels/lcfs/fuelpathways/comments/tier2/elec_update.pdf

$$H2\ CI_{future} = \left(\frac{660{,}000\ kWh}{year}\right)\left(\frac{3.6\ MJ}{kWh}\right)\left(\frac{82.92\ gCO2e}{MJ}\right)\left(\frac{year}{42{,}314\ kgH2}\right)\left(\frac{kgH2}{120\ MJ}\right)$$
$$= \mathbf{38.8\ gCO2e/MJ}$$

In the fall of 2020, SunLine connected on-site solar generation to the medium voltage (MV) buss powering the BOP loads in the electrolyzer system. This solar, integrated via a net-metering arrangement, has already demonstrated significant cost savings. SunLine intends to expand the solar generation on-site in the future. Reducing the carbon intensity of the hydrogen will also increase the number of low carbon fuel standard credits generated per kilogram of hydrogen, which will increase revenue for SunLine. These costs have not been incorporated into the cost of hydrogen shown in this report.

GHG and CAC Emissions

GHG Emissions Reduction

The greenhouse gas (GHG) emissions reduction from the project can be calculated using

$$GHG_{Savings} = GHG_{Baseline} - GHG_{FCEB}$$

$$GHG_{Baseline} = \frac{(Annual\ Mileage)(Number\ of\ Buses)(CI_{Baseline})(Energy\ Density_{Baseline})}{(Fuel\ Economy_{baseline})}$$

$$GHG_{FCEB} = \frac{(Annual\ Mileage)(Number\ of\ Buses)(CI_{FCEB})(Energy\ Density_{H2})}{(Fuel\ Economy_{FCEB})}$$

In the original grant application, the FCEB fuel economy was unknown, so it was estimated using the following formula:

$$Fuel\ Economy_{FCEB} = \frac{(Fuel\ Economy_{Baseline})(Energy\ Density_{H2})(EER)}{(Energy\ Density_{Baseline})}$$

The calculations were completed looking at three sets of parameters representing:

1. The assumptions made in the initial grant application. These assumptions were made before the completion of the trial and so parameters such as annual mileage, and FCEB fuel economy were unknown.
2. The actual bus performance over the one-year trial period (December 2019 through November 2020).
3. Expected performance in future years. This scenario accounts for the anomalous factors impacting 2020 such as COVID-19, the unusual accidents requiring buses to be out of service for long periods, and the decreased hydrogen carbon intensity since SunLine has started purchasing RECs to offset GHG emissions from 100% of the electricity used to generate hydrogen.

Table 7 shows the inputs used for the GHG benefits calculation and the estimated savings used in the initial grant application, based on actual performance, and based on future expected performance.

Table 7 – GHG benefit calculations (diesel baseline)

Parameter	Unit	Application	Actual	Expected
Number of Buses	buses	5	5	5
CI Diesel	g-CO2e/MJ	102.76	102.76	102.76

Parameter	Unit	Application	Actual	Expected
CI H2	g-Co2e/MJ	0.0	85.9	38.8
Diesel Bus Fuel Economy	mi/DGE	4	4	4
Miles per year	mi/year/bus	123,881	30,251	44,305
Energy Density Diesel	MJ/DGE	134.47	134.47	134.47
Energy Density Hydrogen	MJ/kg-H2	120	120	120
EER		1.9	1.86*	1.86*
FCEB Fuel Economy	mi/kg-H2	6.78*	6.87	6.87
GHG Saved	**tonnes-CO2e/year**	**2,139.8**	**295.6**	**615.2**

*Calculated based on other parameters in the table

The estimated GHG emissions reduction is much greater in the application than actually achieved. The primary reason for this is the assumed mileage was much greater in the application than actually achieved. The application assumed each bus would operate 339 miles/day 365 days per year. This represents the maximum capabilities of the bus assuming it achieves its full range on a daily basis. On average, SunLine's buses operate 44,305 miles annually. The actual mileage was lower than this because of external factors limiting bus operation this year including the impacts of COVID-19 and extended downtime of one FCEB resulting from an accident. These issues are discussed in more detail in the *Impact of Unforeseen Events Section*.

The GHG cost effectiveness over 2 and 10 years can be estimated using the following formula:

$$GHG\ Cost\ Effectiveness_{2/10-year} = \frac{(Captial\ Cost_{FCEB} - Capital\ Cost_{Baseline})(Capital\ Rcovery\ Factor_{2/10-year})}{GHG_{Savings}}$$

Table 8 shows the input parameters and calculated GHG cost effectiveness over 2 and 10 years. It shows the result based on data from the initial grant application, from the actual data collected over the one-year trial and based on expected future performance.

Table 8 – GHG Cost Effectiveness

Parameter	Unit	Application	Actual	Expected
Diesel bus Cost	$/bus	$750,000	$750,000	$750,000
FCEB Cost	$/bus	$1,399,680	$1,180,000	$1,180,000
Capital Recovery Factor_2		0.515	0.515	$1
Capital Recovery Factor_10		0.111	0.111	$0
GHG Saved	tonnes-CO2e/year	2,139.8	295.6	615.2
GHG Cost Effectiveness_2 year	**$/tonnes-GHG**	**$782**	**$3,746**	**$1,800**
GHG Cost Effectiveness_10 year	**$/tonnes-GHG**	**$169**	**$807**	**$388**

The calculations above are based on a diesel bus baseline. SunLine does not operate any diesel buses, but the majority of the fleet is made up of CNG vehicles. The calculations were completed to estimate the GHG emissions reduction compared to a CNG bus baseline.

