Performance Report for Humboldt Transit Authority's
Pilot Extended Range New Flyer Xcelsior CHARGE FC™ Fuel Cell Electric Bus

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Summary

We report the results of a series of performance tests of Humboldt Transit Authority's new fuel cell electric bus, the New Flyer Xcelsior XHE40 CHARGE FC™ model. Over a series of six test runs, the bus performed very well, exhibiting smooth performance during full speed highway driving and hill climbing, with excellent acceleration and regenerative braking.

Measured fuel economy and range exceeded expectations. On the most demanding test run—320 miles from Eureka to Ukiah and back with a fully weighted bus—fuel economy was 8.2 miles/kg of hydrogen, resulting in a range of 435 miles. With a lightly weighted bus on the Trinidad to Scotia run, fuel economy was 12.1 miles/kg, resulting in a range of 640 miles.

Based on the bus's performance on these test runs, we determined that the New Flyer XHE40 bus meets its contract performance specifications.

Background

In late March 2025, Humboldt Transit Agency (HTA) received its first fuel cell electric bus, New Flyer's Xcelsior XHE40 CHARGE FC™ model. This pilot bus was designed and configured to be able to successfully negotiate HTA's North State Express: Route 101, an especially demanding 320-mile route from Eureka to Ukiah and back. See Appendix A for the North State Express route and schedule.

For several weeks in April 2025, the Schatz Energy Research Center at Cal Poly Humboldt partnered with HTA, New Flyer, and hydrogen supplier Linde to test the pilot bus. The goal of the testing program was to determine whether the XHE40 meets its contract performance specifications and whether it is suitable for HTA's challenging bus terrain. The bus was tested on increasingly difficult routes, culminating in the run to Ukiah and back, HTA's North State Express: Route 101. As detailed below, extensive data were collected for each run, including battery state-of-charge (SOC), hydrogen fuel use, fuel economy, and other parameters. We report the test results in the following sections.

Bus Specifications and Contract Requirements

New Flyer's Xcelsior XHE40 CHARGE FC™ has the following specifications:

- 40-foot hydrogen fuel cell electric bus
- Curb weight as measured empty: 33,460 lbs
- Weight as measured with 11 water barrels (to simulate passenger loading): 38,800 lbs
- Hydrogen fuel capacity (stored in 9 separate tanks @ 35 MPa): 56 kgs total, 53 kgs usable
- Ballard FCmove™ fuel cell with a nameplate power rating of 100 kW
- Battery storage capacity: 135 kWh XALT Energy, High Power, Gen 2
- Siemens High Grade PEM (1DB2022 FT) motor with a power rating of 275 kW
- Siemens propulsion system (ELFA 3) design, enhanced for efficiency
- Recommended bus tire pressure: 130 psig

HTA's contract with New Flyer required the XHE40 bus to:

- achieve at least 375-mile range at curb weight and Beginning of Life
- maintain 60 MPH over a distance of at least 75 miles with a starting Energy Storage System State of Charge of 65%
- maintain speeds up to 40 MPH on 6% uphill grades at curb weight over at least 8 miles

Testing Plan

The testing plan was tailored to HTA's bus routes in the rugged, hilly terrain of Humboldt County; the location of the county in the State of California is shown in Figure 1 below. It consisted of the following 6 separate test runs with each run starting and ending at the HTA corporation yard in Eureka. The 6 runs are listed below in the order they were performed; details of each run and its rationale are given in Appendix B.

1. Local Operational Check
2. Trinidad-Scotia Performance Test – Unweighted, HVAC Off
3. Berry Summit Performance Test – Unweighted, HVAC Off

4. Trinidad-Scotia Performance Test – Weighted, HVAC On
5. Berry Summit Performance Test – Weighted, HVAC Off
6. Ukiah Performance Test – Weighted, HVAC On

Figure 1. Location of Humboldt County in the State of California

Testing Protocol

A comprehensive testing protocol was developed for each test run. It consisted of the three activities listed below; details of each activity are given in Appendix C.

1. Test Preparation
2. Test Run Data Collection
3. Post Run Data Evaluation

An important choice we made was how to determine fuel usage during bus operation. We chose to use the bus's analog pressure gauge (Figure 2 below) to determine the mass of hydrogen in the tank and thus hydrogen fuel usage. We converted tank pressure to the amount of fuel remaining in the bus's tank via a cubic correlation equation based on the National Institute of Standards and Technology table of hydrogen properties at 20°C. Details of this calculation are given in Appendix D. This corrects for the non-ideality of hydrogen at high pressure; not correcting for the non-ideality of hydrogen can result in errors of fuel mass as large as 24%. It should be noted that using a 2-inch analog gauge whose range is 0 → 10,000 psi to measure pressure is somewhat imprecise. We can confidently report 2 significant figures for this measurement and a similar precision for the calculated fuel usage for each segment of our runs. This does not affect the conclusions about fuel economy, especially for the longer trips.

Figure 2. The hydrogen storage pressure gauge at the start and end of the Ukiah test run

Results

Operational Test, Eureka & Arcata—March 27, 2025

This test consisted of 24.9 miles of driving within Eureka and Arcata, including approximately 12 miles of freeway driving. 13 passengers were on board. The bus performed well and ran smoothly. HTA's bus driver Cody Ferreira remarked that acceleration was excellent, "Quickest bus I've ever driven."

Trinidad to Scotia Runs, April 8 & April 16, 2025

These runs followed HTA's Redwood Transit System (RTS) route (Figures 3 & 4 below and Appendix E) very closely and allowed comparison of weighted and unweighted bus loading. On the unweighted test, the HVAC system was turned off; on the weighted test, it was turned on to simulate realistic operation.

