AMERICAN FUEL CELL BUS PROJECT

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American Fuel Cell Bus

SunLine Transit Organized a Team Of Developers and Funding For An American Made Fuel Cell Bus:

Project Team

- BAE Systems – Drive System And Integrator
- El Dorado National – Bus Chassis Manufacturer
- Ballard Power Systems – Fuel Cell Manufacturer

Funding

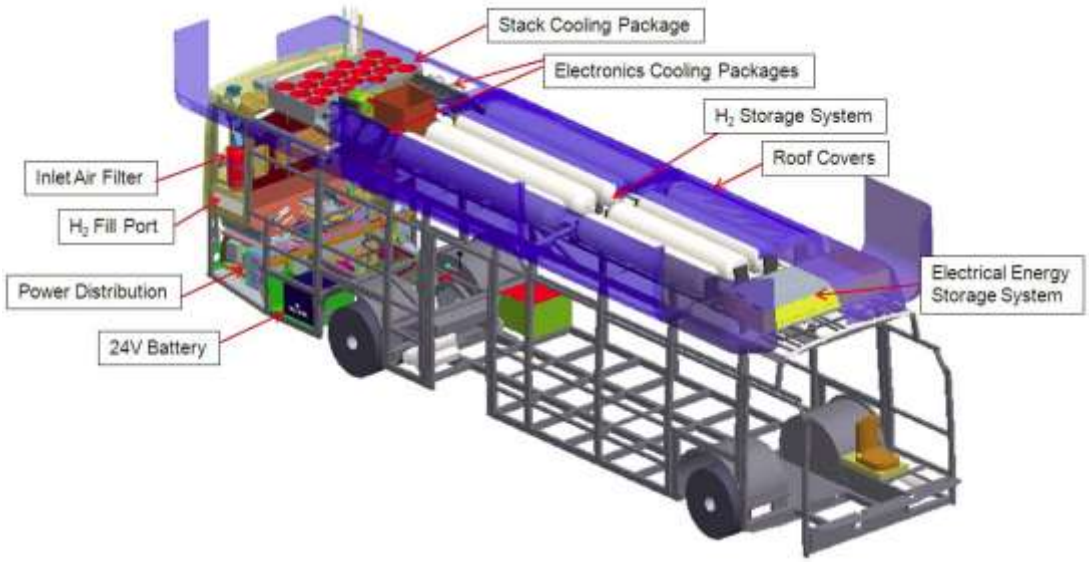
Funding Source	Amount
FTA	$4.2 M
CARB	$800K
AQMD	$400K
Partners	$4.9 M
Total	$10.3M

American Fuel Cell Bus

- Manufacturability Is A Key Step To Move From Demonstration To Commercialization
  - Reduces Costs
  - Preparation For Volume Production
- FTA US Content Provision Is A Major Hurdle For Transit Agencies To Receive Funding For A FCB

American Fuel Cell Bus

- FTA “Buy America” Provision Requires 90% US Manufactured Content – AFCB Is Expected To Exceed That
- El Dorado Chassis Was Designed And Tooled To Package The Drive System, Fuel Cell And Energy Storage System



American Fuel Cell Bus

- Lightweight Chassis To Accommodate US Built Storage System To Enable 300+ Mile Range
- US Built Traction System Proven On Hybrid Electric Buses Throughout North America