Table 9 shows the parameters used to estimate GHG emissions reduction compared to a CNG baseline. The CNG fuel economy was calculated based on performance of the two reference CNG buses – 622 and 624.

Table 9 – GHG benefit calculation (CNG baseline)

Parameter	Unit	Actual	Expected
Number of Buses	buses	5	5
CI CNG	g-CO2e/MJ	79.46	79.46
CI H2	g-Co2e/MJ	85.9	38.8
CNG Bus Fuel Economy	mi/GGE	3.69	3.69
Miles per year	mi/year/bus	30,251	44,305
Energy Density GGE	MJ/GGE	119.53	119.53
Energy Density Hydrogen	MJ/kg-H2	120	120
FCEB Fuel Economy	mi/kg-H2	6.78	6.87
GHG Saved	**tonnes-CO2e/year**	**162.4**	**420.1**

CAC Emissions Reduction

Criteria air contaminants (CAC) emissions are comprised of nitrous oxides (NOx), reactive organic gases (ROG), and particulate matter (PM10). FCEBs emit only water vapor through the vehicle tailpipe, so the emissions savings are equal to the tailpipe emissions of a baseline bus operating over the same duty cycle.

The CAC emissions reduction can be estimated using the following equations:

$$NOx_{Savings} = \frac{(Annual\ Mileage)(Number\ of\ Buses)(Emissions\ Factor_{NOx})}{(Fuel\ Economy_{Baseline})}$$

$$ROG_{Savings} = \frac{(Annual\ Mileage)(Number\ of\ Buses)(Emissions\ Factor_{ROG})}{(Fuel\ Economy_{Baseline})}$$

$$PM10_{Savings} = \frac{(Annual\ Mileage)(Number\ of\ Buses)(Emissions\ Factor_{PM10})}{(Fuel\ Economy_{Baseline})}$$

The weighted emissions reduction (WER) can be calculated using the following equation:

$$WER = (NOx_{WER\ Factor})(NOx_{Savings}) + (ROG_{WER\ Factor})(ROG_{Savings}) + (PM10_{WER\ Factor})(PM10_{Savings})$$

Similar to the GHG emissions reduction, the CAC emissions reduction was calculated based on the assumptions in the initial application, the actual bus performance during the project demonstration period, and the expected future performance.

Table 10 – CAC Emissions Reduction (Diesel Baseline)

Parameter	Unit	Application	Actual	Expected
Number of Buses	buses	5	5	5
Miles per year	mi/year/bus	123,881	30,251	44,305
Diesel Bus Fuel Economy	mi/DGE	4	4	4
NOx Emissions Factor	g-NOx/DGE	3.44	3.44	3.44
ROG Emissions Factor	g-ROG/DGE	0.18	0.18	0.18
PM10 Emissions Factor	g-PM10/DGE	0.15	0.15	0.15
WER NOx Factor	-	1	1	1
WER ROG Factor	-	1	1	1
WER PM10 Factor	-	20	20	20
Conversion Factor	ton/tonnes	1.102	1.102	1.102
NOx Emissions Savings	ton-NOx/year	0.587	0.143	0.210
ROG Emissions Savings	ton-ROG/year	0.031	0.008	0.011
PM10 Emissions Savings	ton-PM10/year	0.026	0.006	0.009
WER	**ton-CAC/year**	**1.13**	**0.28**	**0.40**

Similar to the GHG emissions reduction, the major factor causing the actualized emissions reduction to be less than the application is the reduction in mileage.

The CAC cost-effectiveness over 2 and 10 years can be estimated using the following formula:

$$CAC\ Cost\ Effectiveness_{2/10-year} = \frac{(Captital\ Cost_{FCEB} - Capital\ Cost_{Baseline})(Capital\ Recovery\ Factor_{2/10-year})}{WER}$$

Table 8 shows the input parameters and calculated CAC cost-effectiveness over 2 and 10 years. It shows the result based on data from the initial grant application, from the actual data collected over the one-year trial and based on expected future performance.

Table 11 – CAC Cost Effectiveness

Parameter	Unit	Application	Actual	Expected
Diesel bus Cost	$/bus	$750,000	$750,000	$750,000
FCEB Cost	$/bus	$1,399,680	$1,180,000	$1,180,000
Capital Recovery Factor_2		0.515	0.515	0.515
Capital Recovery Factor_10		0.111	0.111	0.111
WER	ton-CAC/year	1.13	0.28	0.40
CAC Cost Effectiveness_2 year	**$/ton-CAC**	**$1,480,495**	**$4,012,766**	**$2,739,884**
CAC Cost Effectiveness_10 year	**$/ton-CAC**	**$319,097**	**$685,351**	**$590,538**

The same analysis was conducted using a CNG baseline to investigate the emissions reduction relative to the fossil fuel powered vehicles in SunLine's fleet. Table 12 shows the CAC emissions reduction relative to a CNG baseline.