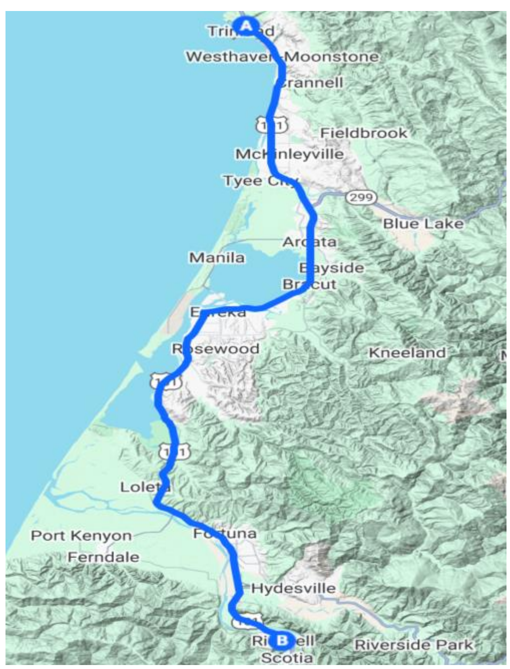


Figure 3. HTA's Redwood Transit System - Trinidad to Scotia Route

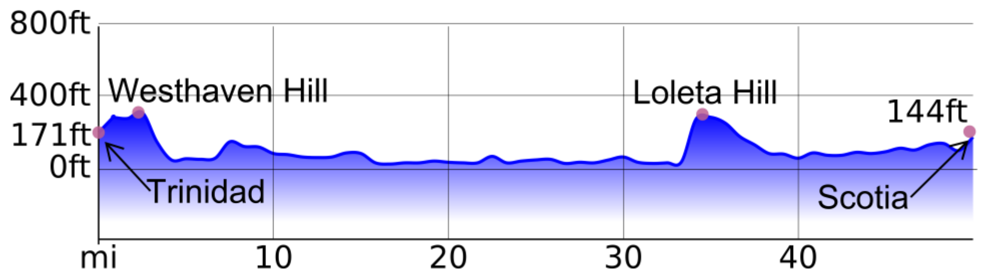


Figure 4. Topography of the Trinidad to Scotia Route

Results for these two runs are shown in Tables 2 and 3. Once again, the bus ran smoothly and showed good acceleration. Where permitted on the freeway, the bus easily maintained its governed speed of 60 mph. On the two significant hills on the route—Westhaven Hill and Loleta Hill—the bus generally kept speeds of 50 mph, with the lowest speed being 47 mph. Using the results shown in the tables, the calculated fuel economy in both cases is excellent, ranging from **12.1 miles/kg** for the unweighted run to **9.7 miles/kg** for the weighted run, a 20% decrease. A high battery state of charge was maintained throughout, ranging between 68 and 72%.

Table 2. Trinidad to Scotia Run—**Unweighted**, HVAC off
Passenger weight = 1,330 lbs

Route Segment	Distance (mi)	Initial Battery SOC (%)	Final Battery SOC (%)	Fuel Use (kg)
Eureka to Trinidad to Arcata Transit Center	51.2	70	72	3.6
Arcata Transit Center to College of the Redwoods	17.4	72	68	1.6
College of the Redwoods to Scotia	22.6	68	68	2.1
Scotia to Eureka	28.6	68	70	2.7
Entire Route	**119.8**	**70**	**70**	**9.9**

Table 3. Trinidad to Scotia Run—**Weighted**, HVAC on
Passenger + Water Drum weight = 6,065 lbs

Route Segment	Distance (mi)	Initial Battery SOC (%)	Final Battery SOC (%)	Fuel Use (kg)
Eureka to Trinidad to Arcata Transit Center	49.4	70	72	4.5
Arcata Transit Center to College of the Redwoods	17.2	72	68	1.3
College of the Redwoods to Scotia	22.5	68	68	3.0
Scotia to Eureka	28.1	68	70	3.3
Entire Route	**117.2**	**70**	**70**	**12.1**

Berry Summit Runs, April 10 & April 15, 2025

The unweighted and weighted runs to Berry Summit on CA 299—the highway running east from Arcata—were conducted to determine the performance of the bus on two long, steep climbs and descents (Figures 5 & 6 below). This route is part of HTA's regular service route to the town of Willow Creek. HTA regularly runs low floor buses on this route. We broke the run up into the relatively flat section from Eureka to Blue Lake and the hill section from Blue Lake to Berry Summit. After leaving Blue Lake and traversing a couple of smaller hills, the first sustained climb is from the North Fork of the Mad River (elevation 600 feet) to Lord Ellis Summit (elevation: 2263 feet); this climb is 6.1 miles at a 5.2% average grade. After descending to Redwood Creek (elevation: 1320 feet), the climb to Berry Summit (elevation: 2720 feet) is 6.1 miles at an average grade of 4.4%. This climb steepens to 5.7% for the last 3.9 miles.

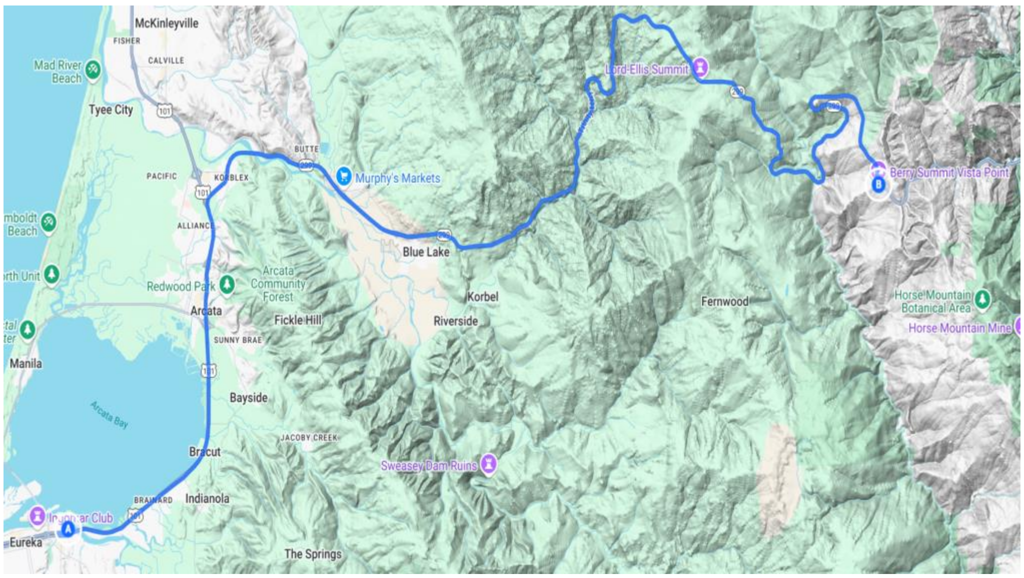


Figure 5. Berry Summit Route

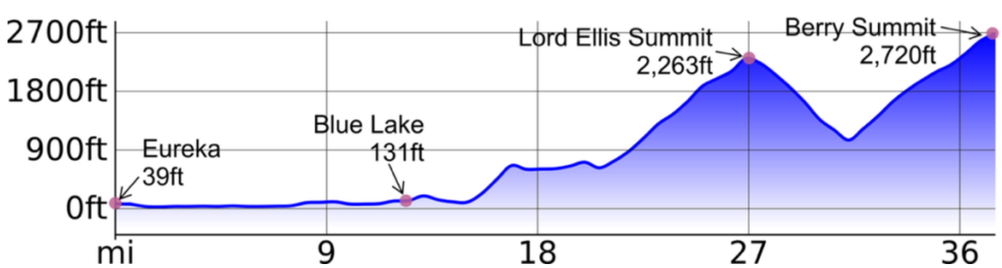


Figure 6. Topography of the Berry Summit Route

The overall results of these two runs are shown in Tables 5 & 6. The unweighted bus was able to maintain 50 mph up both hills; the weighted bus generally maintained 45-50 mph up both hills, with a minimum of 42 mph on a steep section of the Lord Ellis climb.