American Fuel Cell Bus

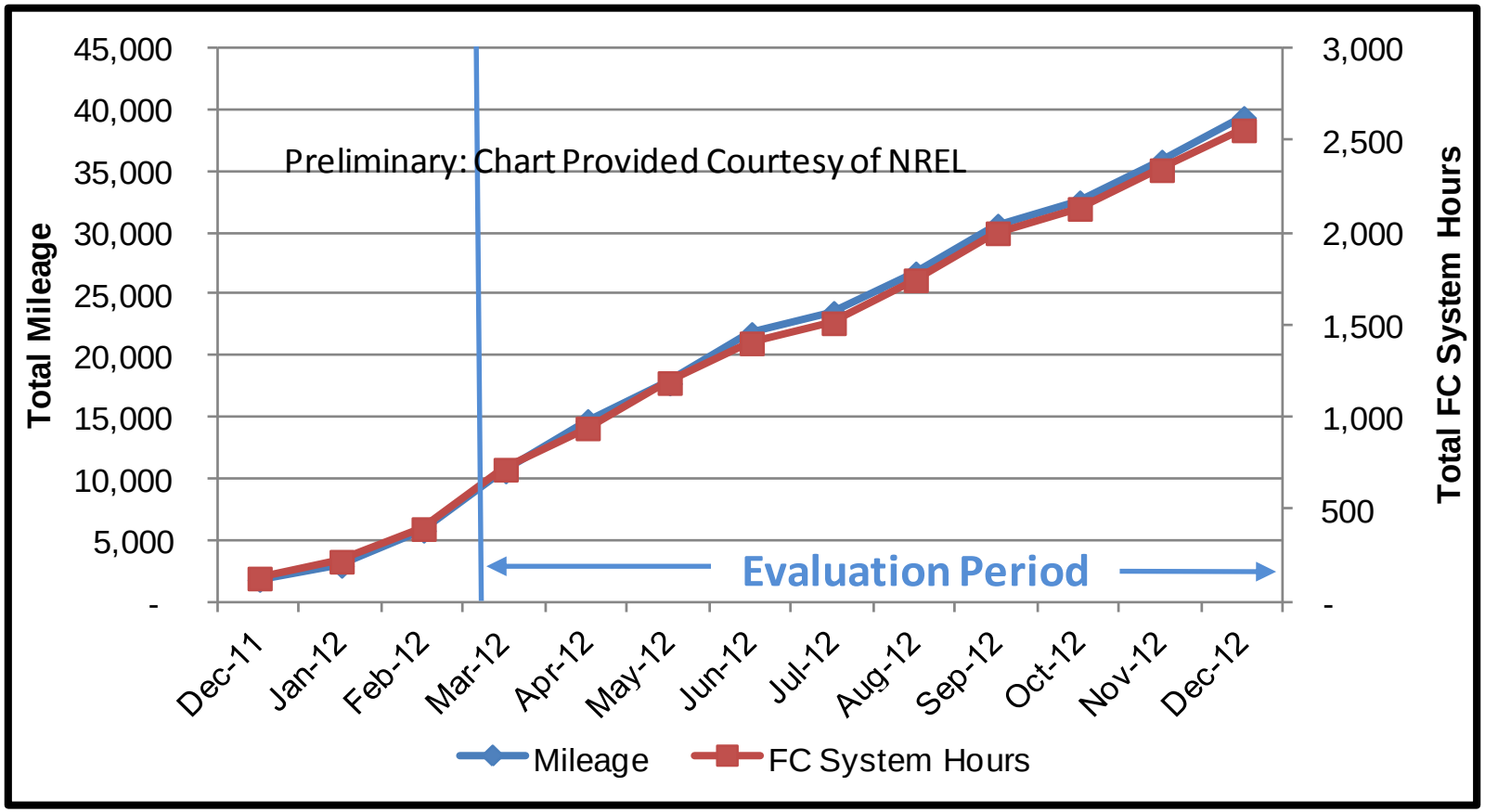
- Ballard Power Systems 150 Kw Fuel Cell Built In Lowell, MA
- System Warranty For 12,000 Hours Or 5 Years
- Lithium-ion Energy Storage System

American Fuel Cell Bus

- Upon Completion SunLine Incorporated The Bus Into Revenue Service In The Coachella Valley - Q4 2011


78-447
Yogurt Island
li-create
Zero Emission
FC3
HYDROGEN FUEL CELL
7th GENERATION
MADE IN AMERICA
SunBus
www.sunline.org
LA REINA del Sur