Table 12 – CAC Emissions Reduction (CNG Baseline)

Parameter	Unit	Actual	Expected
Number of Buses	buses	5	5
Miles per year	mi/year/bus	30,251	44,305
CNG Bus Fuel Economy	mi/GGE	3.69	3.69
NOx Emissions Factor	g-NOx/GGE	0.135	0.135
ROG Emissions Factor	g-ROG/GGE	0.043	0.043
PM10 Emissions Factor	g-PM10/GGE	0.007	0.007
WER NOx Factor		1	1
WER ROG Factor		1	1
WER PM10 Factor		20	20
Conversion Factor	ton/tonnes	1.102	1.102
NOx Emissions Savings	ton-NOx/year	0.149	0.218
ROG Emissions Savings	ton-ROG/year	0.047	0.069
PM10 Emissions Savings	ton-PM10/year	0.008	0.011
WER	**ton-CAC/year**	**0.348**	**0.510**

Impact on Disadvantaged Communities

The majority of SunLine's fixed route buses pass through and provide transportation for people living in disadvantaged communities on a daily basis. This service is critical as it is relied upon by these communities for essential travel including to workplaces, medical appointments, government agencies, etc.

Figure 16 shows the disadvantaged communities within SunLine's service territory as defined by the latest version of CalEnviroScreen.[4]

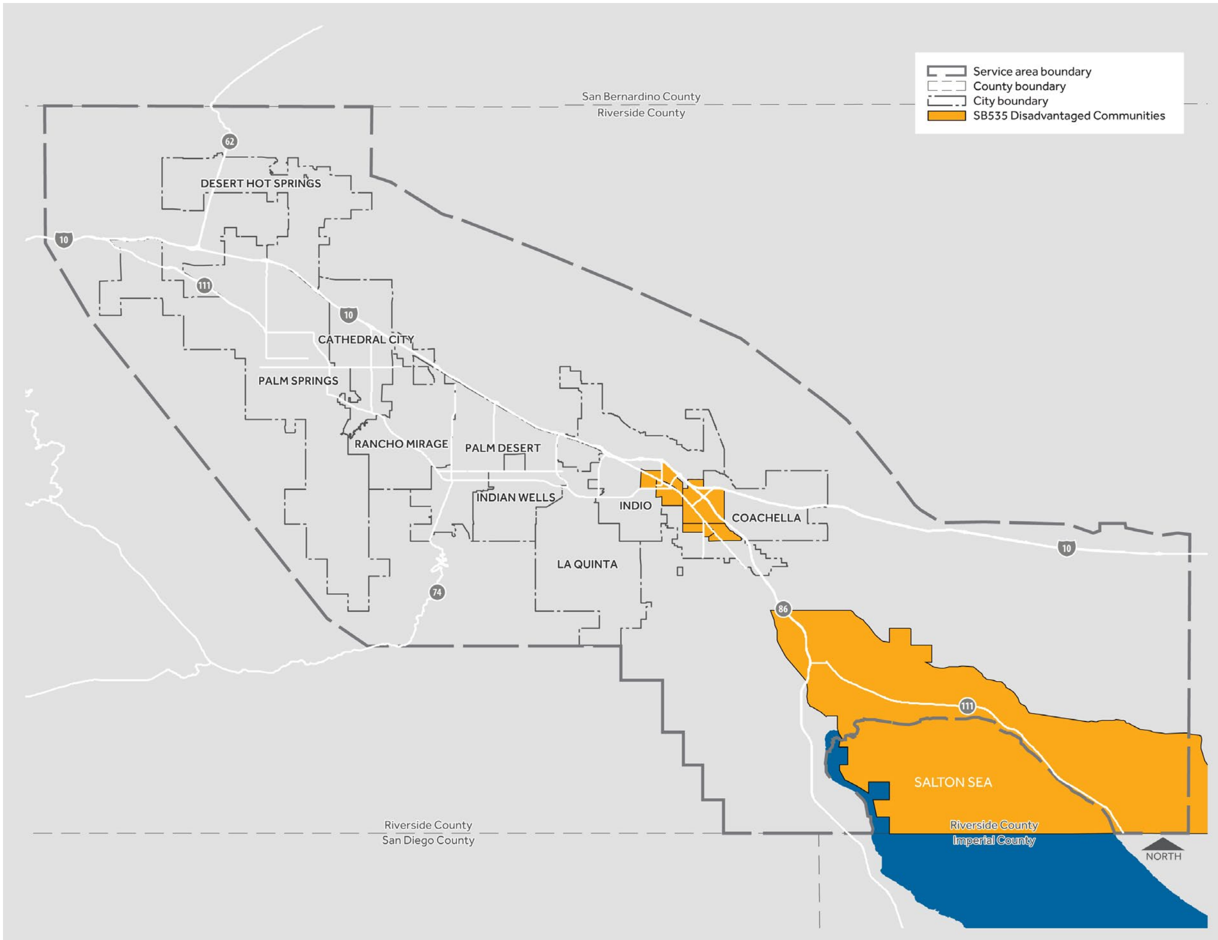


Figure 16 – Disadvantaged communities within SunLine Service territory

The Census Tracts located within SunLine's service territory are:

- 6065045303
- 6065045502
- 6065045604
- 6065045706
- 6065045707
- 6065049500
- 6065940400

Disadvantaged communities experience disproportionately high levels of air contaminants such as NOx, ROG, and PM10. Buses often drive in stop-and-go traffic where they spend considerable time idling, wasting fuel, and increasing emissions. Pollution from bus operation is a concern for populations living along bus routes, and benefit from the deployment of zero-emission