Table 5. Berry Summit Run, **Unweighted**, HVAC off
Passenger weight = 1,485 lbs

Route Segment	Distance (mi)	Initial Battery SOC (%)	Final Battery SOC (%)	Fuel Use (kg)
Eureka to Blue Lake	15.2	72	66	0.7
Blue Lake to Berry Summit	22.7	66	48	3.2
Berry Summit to Blue Lake	22.7	48	61	1.0
Blue Lake to Eureka	16.5	61	65	2.0
Entire Route	**77.1**	**72**	**65**	**7.0**

Table 6. Berry Summit Run, **Weighted**, HVAC off
Passenger + Water Drum weight = 6,180 lbs

Route Segment	Distance (mi)	Initial Battery SOC (%)	Final Battery SOC (%)	Fuel Use (kg)
Eureka to Blue Lake	15.1	70	64	1.5
Blue Lake to Berry Summit	22.8	64	51	4.1
Berry Summit to Blue Lake	22.8	51	76	2.1
Blue Lake to Eureka	15.3	76	69	0.5
Entire Route	**76**	**70**	**69**	**8.2**

To determine the overall fuel economy in these runs, the decrease in battery state of charge from the beginning to the end of the run must be accounted for. This is done as follows:

In the unweighted run, the SOC decreased by: 72% – 65% = 7%

In the weighted run, the SOC decreased by: 70% – 69% = 1%

For the 135 kWh bus battery, this corresponds to:

7% x 135 kWh = 9.5 kWh for the unweighted run

1% x 135 kWh = 1.4 kWh for the weighted run

This additional energy would need to be added to the battery to restore it to its original SOC. The fuel cell was measured by New Flyer Connect as furnishing 22.0 kWh per kilogram of hydrogen consumed (See Appendix F for a further discussion of fuel cell efficiency). Thus, to charge the battery to its original level would require:

Additional hydrogen required, unweighted = 9.5 kWh ÷ 22.0 kWh/kg = 0.43 kg

Additional hydrogen required, weighted = 1.4 kWh ÷ 22.0 kWh/kg = 0.06 kg

The resulting fuel economies for the Berry Summit runs are **10.4 miles/kg** for the unweighted run and **9.2 miles/kg** (a 12% decrease) for the weighted run.

Of particular interest to us on these runs was how the state of charge of the battery would behave on both the steep climbs and the descents. The most challenging conditions occurred on the weighted run. The climbing portion of the weighted run is shown on Figure 7 below, which is taken from a New Flyer Connect Report. The climb to Lord Ellis began at approximately 9:10 AM; the climb to Berry Summit began at approximately 9:30 AM. Each climb lasted about 8 minutes and is demarcated by the SOC declining throughout the climb. As can be seen in Figure 7, the battery SOC remained fairly robust, reaching a low value of 46% on both climbs. The fact that the SOC did not decline any lower is due, in large part, to the fuel cell running at full power of 110 kW for most of the climb. The SOC increased to a maximum of 77% on the weighted descents and the bus briefly entered EV mode during those times. The maximum of 77% indicated that even on these extended descents, the battery maintained a comfortable amount of headroom to provide regenerative braking.

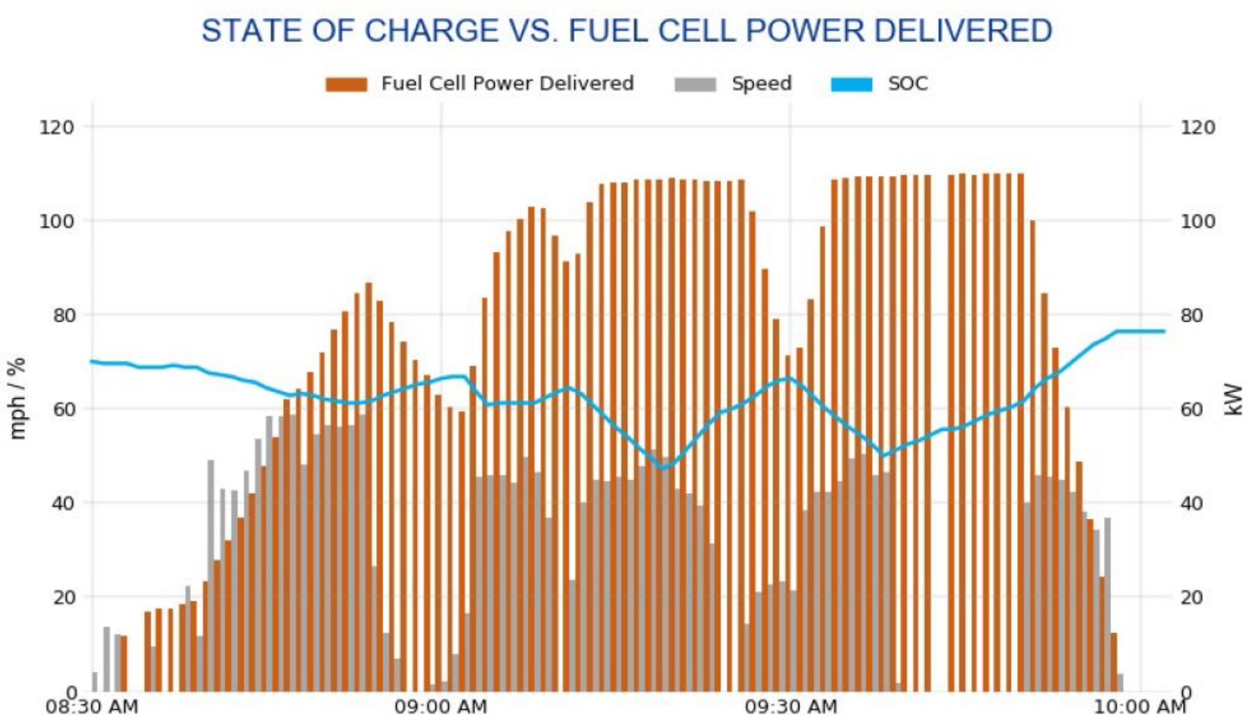


Figure 7. Fuel Cell Power, Battery SOC, & Speed, Weighted Run, Eureka to Berry Summit

Ukiah Run, April 17, 2025

This was the culminating test of our program. Being able to make this demanding run to Ukiah and back along U.S. 101 (Figures 8 & 9 below) was the goal of the redesign of the New Flyer fuel cell bus. This is HTA's new North State Express: Route 101 service.