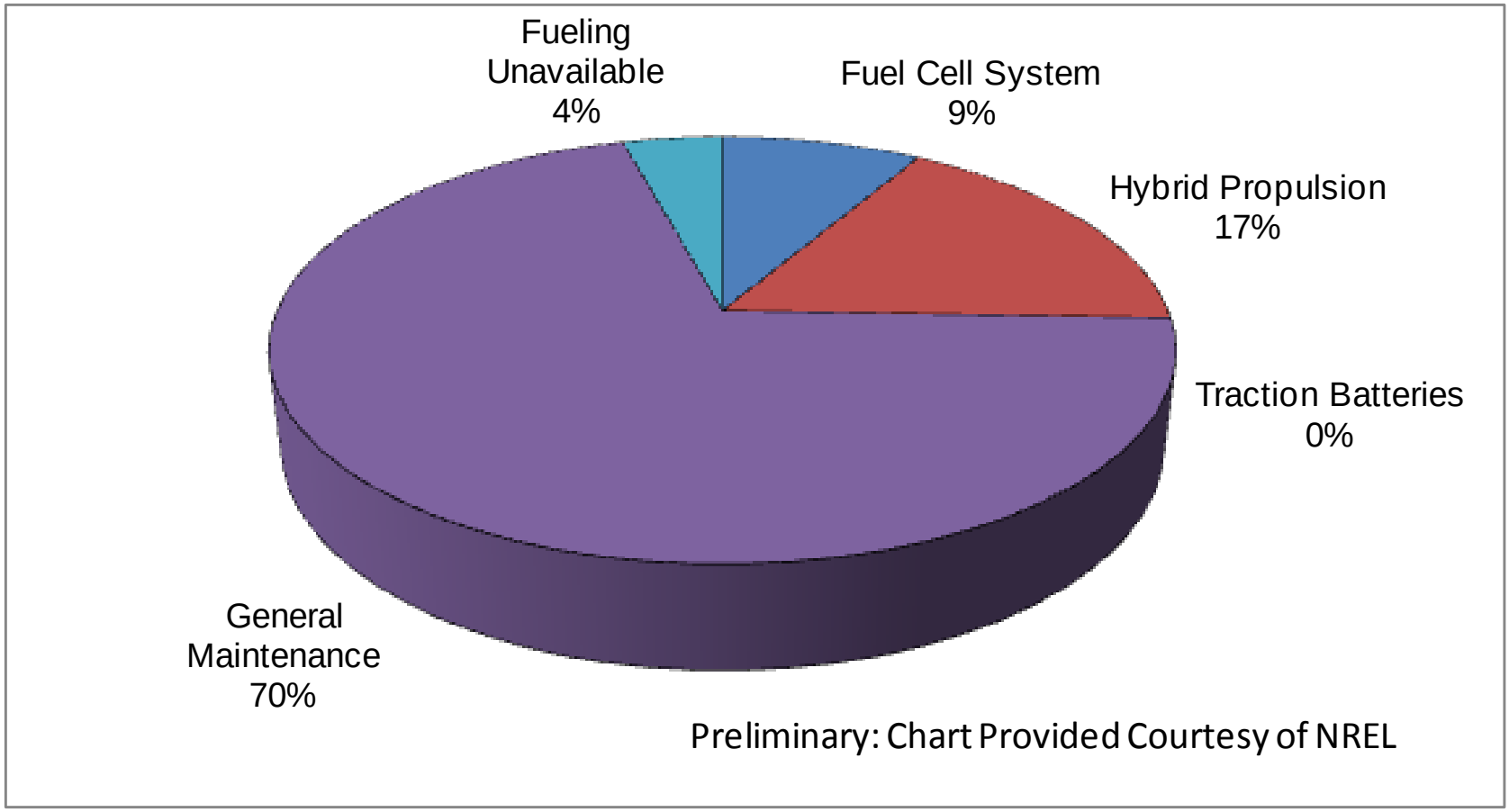
Mileage and FC Operating Hours



List Of Relevant Issues

Date	Description	Solution
Dec. 2011	Hydrogen Storage System control valve leak	Replaced Valve, Performed failure inspection, no latent issues expected in other valves
Dec. 2011	Hybrid Traction Batteries depleted after lengthy bus troubleshooting with accessories running and FC off	Added battery state of charge protection to prevent complete discharge when Fuel Cell is not running
Jan. 2012	Fuel Cell Hydrogen Recirculation Blower fault.	Replaced Blower
Feb. 2012	Air Compressor motor tripping ground faults	Motor wet from bus wash water – replaced motor with Totally Enclosed Fan Cooled version
Mar. 2012 Apr. 2012	Fuel Cell ventilation filter clogging / vent fan intermittent	Replaced filter, discovered fan blade interference, corrected interference. Filter eventually upgraded to improved filter and filter inlet "snorkeled" to cleaner air intake location.
June 2012	Air Compressor breaker tripping	Upgraded breaker to motor rated circuit protector
July 2012	Rear door exhibiting erratic operation. Air Conditioner compressor tubing failure. Bus taken out of service for extensive inspection at ElDorado.	Failed door sensor replaced. Door operation fixed and verified. Compressor not properly secured in AC unit, caused fatigue on tubing. Repaired tubing, secured compressor and recharged system. Other non critical upgrades performed by BAE Systems.
Aug. 2012	Air Conditioner breaker tripping.	Air conditioner exhibiting high head pressure and high starting current. Condenser cooling air recirculating causing poor condenser heat rejection. ElDorado to install gasket to prevent recirculating air.
Oct. 2012	Low Coolant Level on Fuel Cell Stack Cooling	Identified leak in cooling loop – repaired leak. BAE Systems is exploring cooling system plumbing/interconnect upgrade on future buses.
Dec. 2012	Took bus out of service for 4 days (after technical end of demo period) to perform non-critical upgrades prior to end of demo phase.	Upgrades installed including improved fuel cell exhaust water separator, improved cooling system clamps and cooling pump software update