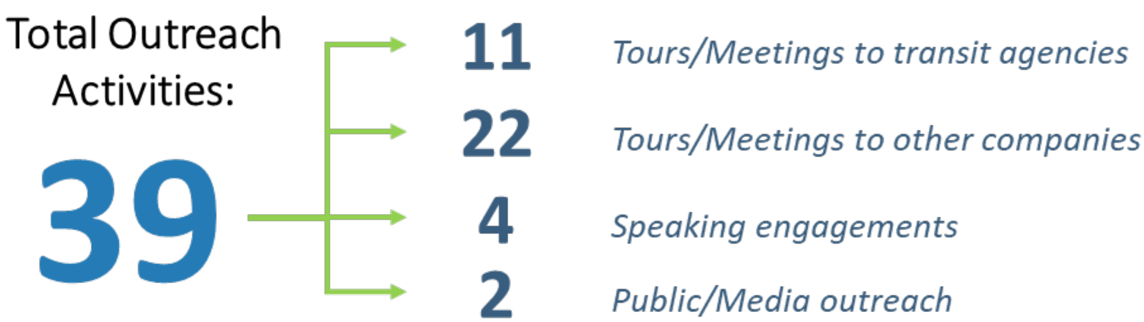
[4] CalEnviroScreen 3.0. (June 2018). SB535 Map of Disadvantaged Communities. Retrieved from http://oehha.maps.arcgis.com/apps/View/index.html?appid=c3e4e4e1d115468390cf61d9db83efc4

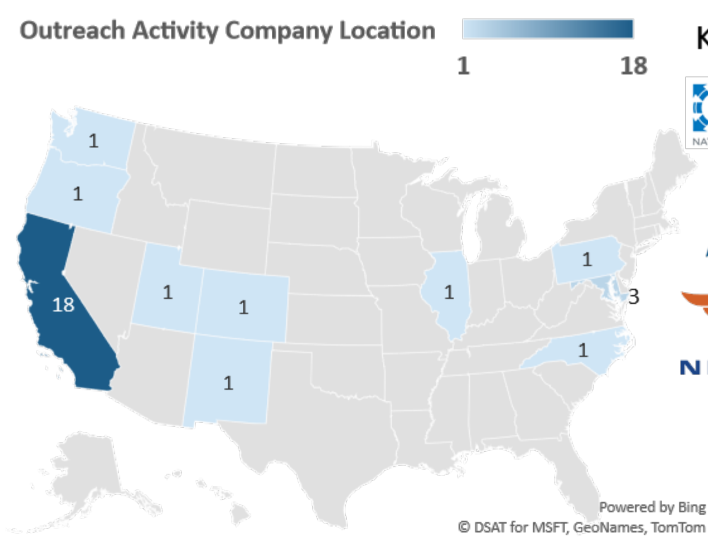
technology such as FCEBs.

All five of the LCT FCEBs were deployed out of SunLine's Thousand Palms facility. They were dispatched to serve disadvantaged communities on numerous different routes, which also enabled SunLine to test performance over a range of duty cycles and ensure service was met. As described in the *Impact of Unforeseen Events Section*, COVID-19 impacted the way in which all buses were dispatched including the LCT FCEBs. Approximately 43% of the time during the demonstration period, the LCT FCEBs were dispatched as additional buses following regularly scheduled Sunday service to limit the number of passengers on each bus.

OUTREACH ACTIVITIES

Outreach and sharing of lessons learned was an important part of the project. As a leader in zero emission transit, SunLine has a long history of sharing project results and providing guidance to other agencies new to zero emission buses and supporting infrastructure. SunLine conducted 39 outreach activities throughout the project, with agencies and media outlets spanning the country. Engagements included tours and meetings with public transit agencies and companies such as technology providers and potential fuel off-takers, speaking engagements at conferences, and media events to showcase the project.





Key Companies:

Transit Agency Meetings & Tours

SunLine held 11 tours/meetings with American transit agencies including eight agencies from California and 3 from other states. Agencies typically met with SunLine and toured the site to understand the benefits and practical considerations related to deploying hydrogen fuel cell buses and supporting infrastructure, including maintenance considerations and driver training.

Other Meetings & Tours

This project generated significant interest outside of transit agencies as well. Private companies and public institutions in the following categories met with SunLine specifically about project elements throughout the project timeframe:

- Hydrogen fuel cell vehicle OEMs
- Universities / academic institutions
- Government agencies
- Industrial gas companies

Speaking Engagements

SunLine participated in four speaking engagements throughout the project timeframe where information about the project was shared:

- *Advancing the Commercialization of Hydrogen Fuel Cell Technology*; *Charge Expo Symposium,* October 2, 2019
- *NorCal Clean Fleet Technology Conference and Expo*; October 16-17, 2019
- *Impact of Zero Emission Buses*: *The Costs of BEB and Hydrogen Fuel Cell*; CALACT 2019 Autumn Conference, October 31, 2019
- *Panelist at CALSTART event*, Virtual Site Visit at New Flyer Alabama, August 4, 2020

Public/Media Outreach - Earth Day

In April 2019, SunLine hosted Earth Day which involved the unveiling of the 5 LCT fuel cell buses, introduction to the Nation's largest transit-related hydrogen fueling station with on-site production under construction, and an environmental exhibitor fair and Learning Center tours. The full day event aimed to educate the public on fuel cell and clean technology transit buses. The event had excellent turnout and resulted in several local articles being published.

In November 2020, the New York Times published an article entitled, "*California is Trying to Jump-Start the Hydrogen Economy*". An excerpt of the article is as follows:

"Some proponents of hydrogen think its biggest use will be in larger vehicles. Among them is SunLine Transit, which serves Palm Springs and other cities in Riverside County.