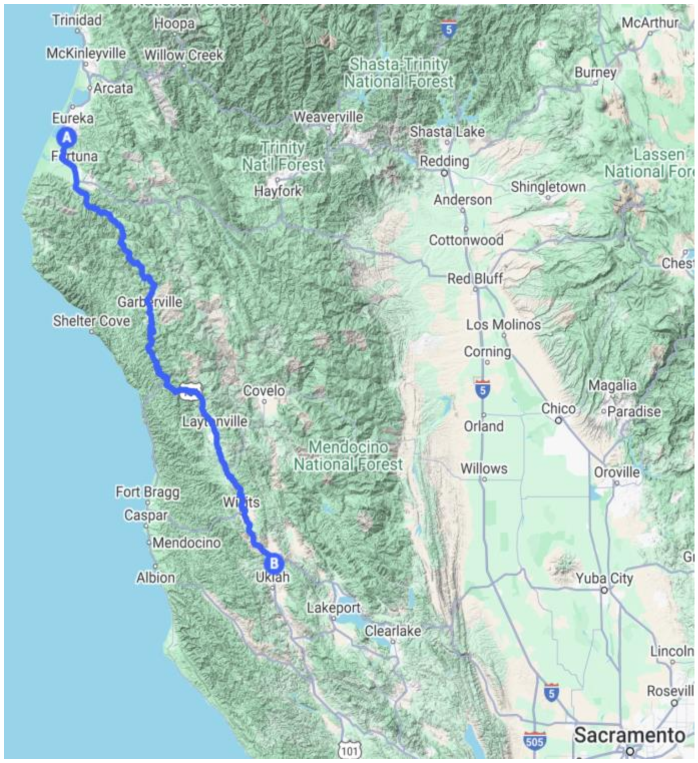


Figure 8. North State Express: Route 101

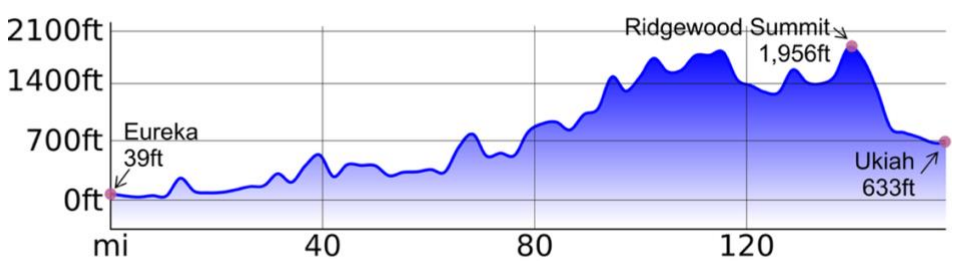


Figure 9. Topography of the Ukiah Route

To simulate worst case conditions, we loaded the bus with over 6,400 pounds and ran both the driver and the cabin heaters at full power. HTA's driver Cody drove at full speed (governed at 60mph) whenever possible; the bus negotiated the route easily within HTA's time schedule.

The results for this run are shown in Table 7. The bus ran smoothly and performed well throughout this demanding run. Using the same methodology as shown above to correct for the small increase in battery state of charge from 72% to 74%, the overall fuel economy of **8.2 miles/kg** is excellent. This was despite the fact that, according to the New Flyer report shown in Figure 10 below, the heaters used 17% of the total fuel energy. With this measured fuel economy and a full tank of 53 kgs of usable hydrogen, the range of this bus is 435 miles.

Table 7. Ukiah Run—**Weighted**, Driver & Cabin Heaters at Full Power
Passenger + Water Drum weight = 6,420 lbs

Start of Segment	End of Segment	Distance (mi)	Initial Battery SOC (%)	Final Battery SOC (%)	Fuel Use (kg)
Eureka	Fortuna	18.9	72	62	2.0
Fortuna	Garberville	49.9	62	52	5.6
Garberville	Leggett	21.3	52	61	4.2
Leggett	Laytonville	23.6	61	57	2.6
Laytonville	Willits	22.6	57	70	3.7
Willits	Ukiah	22.6	70	74	2.1
Ukiah	Willits	23.3	74	60	2.2
Willits	Laytonville	22.6	60	63	2.3
Laytonville	Leggett	23.6	63	74	2.8
Leggett	Garberville	21.0	74	72	2.6
Garberville	Fortuna	49.9	72	67	5.7
Fortuna	Eureka	18.9	67	74	2.8
Entire Route		**318.2**	**72**	**74**	**38.6**