Causes Of Fuel Cell Bus Non-availability

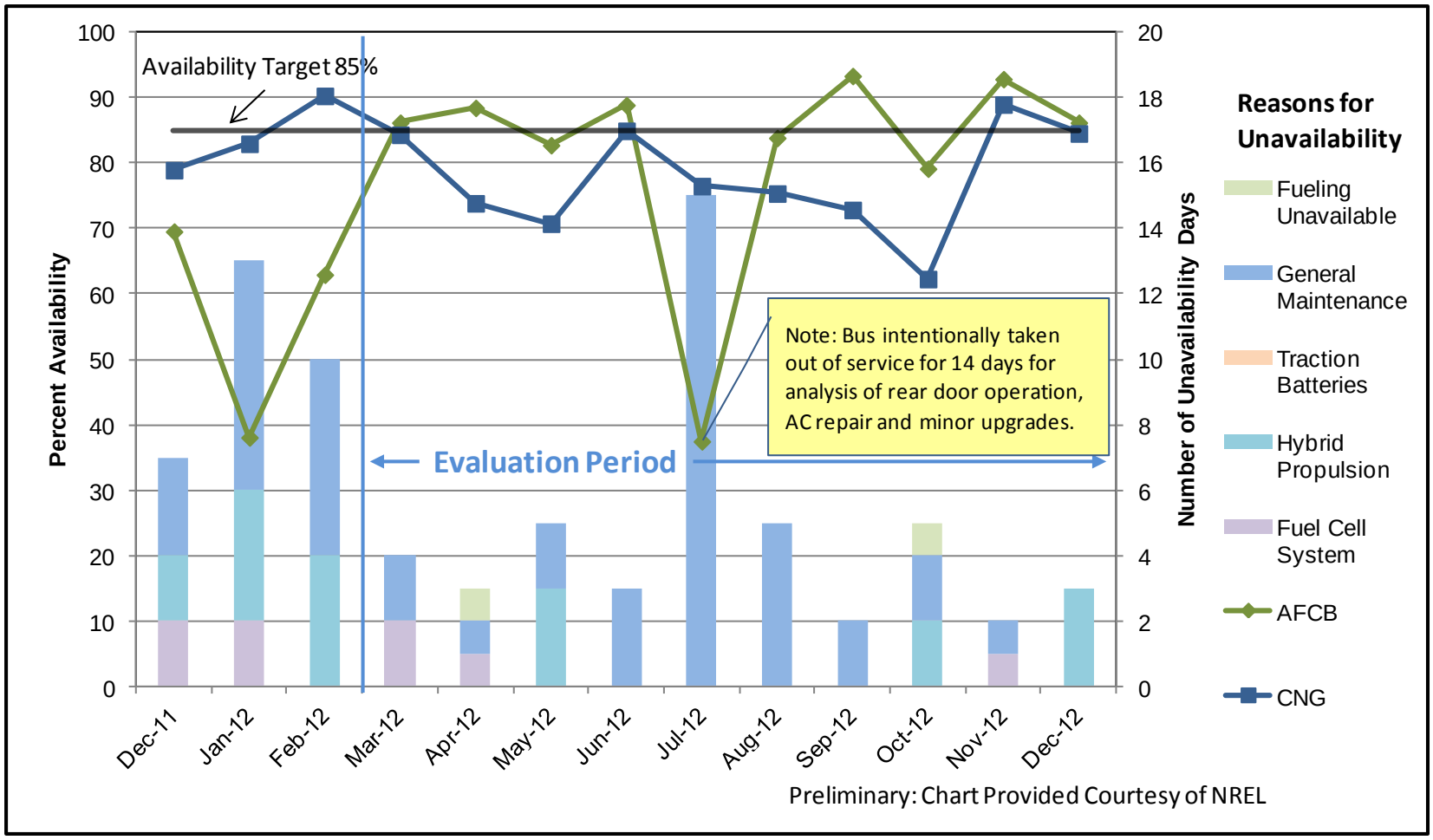


- (Note: Hybrid Propulsion category includes Electric Accessories)

Operations and Maintenance Experience

- SunLine has operated seven generations of FCB's
- Transitioned into Sunline operations much like any other new fixed route bus
- AFCBus was noticeably closer to being in-service when delivered
- Cost to maintain the AFCB is lower than earlier FCB's
- The cost per mile ~ 50% higher for the AFCB than CNG buses

Fuel Cell Bus Availability Compared to CNG Reference Fleet



Steps toward Commercialization – Objectives and Challenges

- The primary challenge is achieving economic affordability and market volume
- The supply chain for fuel cell systems is developing – i.e. hydrogen storage
- AFCB team focused on commonality with systems used in commercial hybrid electric applications