The transit system has 17 hydrogen buses and is planning to add 10 in the next year. SunLine used more than $27 million in grants over the last 10 years to buy the vehicles and equipment to produce hydrogen, which it makes with the help of electricity from the grid and solar panels. The transit agency already sells compressed natural gas, which fuels most of its buses, to commercial and government agencies, and it plans to sell hydrogen, too."

SunLine Transit has invested in equipment that can split water into oxygen and hydrogen atoms. Philip Cheung for The New York Times

POTENTIAL FOR FUTURE EXPANSION

SunLine Operations

The LCT project will directly enable SunLine to increase the number of FCEBs in the fleet beyond the five buses funded by the program. As of the completion of this report, SunLine operates 17 fixed route FCEBs and plans to add five more in the coming year. The 900 kg/day electrolyzer allows for the fleet to expand up to 30-36 FCEBs without the need for additional infrastructure.

Figure 17 and Figure 18 show the forecasted fixed route and paratransit bus fleet compositions as SunLine transitions to zero-emission as outlined in SunLine's Zero-Emission Bus Rollout Plan.[5] The number of FCEBs is expected to increase until 2035 at which point the entire fleet will be zero-emission.

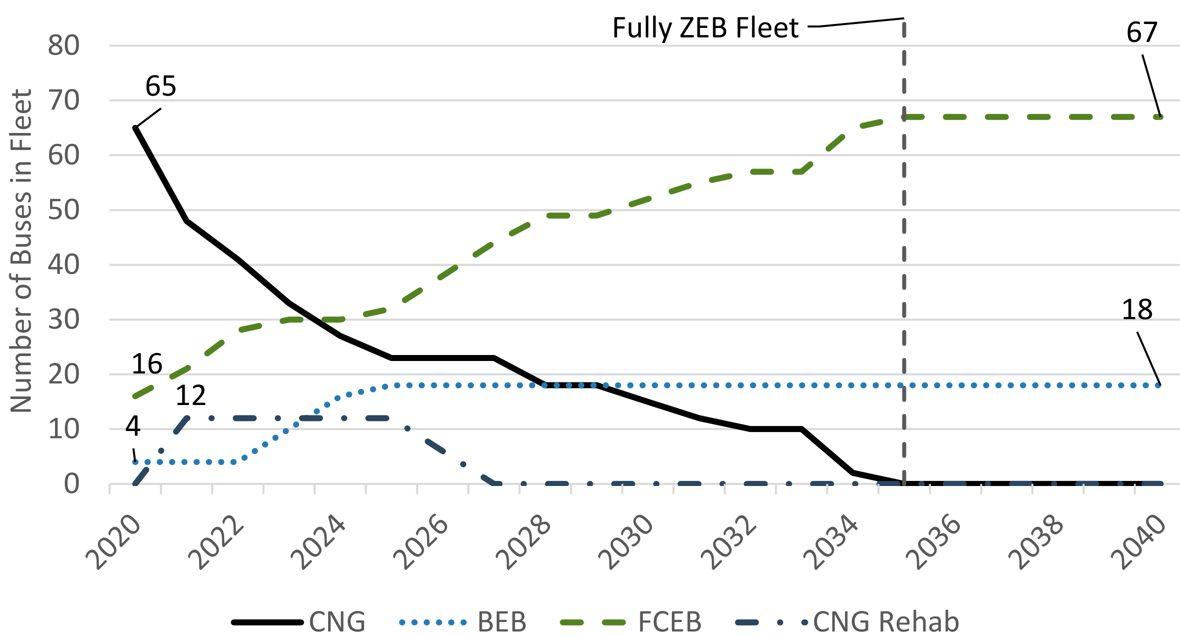


Figure 17 – Fixed route bus fleet composition by year

[5] SunLine Transit. (2020). *Zero-Emission Bus Rollout Plan*. Retrieved from https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans