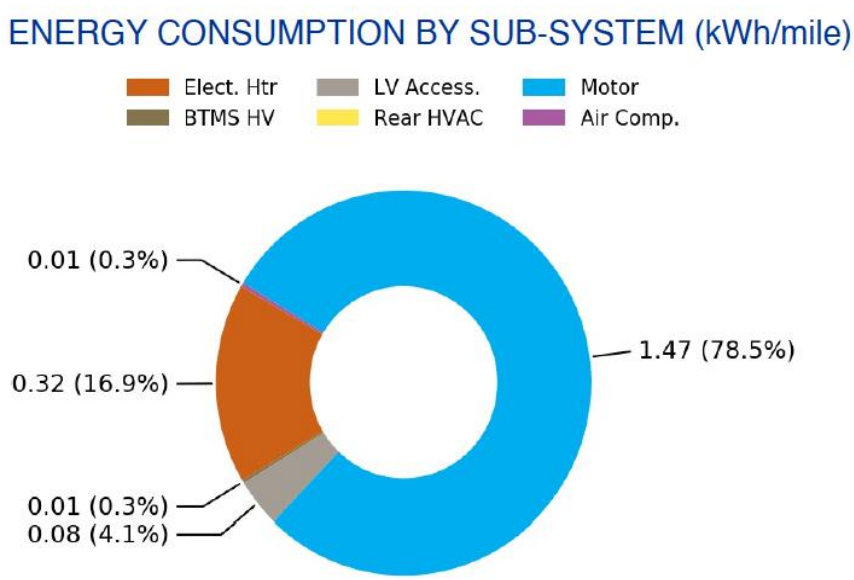


Figure 10. Subsystem Energy Consumption during the Eureka to Ukiah Run

To assess the bus's ability to travel at highway speeds for extended periods, we focused on the Fortuna to Garberville segment of this trip. This segment is 50 miles long and though it is far from straight and has many small hills, it is sustained freeway driving (and the best we can do for extended highway driving here in Humboldt County). We left Fortuna at 8:28 AM and arrived at Garberville at 9:25 AM. There was a small amount of town driving at slow speeds at the beginning and end of this segment. Other than a point at which we had to slow for construction, Cody drove at highway speeds most of the way, frequently at 60 mph. The performance is shown in Figure 11 below, taken from New Flyer Connect. The battery SOC started at 62% and decreased approximately linearly to a low of 50%, while climbing a steep hill just before Garberville. The 50% SOC was the lowest level on the entire trip; on the overall trip from Eureka to Ukiah, the battery SOC increased slightly from 72% to 74%. And just as it did while climbing Lord Ellis and Berry Summits, the fuel cell generated full power of 110 kW throughout this segment. Going forward, it will be important to monitor whether running at full power for extended periods will affect long term fuel cell performance.

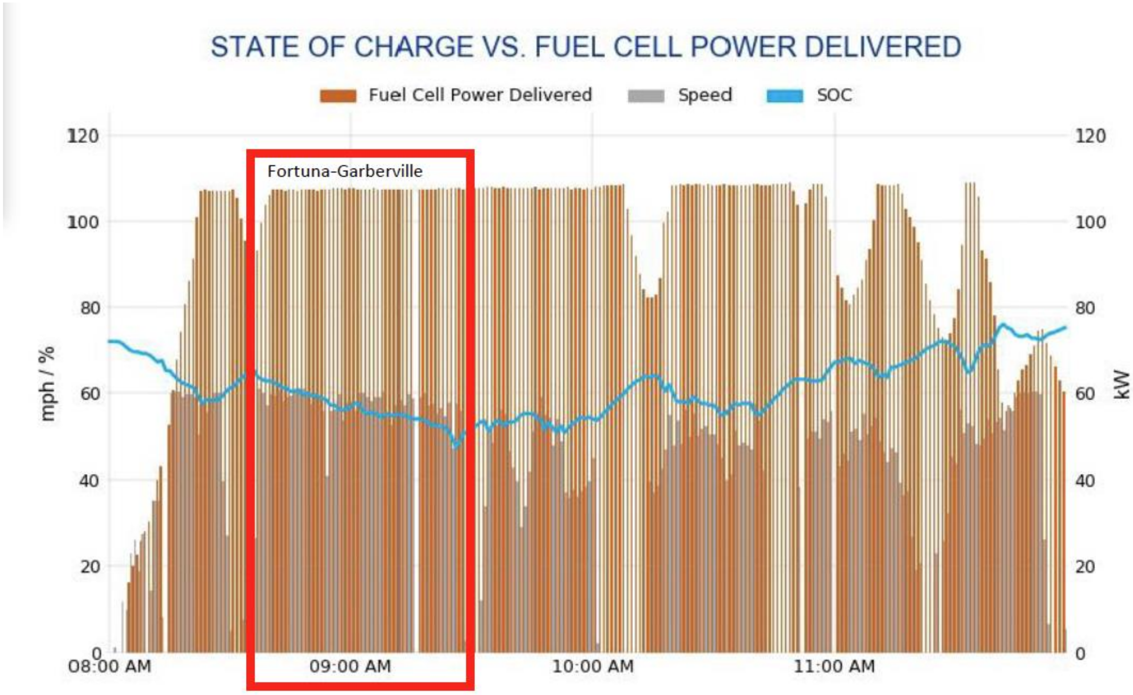


Figure 11. Fuel Cell Power, Battery SOC, & Speed, Eureka to Ukiah

The longest hill climb during this entire testing period was the climb to Ridgewood Summit (1,956 feet) from the outskirts of Ukiah (800 feet) on the return trip. This is an 8.1 mile climb at 3.5% grade. The bus started the climb at 60 mph, slowing to the speed limit of 55 mph part way up, and slowing further for sharp turns. The battery SOC started the climb at 67% and ended at 50% at Ridgewood Summit. After a short downhill and slower driving into downtown Willits, the SOC had recovered to 60%.

Fuel Economy

A summary of the fuel economies for each of the test runs is shown graphically in Figure 12. Not surprisingly, weighted runs were less fuel efficient than unweighted runs and hilly runs were less efficient than flatter runs. The run to Ukiah and back had the lowest—though still excellent—fuel economy; this is almost certainly due to the protracted amount of freeway driving at full speed and the hilly nature of the route.