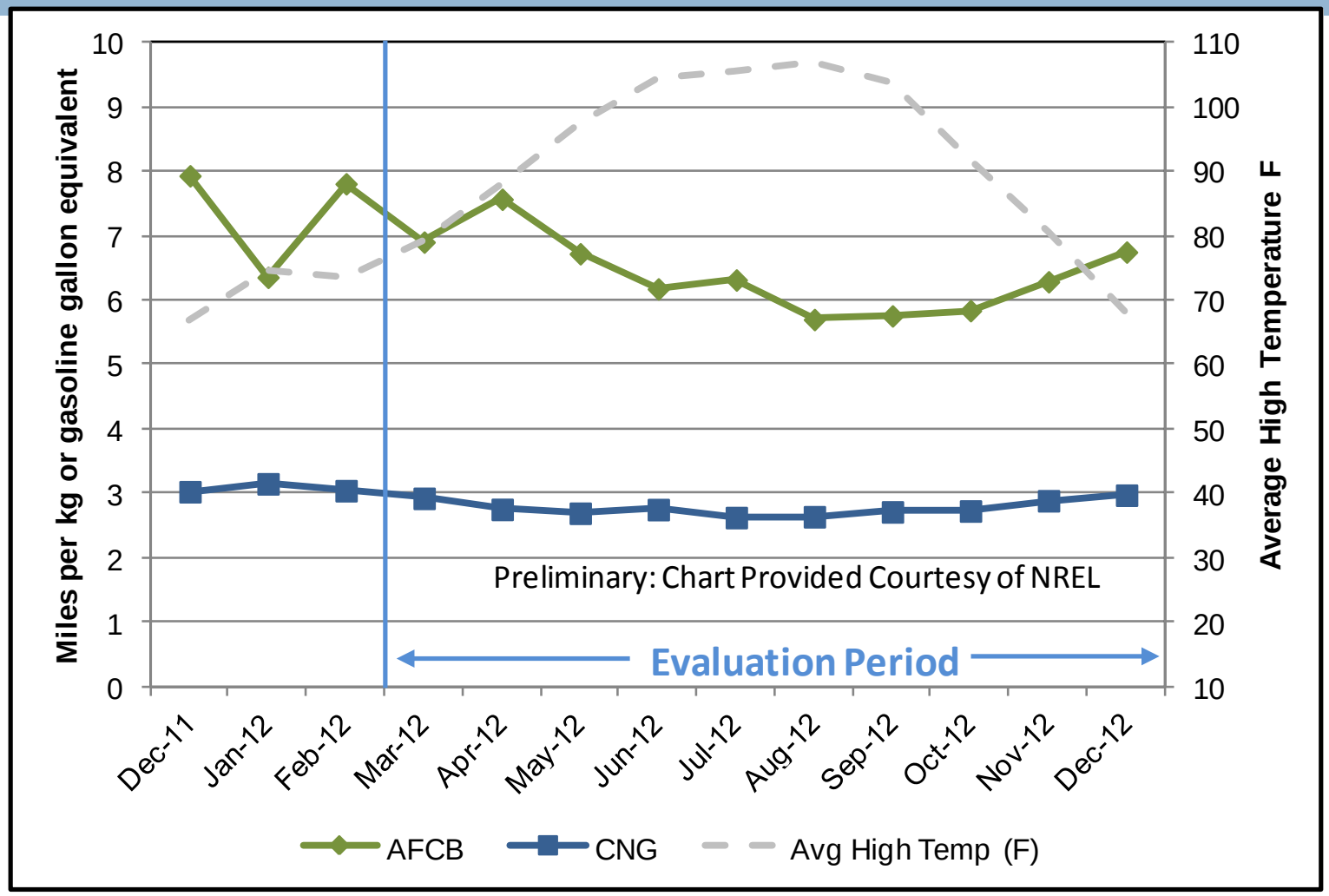
Weight Reduction

- Material selection that allows minimum weight of selected material - Roof cover hardware
- Utilizing minimum component quantities, merging of functionality - Cooling Systems
- Eliminating parts through multifunctional design, simplifying cable routing
- Sheet metal construction vs. machined construction of components
- Mechanical Geometries. - Round tubular construction vs. square tubular construction of mounts and cradles