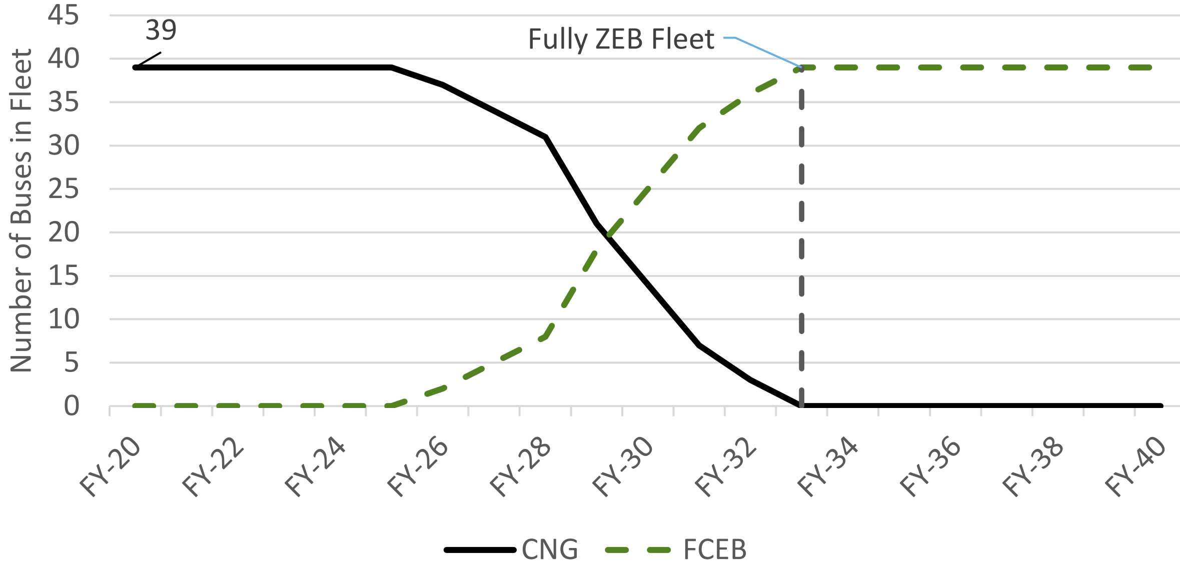


Figure 18 – Paratransit bus fleet composition by year

Figure 19 shows the estimated hydrogen consumption based on the fleet transition schedule outlined in the Zero-Emission Bus Rollout Plan.[6] The 900 kg-H2/day electrolyzer is expected to meet SunLine's demand until approximately 2026, at which point, additional infrastructure will be required.

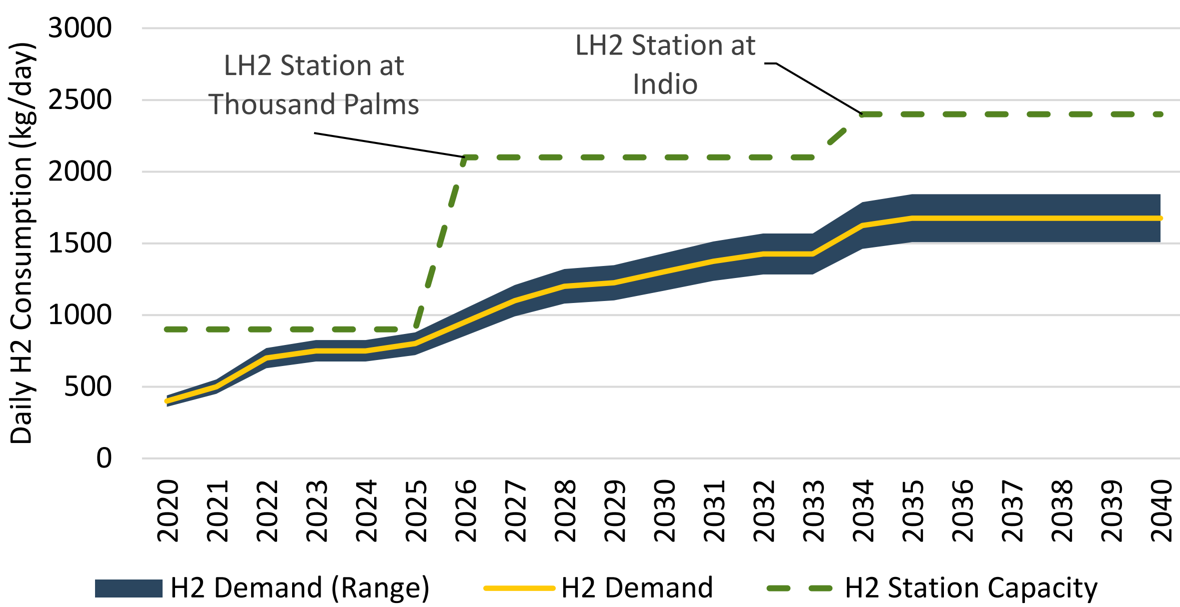


Figure 19 – Estimated daily hydrogen demand and station capacity

[6] SunLine Transit. (2020). *Zero-Emission Bus Rollout Plan*. Retrieved from https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans

In addition to providing fuel for fixed route and paratransit vehicles, the electrolyzer could enable SunLine to pursue other hydrogen projects. SunLine may install a public hydrogen fueling station that could serve light- and heavy-duty vehicles, which would provide a new revenue stream to the agency similar to their current public CNG station. SunLine could also use some of the hydrogen produced from the electrolyzer to operate light-duty fuel cell electric vehicles as part of their support fleet or as a new rideshare/microtransit service offering.

As demand for hydrogen grows – whether through additional fixed route buses or new hydrogen activities – the increased utilization of the 900 kg-H2/day electrolyzer will lead to reduced hydrogen cost in two ways.

First, electrical demand charges will be lower. The electrolyzer does not operate using variable electric load – the system is either on at a defined peak power or off with no electric load. If it is running more continuously, the peak demand will be the same, but more hydrogen will be produced since it is running for a longer duration. Since the demand charge is dependent only on peak demand, increased hydrogen production for the same peak demand will result in a lower price per kg-H2 produced. Note that the expected/potential cost of hydrogen of <$8/kg discussed in other parts of this report was determined without accounting for future reductions due to lower peak demand charges discussed here.

Second, less hydrogen will be vented by the system. Every time the electrolyzer is activated, some hydrogen must be vented to the atmosphere. If the station is operating more continuously, it will reduce the number of times the electrolyzer turns on and off, limiting the number of venting events. Electricity is required to produce the hydrogen that is vented, but the fuel is not usable, so a reduction in vented hydrogen will result in lower costs on a per kg-H2 dispensed basis.

Other Public Transit Operations

In the wake of the passing of the Innovative Clean Transit Regulation, California public transit agencies are increasingly considering FCEBs as part of the transition to zero-emission fleets. As of September 2020), the California Air Resources Board has posted Zero-Emission Bus Rollout Plans from ten agencies across the state. Of these plans, only one agency indicates they are only looking at BEBs. Seven indicate the agency will use a mix of FCEBs and BEBs, one does not specify the technology, and one plans for BEBs because of a lack of space for hydrogen infrastructure but notes that FCEBs could be used if offsite fueling is available and considers the opportunity to convert to primarily FCEBs.