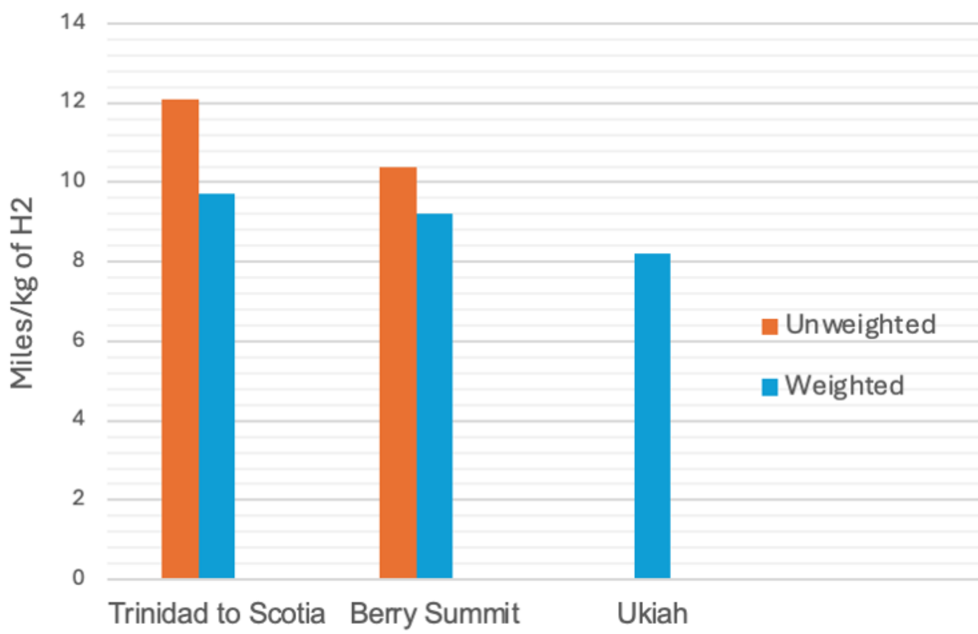


Figure 12. Bus Fuel Economy on Test Runs

Conclusions

The Schatz Center and HTA teamed to plan and execute a comprehensive test of HTA's recently acquired New Flyer's Xcelsior XHE40 CHARGE FC™ fuel cell electric bus.

Throughout the test runs, bus performance was excellent. The bus ran smoothly and quietly, accelerated well, maintained highway speed, and climbed and descended long, steep hills quickly and safely. Regenerative braking worked well, with drivers reporting that they rarely had to use the brake pedal. The bus was able to complete HTA's Redwood Transit System and Ukiah routes successfully and well within the time schedule.

Based on our measurements on these test runs, the range of the bus is excellent. Maximum range occurred on Test 2, in which the bus was lightly loaded while driving the 120-mile RTS route. Although this route has two significant hills and a good portion of freeway driving at full speed, **measured range is 640 miles**. On the demanding Ukiah run with heaters at full power, **measured range is 435 miles.**

One of the major goals of the tests was to determine whether the bus could meet New Flyer's contractual performance specifications. As mentioned above, these requirements are:

- "Achieve at least 375-mile range at curb weight and Beginning of Life"
  We did not drive the bus 375 miles in a single test. However, during the demanding run from Eureka to Ukiah and back, the bus drove nearly 320 miles under worst case conditions, weighted and with heaters on. Based on our measured fuel economy under these conditions, the range with a full fill of 53 kgs of usable hydrogen is 435 miles.
- "Maintain 60 MPH over a distance of at least 75 miles with a starting Energy Storage system State of Charge of 65%"

Because of highway circumstances in Humboldt County, we were not able to drive 75 miles at 60 mph in a single stretch. However, during the Ukiah run, the bus drove nearly 50 miles from Fortuna to Garberville, much of it at 60 mph. Since the battery SOC started at 62% and never dropped lower than 50% for this segment, we expect that travel at 60 mph for the full 75 miles is easily achievable.

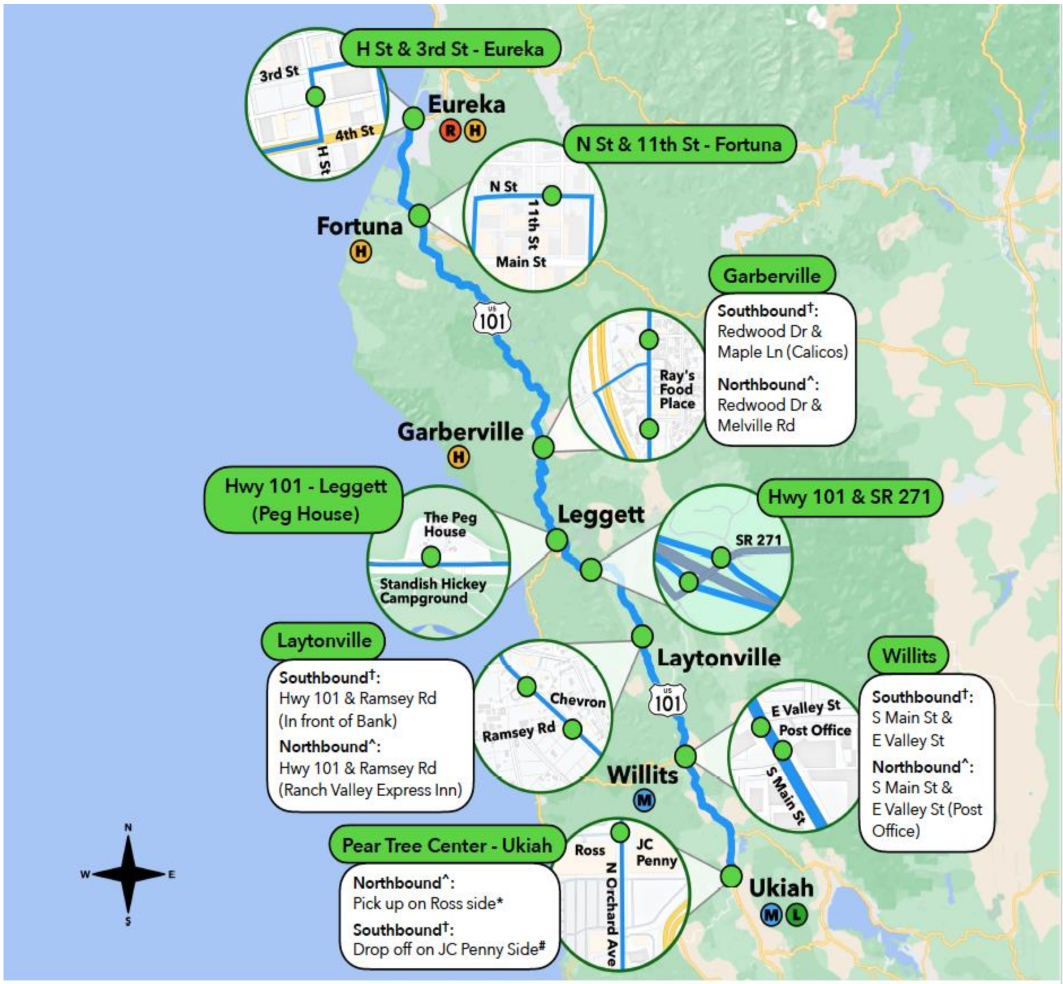
- "Maintain speeds up to 40 MPH on 6% uphill grades at curb weight over at least 8 miles" Again, because of highway circumstances, the bus was not able to perform this test exactly. However, the weighted bus drove the 6.1 mile Lord Ellis and Berry Summit climbs—which range between 4 and 6%—at 45-50 mph, only once dropping to a low of 42 mph. It also successfully climbed the less steep 8.1 miles to Ridgewood Summit at 45-60 mph.