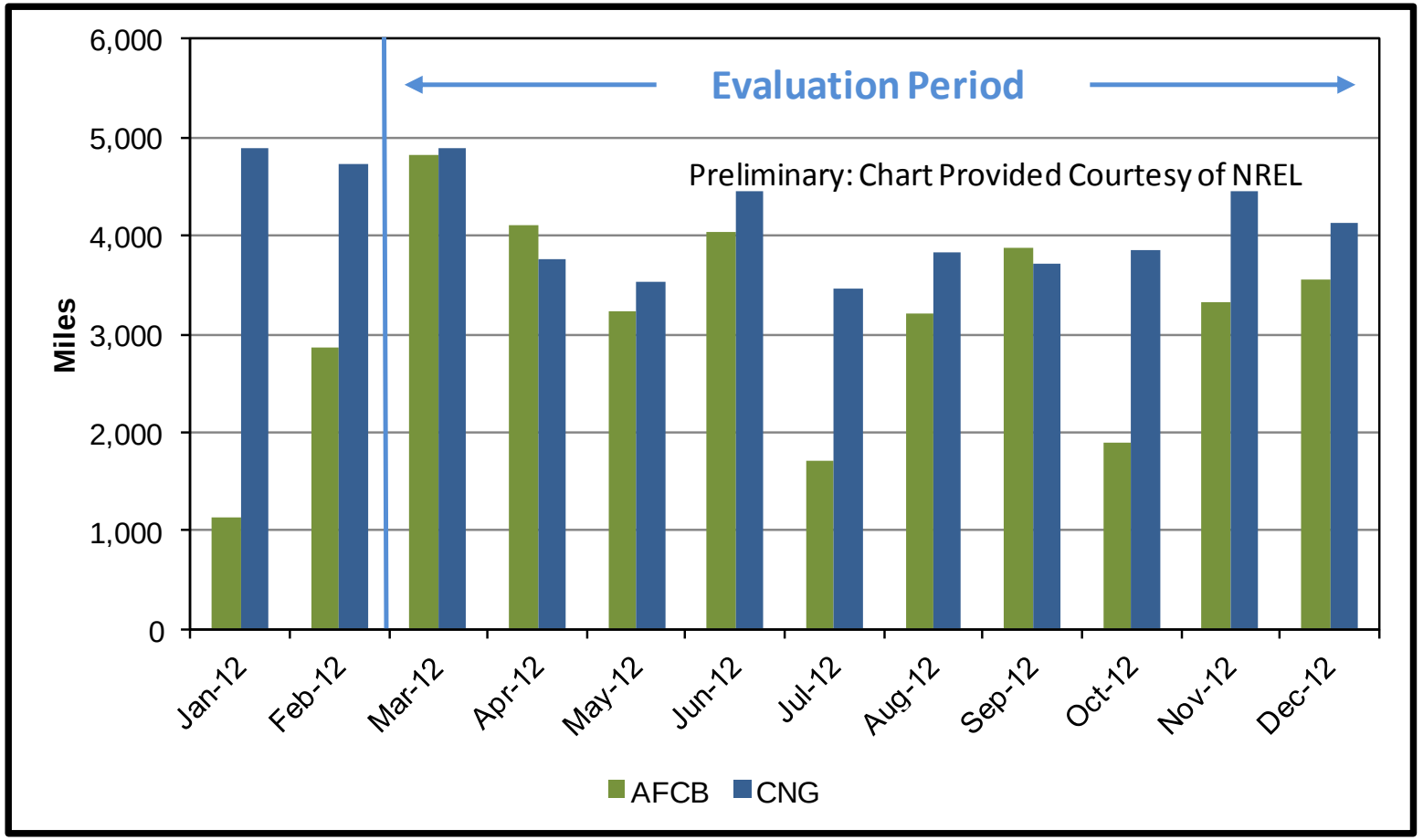
Weight Reduction

- The mounting cradles for roof mounted components provide an example of where strong, light weight structures were used

Fuel Economy Summary Compared to CNG Reference Fleet



Fuel Cell Bus Miles Compared to CNG Reference Fleet



Summary of FCEB Performance Compared to DOE/FTA Targets (NREL)

	Units	November 2012 Report[a] (Range)	2012 Status[1]	2016 Target[1]	Ultimate Target[1]
Bus lifetime	years/miles	<1 – 2.5 / 8,669 – 54,927[c]	5/100,000	12/500,000	12/500,000
Power plant lifetime[b]	hours	940 – 12,038[c,d,e]	12,000	18,000	25,000
Bus availability	%	53 – 71	60	85	90
Fuel fills[f]	per day	1	1	1 (< 10 min)	1 (< 10 min)
Bus cost[g]	$	2,000,000	2,000,000	1,000,000	600,000
Power plant cost[b,g]	$	N/A[h]	700,000	450,000	200,000
Hydrogen storage cost	$	N/A[h]	100,000	75,000	50,000
Roadcall frequency (Bus/fuel cell system)	miles between roadcalls	1,692 – 2,479/ 6,838 – 19,005	2,500/ 10,000	3,500/ 15,000	4,000/ 20,000
Operation time	hours per day/days per week	7 – 19 / 5 – 7	19/7	20/7	20/7
Scheduled and unscheduled maintenance cost[i]	$/mile	N/A[j]	1.20	0.75	0.40
Range	miles	227 – 346[k]	270	300	300
Fuel economy	miles per gallon diesel equivalent	5.97 – 7.84	7	8	8

Fuel Cell Technologies Program Record # 12012, September 12, 2012, http://www.hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf.

AFCB & DOE/FTA 2016 Targets

Bus lifetime	500,000miles/12 yrs.
Power plant lifetime	12,000 hours
Bus availability	85%
Fuel Fills	1 per day