As a recognized leader in the hydrogen and FCEB sector, SunLine provides invaluable information to other transit agencies. SunLine has been using FCEBs since the early 2000s and currently operates one of the largest FCEB fleets in North America. Through the West Coast Center of Excellence in Zero-Emission Technology and other outreach activities (see Outreach Activities

Section), SunLine shares their knowledge and experience operating and maintaining FCEBs to other California agencies. This is especially helpful to agencies that have never trialed zero-emission buses before.

Learnings from the LCT project will also provide valuable information to other agencies in the state. This report, as well as the more comprehensive data analysis report to be completed by Ricardo, outline key performance and costs metrics related to the operation of FCEBs and are directly compared to CNG buses. This information will aid transit agencies in evaluating FCEB technology and planning for their own deployments.

The LCT project also demonstrates the ability to reduce capital costs by procuring in bulk. The SunLine order for five FCEBs delivered as part of this project were bundled with additional FCEB purchases deployed at other California agencies. Increasing the volume of the order enabled New Flyer to lower the per-bus cost. This procedure could be replicated through a statewide initiative to pursue bulk procurement on behalf of multiple agencies.

Other Heavy-Duty Applications

The SunLine LCT Project will help support further deployment of other heavy-duty fuel cell vehicle applications. Much of the same core technology deployed on the fixed route buses is the same as in other applications. Most notably, the Ballard HD85 fuel cell module used in the New Flyer buses included in the LCT Project are identical to those used currently in trucking applications such as the fuel cell yard trucks to be deployed at the Port of Los Angeles and the 4 next generation delivery vans to be deployed by UPS in Ontario, California. Increased deployment of these fuel cell systems helps bring down the cost of manufacturing and therefore the vehicle itself. Additionally, learnings from the deployment help to provide feedback that will improve future system design iterations.

The electrolyzer deployed as part of the LCT Project may also directly support the deployment of other heavy-duty fuel cell vehicles. Available low-carbon hydrogen generation could enable SunLine to construct a light- and heavy-duty hydrogen fueling station at their Thousand Palms facility. This station could provide essential infrastructure to support hydrogen powered trucks and other heavy-duty vehicles operating in the region. Conveniently located near Interstate-10, a station at SunLine could help enable long-haul trucking throughout Southern California and into Arizona.

LESSONS LEARNED

This project yielded some key lessons learned that can benefit other agencies or operators considering deploying hydrogen fueling vehicles and/or hydrogen production and dispensing equipment. Lessons learned are summarized by category below.

General

- Contracting
  - Contracting with equipment providers can be complex and takes longer than expected. It is important to allot ample time during this first phase of the project. Shortcuts and lack of detail will lead to disputes and time lost later on in the project.
  - Engaging technical experts as owner's representatives to develop a well-defined scope of work including clearly defined technical requirements, performance criteria and how they will be measured, and deliverables, is important to future project success and can avoid timely and costly disputes during execution.
  - Liquidated damages are important to consider given the impact timely completion and cost of delivered fuel have on transit operations.
- Technical requirements
  - Ensure equipment is designed for worst-case environmental conditions. SunLine Transit experiences extreme ambient heat conditions. Equipment that works well in milder climates struggled in the desert heat, leading to a need to retrofit the hydrogen station cooling systems and add chiller capacity.
  - Performance requirements of fueling station equipment needs to be carefully aligned with transit operations. For example, back-to-back fill requirements should be modeled for expanded fleet to ensure station design constraints will not drive compromises in operations.
  - Parameters for station reliability and uptime should be included as an important technical requirement. It is recommended that transit agencies consider how downtime would impact their operating costs and ensure the contract considers that cost via terms such as guaranteed uptime, provision of backup fuel when the station is down, and/or liquidated damages. It is also recommended that a Station Acceptance term be defined that includes both meeting station performance (e.g. back-to-back fill requirements) and also a period of sustained reliable operation.

- Site integration and future scale up
    - If integrating new equipment with a pre-existing hydrogen station, it is important to work through interconnection details in the design phase. This will save cost and time later on.
    - If new hydrogen fueling stations are being integrated into a larger fueling facility or a new station such as SunLine's CNG station, coordination and regular communications will be critical to ensure an optimized integrated design is developed, as well as ensuring ongoing safe and continued operation of fueling facilities. Where equipment shares common safety infrastructure such as emergency shutdown systems (ESDs) and alert beacons, it is recommended that the team participated in a joint site hazard and operability (HAZOP) study facilitated by an independent 3rd party facilitator.
    - Think about future capacity expansion at outset and consider investing in some aspects of the expanded system at the outset. For example, SunLine could have benefited from having added hydrogen storage to provide extra redundancy and improved back-to-back fill capability.
    - Most transit agencies utilize fuel management systems to track bus fill data, and in some cases these systems are used to provide security by locking out dispensers until access codes are entered. It is important to understand how new dispensing equipment will communicate with fuel management systems at the outset of the project. Communication protocols as well as physical connections can be difficult and costly to add as a retrofit.
- Budget
    - Scope out critical infrastructure constraints and upgrades to support the new equipment during preliminary costing of the project. SunLine unexpectedly required a new high voltage power line to the site that added close to $1 million to the project. This could have been planned in advance if electrical requirements and existing infrastructure constraints were better understood at the outset of the project.
    - Site construction and interconnection to existing infrastructure and facilities tends to take longer and cost more than expected. Site construction and equipment supply may be better provided by separate partners rather than bundled into a turnkey delivered station. However, coordination of multiple contractors can blur lines of accountability and require more support from the transit agency, so the decision needs to be well thought-out.