Because of these performances, it is clear that the New Flyer Xcelsior XHE40 CHARGE FC™ fuel cell electric bus meets its contractual specifications.

Acknowledgements

We are pleased to acknowledge the assistance of the following people in completing this performance evaluation: Cody Ferreira, Kevin Grundhofer, Kelly Masterson, Jerome Qiriazi, Kevin Robertson, and Jim Wilson of the Humboldt Transit Authority; Colter Alvarado, Shea Arneson, Colton Howell, Jacob Perez, Ross Thompson, and Sandra Wadsworth of New Flyer; and Jaimie Levin, Alison Smyth, and Chase Stell of the Center for Transportation and the Environment.

Appendix A: HTA North State Express: Route 101



^ Hacia el Norte † Hacia el Sur * Parada en Ross # Parada en JC Penny

Transfer to / Transferencia a

(R) Redwood Coast Transit (H) Humboldt Transit Authority (M) Mendocino Transit Authority (L) Lake Transit Authority

SCHEDULE / FORMULARIOS

Operates **Monday - Friday** except on holidays, road closures, and snow / Servicio de **lunes a viernes** excepto días festivos, cierre de carretera, o clima con nieve

SOUTHBOUND / HACIA EL SUR (RUN 1)	
H St & 3rd St - Eureka	10:00 AM
N St & 11th St - Fortuna	10:25 AM
Redwood Dr & Maple Ln Garberville (Calico's)	11:15 AM
Hwy 101 - Leggett (Peg House)	12:05 PM
Hwy 101 & SR 271 - SB Stop (S. Leggett)	12:08 PM
Hwy 101 & Ramsey Rd - Laytonville (Bank)	12:30 PM
S Main St & E Valley St - Willits (Across from PO)	1:00 PM
N Orchard Ave - Ukiah (Pear Tree Center)	1:30 PM

NORTHBOUND / HACIA EL NORTE (RUN 2)	
N Orchard Ave - Ukiah (Pear Tree Center)	2:15 PM
S Main St & E Valley St - Willits (Post Office)	2:45 PM
Hwy 101 & Ramsey Rd - Laytonville (Inn)	3:15 PM
Hwy 101 & SR 271 - NB Stop (S. Leggett)	3:36 PM
Hwy 101 - Leggett (Peg House)	4:05 PM
Redwood Dr & Melville Rd - Garberville	4:30 PM
N St & 11th St - Fortuna	5:20 PM
H St & 3rd St - Eureka	5:45 PM

Appendix B: XHE40 Bus Testing Plan

Test 1. Local Operational Check

- Drive the bus locally to ensure the bus operates properly and is ready for longer routes
- Run was through Eureka to Arcata and back, including freeway driving at full speed
- Confirm the New Flyer Connect 360 is operational
- Test the manual data collection process to ensure it is capturing all pertinent data

Test 2. Trinidad-Scotia Performance Test – Unweighted, HVAC Off

- Test the bus on the actual Redwood Transit System route between Trinidad and Scotia
- Run broken down into the following segments:
    - HTA through Manila to Arcata Transit Center
    - Arcata Transit Center to Trinidad
    - Trinidad to College of the Redwoods
    - College of the Redwoods to Scotia
    - Scotia to HTA
- Compare the test results to the September 2021 test run of the AC Transit XHE40 hydrogen fuel cell electric bus on the same run

Test 3. Berry Summit Performance Test – Unweighted, HVAC Off

- Test the bus on a steep, extended uphill and downhill run (Berry Summit elevation is 2803 feet)
- Run broken down into the following segments:
    - HTA to Blue Lake
    - Blue Lake to Berry Summit
    - Berry Summit to Blue Lake
    - Blue Lake to HTA
- Assess the regenerative braking systems ability to handle steep downhill grades
- Confirm that the fuel cell will not charge the batteries past 70%, and that the bus will allow the regen to charge the batteries past 70%.
- Assess the New Flyer contract requirement to “maintain speeds up to 40MPH on 6% uphill grades at curb weight over at least 8 miles.”
- Weigh bus empty to determine curb weight at local weigh station in Arcata

Test 4. Trinidad-Scotia Performance Test – Weighted, HVAC On

- Repeat Test 2 with a weighted bus with HVAC On
- Weight the bus with 11 water barrels to simulate full passenger loading
- Weigh the bus to determine loaded weight
- Run broken down into the following segments:
    - HTA to Trinidad back to Arcata Transit Center
    - Arcata Transit Center to College of the Redwoods
    - College of the Redwoods to Scotia
    - Scotia to HTA

- Evaluate the impact of passenger loading and heater operation on efficiency by comparing the results with those of Test 2.

Test 5. Berry Summit Performance Test – Weighted, HVAC Off

- Repeat Test 3 with a weighted bus with the HVAC Off
- Run broken down into the following segments:
  - HTA to Blue Lake
  - Blue Lake to Berry Summit
  - Berry Summit to Blue Lake
  - Blue Lake to HTA
- Assess the ability of a loaded bus to climb steep, sustained uphill grades
- Assess the regenerative braking system's ability to handle steep downhill grades with a loaded bus
- Confirm that the fuel cell will not charge the batteries past 70%, and that the bus will allow the regen to charge the batteries past 70%.
- Potentially get a sense of how high of an SOC the bus will allow the batteries to charge

Test 6. Ukiah Performance Test – Weighted, HVAC On

- Test the bus on the demanding, HTA's 320-mile North State Express route under worst case conditions, weighted, driven at full speed, and with passenger and driver heaters on full power
- Run broken down into the following segments:
  - HTA to Fortuna
  - Fortuna to Garberville
  - Garberville to Leggett (Peg House)
  - Leggett to Laytonville
  - Laytonville to Willits
  - Willits to Ukiah and return with previous stops
- Confirm the pilot bus can successfully make the roundtrip to Ukiah and back under worst case conditions
- Assess the New Flyer contract requirement of "maintain 60 MPH over a distance of at least 75 miles with a starting Energy Storage system State of Charge of 65%."
- Measure fuel remaining to confirm that the bus can satisfy the New Flyer contract requirement of "375-mile range at curb weight and Beginning of Life."