Hydrogen Storage cost	$110,000
Bus Cost	$2,000,000
Power plant cost	$740,000*

AFCB & DOE/FTA 2016 Targets

Road Call Freq	3,200 miles MBRC*
Operation time	18/7*
Sch/Unsch Maint cost	$1.10 per mile*
Range	300 miles
Fuel Economy	7.25 miles per DGE*

Lessons Learned - Project Management

- Formation of the Integrated Project Team
- Integration of the complete power and propulsion system in the System Integration Lab
- Community Outreach
- Scheduling and Conducting Critical Reviews

Lessons Learned – Components and Systems

- Simplify De-fueling procedure
- Protect Traction Batteries against low state of charge
- Manage parasitic load on Coach Battery
- Manage cooling system materials

Conclusions

- The project addressed challenges of cost competitiveness, reliability, durability, integration and manufacturing.
- The relatively “low tech” nature of the issues encountered during demonstration period suggest that the major technological hurdles of fuel cell powered transit have been substantially addressed
- The average availability of the bus exceeded the availability of the CNG reference fleet and availability is expected to improve as the integration is refined.

Conclusions

- The performance, reliability, maintenance and operating cost of the AFCB is stable and approaching an affordability point
- Further work is needed toward driving down capital cost of the vehicle
- Standardizing configurations and increasing volume is expected to encourage investment and support throughout the supply chain

Questions