- Communications
    - Strong communications are a critical factor in any successful project. It is important to set up regular check-in meetings between all project partners early in the project to coordinate requirements and align schedules.
- Expect the unexpected.
    - Several unexpected events occurred throughout the project. One of the fuel cell buses was damaged and taken out of service for an extended period due to damage sustained when a front-end loader from a neighbouring facility broke through the fence and rolled into bus FC14. One of the baseline CNG buses was stolen, taken on a joyride, and sustained damages that led to significant time out of service. The team discovered early on that a new power line to the site was required, driving up cost and adding complexity to the project. In December 2020, a landscaping truck damaged the water line feeding the electrolyzer and resulted in mud, sand, and rock ingress throughout the water systems of the electrolyzer and H2 station. These external factors all impacted the project and resulted in extra time and effort by the team to overcome. Schedule and budget contingency planning and a team with a can-do attitude to react to the unexpected can help prevent these types of events from de-railing projects.

Bus

- The latest generation of fuel cell bus technology is mature, leveraging reliability improvements from previous generations. Very little of bus downtime was related to the fuel cell system.
- Vehicle fuel economy is impacted by hot ambient temperatures; SunLine observed a decline in fuel economy of the fuel cell fleet over the spring and summer months that correlated with increased ambient temperature in Thousand Palms, reaching as high as 122°F in 2020. This loss in fuel economy in hot weather is believed to be primarily a result of high air conditioning loads for cabin cooling, as well as higher fuel cell system cooling loads.
- Procurement of FCEBs is now much simpler with the OEM New Flyer offering a completely integrated bus, as is done with conventional bus offerings. Past FCEB procurements relied on the transit agency entering into separate contracts with the coach manufacturer, system integrator, and fuel cell supplier, which greatly complicated procurement and added risk to the transit agency.
- Communication protocols between the dispenser and the bus during hydrogen refueling

need to be determined early in the procurement cycle and coordinated between the bus OEM and fueling station equipment provider. With faster fueling times and pre-chilled hydrogen, communications-based filling is becoming common in transit vehicles but there are few common standards.

  - Older buses on-site may also have to be upgraded for communication fills, and this will need to be planned as new dispenser technology is deployed.

- It is highly recommended that transit agencies include a one-year complete service package that includes training of transit staff when procuring new zero emission buses.

Station

- The overall level of maturity of the hydrogen production and fueling station is lower than the buses and will require more of the project resources to achieve stable and reliable operation and smooth integration into transit operations.
- Site design and permitting work was much more extensive than anticipated and needs to be adequately considered during budget and schedule development. It is recommended to engage a design firm with previous hydrogen station experience.
- Site civil costs were much higher than originally budgeted. The cost and complexity of the building systems (heating, ventilation, and air conditioning (HVAC) system, safety systems, building enclosure) were underestimated in original project scoping.
- The commissioning plan and acceptance criteria for the station need to be clearly defined at the outset of the project. It is recommended that station acceptance criteria includes both performance and reliability metrics.
- It is important to consider a backup supply of hydrogen, particularly when agencies rely primarily on on-site production. Backup supply needs to be readily available to maintain continuity of operations when the unexpected happens.
- It is recommended that contracts with station providers include a firm price for optional extension of the O&M service for up to three years following the first year of O&M included with equipment. This reduces risks to the transit agency if the equipment requires more preventative and corrective maintenance than initially projected.
- It is important to design in measurement systems throughout the hydrogen station to ensure hydrogen mass balances are regularly checked. The SunLine station initially lacked checks and balances that enabled the team to see that significant venting losses were occurring due to compressor wear. These losses resulted in months of high operating costs, and the lack of measurement systems made finding the root cause very challenging.

- It is important to identify a champion in the agency to be trained in detail on the new equipment, to provide on-site support during initial operation, and be capable of training technicians and transferring some maintenance activities in house over time to reduce costs.
- Work with the station equipment provider to define measurement methods and data recording systems for important process parameters that will help in future root cause analysis investigations. Some key metrics need to be directly measured, not just extrapolated. For example, the amount of hydrogen vented during system startup.
- The site footprint for on-site generation via electrolysis can be larger than expected. New containerized options offer a more compact footprint and simplified integration.

Operations

- It is important to get drivers and maintenance staff excited and engaged in the project at the outset, so they become champions for successful integration and provide feedback to improve the rollout of zero emission bus and infrastructure technologies. Providing information about the new technology that explains the 'why' as well as the 'how it works' is important.
- Staff training is critical to successful project rollout. Training plans for bus maintenance staff, station maintenance support staff, and fueling personnel need to be developed before equipment goes into operation. Staff on both day and night shift need to be trained sometimes multiple times if the technology is new to the agency. First responder training also needs to be planned.
- Cost savings can be achieved through implementation of more sophisticated operational control strategies that balance hydrogen production requirements with costs associated with utility peak demand charges. Techno-economic models developed jointly between the transit agency and station provider can help inform decision making. California electric utilities could benefit hydrogen transit by introducing special hydrogen generation tariffs that would bring down costs as well as increase the renewable energy content.
- Development of visual and intuitive key performance indicator (KPI) dashboards that get updated on a regular interval (e.g., monthly) will drive optimized performance and informed decision making.