Appendix C: Testing Protocol

Test Preparation

- Refuel bus the day before and record the mobile fueler data (time, starting pressure, final pressure, and quantity) and bus starting and final pressure
- Record settled pressure prior to starting run
- Monitor the NFI Connect 360 system to ensure it is operational
- Confirm test procedure and data record sheet on hand
- Confirm tire pressure is at OEM Specification

Test Run Data Collection

- Record the following general data:
    - Operator name
    - Loading condition
    - HVAC Setpoint
    - Ambient temperature
- At the start, at each stopping point, and at end of the run record:
    - Time
    - State of Charge (SOC) of the battery energy storage system
    - State of Fill (SOF) of the hydrogen tanks (dash)
    - Tank Pressures (analog gauge and dash)
    - Odometer Reading (dash)
    - Any alarms (i.e., low SOC)
- Record the time and describe any:
    - Unusual events that may impact test results
    - Route deviations and reason (e.g., construction or accidents)
    - Mechanical issues or dashboard fault lights
    - Noted changes in bus operation
- Take interior and exterior photos of:
    - Hydrogen tank analog pressure gauge
    - Driver control panels
    - Any other photos that may be helpful for data analysis

Post Run Data Evaluation

- Calculate range and fuel economy for each trip segment and overall route
- Assess how the bus's battery SOC responded in each segment of the run
- Determine whether the bus has met contractual requirements based on results
- Record qualitative assessments and any noteworthy observations of bus performance

Appendix D: Determining Hydrogen Usage During Test Runs

We determined the mass of hydrogen in the bus's fuel tank using the pressure read from the bus's analog fuel gauge. Using a table of hydrogen density and pressure at 20°C published by the National Institute of Standards & Technology[1], we[2] developed a cubic correlation equation relating hydrogen density (in kg/m3) to hydrogen pressure (in psi). It is shown below.

H2 density (kg/m3) = K1*(H2 pressure(psi))^3 + K2*(H2 pressure(psi))^2 + K3*(H2 pressure(psi))

where:

K1 = 4.57822E-12
K2 = -2.18423E-07
K3 = 5.65507E-03

This cubic equation is very accurate over the entire range of pressures in the bus's tank; its correlation coefficient is 0.999997. Since hydrogen deviates considerably from ideal gas behavior at higher pressures, not correcting for non-ideality can lead to significant errors.

For each pressure reading, we calculated the corresponding density using the equation above. We determined tank volume by assuming that the full tank at 35 MPa (5076 psi) pressure held 56 kgs of hydrogen. This yielded a tank volume of 2.366 m3. For each pressure reading then:

Mass of H2 (kg) = (H2 density (kg/m3))*(2.366 m3)

For any run segment, simply subtracting the mass at the end of the segment from the mass at the start yields the mass of fuel used.

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[1] NIST Office of Data and Informatics. "Isothermal Properties for Hydrogen." Isothermal Properties for Hydrogen. Accessed May 9, 2025. https://webbook.nist.gov/cgi/fluid.cgi?T=20C&PLow=0.1&PHigh=50&PInc=0.1&Digits=5&ID=C1333740&Action=Load&Type=IsoTherm&TUnit=C&PUnit=MPa&DUnit=kg%2Fm3&HUnit=kJ%2Fmol&WUnit=m%2Fs&VisUnit=uPa%2As&STUnit=N%2Fm&RefState=DEF.

[2] Thanks to our colleague Dr. Charles Chamberlin for developing this equation.

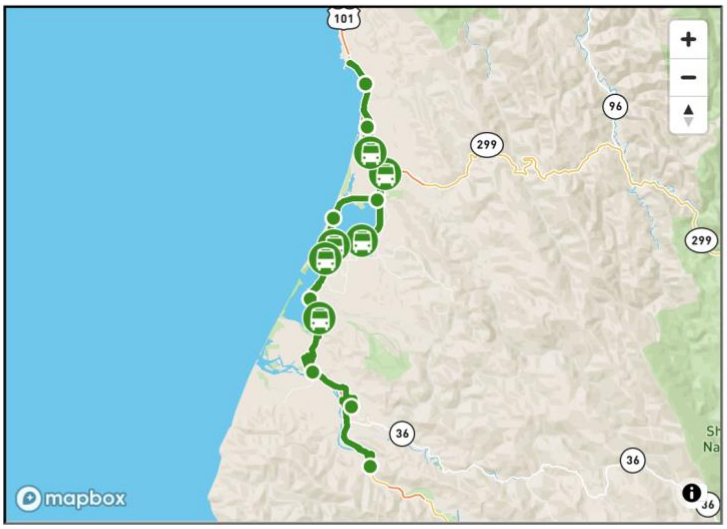
Appendix E: HTA Redwood Transit System Route

Redwood Transit System

REDWOOD TRANSIT SYSTEM

Redwood Transit System (RTS) offers service between Scotia, Rio Dell, Fortuna, Loleta, Fields Landing, King Salmon, Eureka, Arcata, McKinleyville, Westhaven, and Trinidad 6 days per week, Monday through Saturday.

REDWOOD TRANSIT SYSTEM SERVICE MAP



Appendix F: Fuel Cell Efficiency

New Flyer Connect reports hydrogen fuel use (kgs) and fuel cell energy generated (kWh) for each segment of the test runs we performed. Totaling those data for the entire run provides a value of fuel cell efficiency as kWh generated/kg of H2 consumed. We used a value of 22.0 kWh/kg—taken from New Flyer Connect data—in our calculation accounting for a change in the battery's SOC from the start to the end of the Berry Summit and Ukiah runs. Since 1 kg of hydrogen has 33.3 kWh of chemical energy, this implies that the fuel cell efficiency is:

$$\text{Fuel cell efficiency} = 22.0 \text{ kWh/kg} \div 33.3 \text{ kWh/kg} = 66\%$$

This seems unrealistically high, as we measured the voltage efficiency of the fuel cell at full power to be 58%. Accounting for parasitic losses, actual efficiency will be lower.

Will this affect our overall fuel economy calculations? To examine this, we do the following thought experiment. Based on our measurement above, we assume that the fuel cell efficiency is a realistic (and conservative) 50%. For the unweighted Berry Summit run—the run with the largest change in SOC—we would need an additional 0.57 kg of H2 to charge the battery, rather than the 0.43 kg we originally calculated. The resulting fuel economy would be **10.2 miles/kg** for this run, rather than **10.4 miles/kg** we originally calculated, a 2% decrease. For all other runs, the change is much less. The result is that the difference in the fuel economies resulting from fuel cell efficiency assumptions is small and does not affect our overall conclusions.