

Development of a “Half-Sized” BA-5590 with Li/CFx Cells

Gregg C. Bruce

EaglePicher Technologies

Presented at:
2009 Joint Services Power Expo
May 5th – 7th, 2009
New Orleans, Louisiana

Topics

- **Introduction**
- **EP-X590 and EP-X295 Batteries with Li/CFx Cells Development**
- **“Half-Sized” BA-5590 Li/CFx Battery Development**
- **Conclusions**

Introduction

- **EPT has carried out a development program to enable Li/CFx to be used in applications that require moderate or high rates.**
- **The goal has been to increase rate capability and improve low temperature performance.**
- **Efforts initially focused on a D cell format and evaluation in EP-X347 (2 D cells), EP-X380 (2 D cells), EP-X590 (10 D cells), EP-X295 (5 D cells) and the “Half-Sized” BA-5590 battery.**
- **Extensive performance, safety and transportation testing has been successfully completed.**
- **The EPT Li/CFx D cell has safely passed all the requirements of the UN Transportation testing protocol.**

Introduction

- **EPT has delivered the following CFx Cells and Batteries for evaluation:**

Organization	Cell Size, Ah	No. of Cells/Batteries	Date
USAF	D Cell 15.5-Ah	20 Cells	08/05
US Army	D Cell 15.5-Ah	60 Cells	08/05
US Army	EP-XX47	10 Batteries	08/05
US Navy	D Cell 15.5-Ah	10 Cells	10/06
US Army	EP-X380	15 Batteries	04/07
US Army	EP-XX47	20 Batteries	05/07
US Army	D Cell 15.5-Ah	10 Cells	06/07
US Army	EP-X590	5 Batteries	06/07
US Navy	EP-X590	2 Batteries	11/07
Canadian DND	EP-X590	4 Batteries	12/07
Canadian DND	D Cell 15.5-Ah	10 Cells	12/07
NASA Goddard	D Cell 15.5-Ah	8 Cells	12/07
Natick	EP-X295	2 Batteries	04/08
US Army	EP-X295	30 Batteries	05/08
US Navy (Crane)	EP-X295	6 Batteries	08/08
US Army (Natick)	EP-1/2 5590	30 Batteries	12/08
US Navy (Crane)	EP-X590	10 Batteries	01/09
US Army	EP-1/2 5590	20 Batteries	02/09

Electrical Performance (D Cell) Lithium Battery Chemistries at 20°C and 2A

Cell Chemistry	Capacity (Ah)	Weight (g)	Volume (cc)	Specific Energy (Wh/kg)*	Energy Density (Wh/l)*
Li/SO ₂	7.5	80	47.3	262.5	444.0
Li/MnO ₂	10.5	113	47.3	260.2	621.6
Li/CFx	15.5	87	47.3	463.2	852.0

*Li/SO₂ and Li/MnO₂ based at 2.8V and Li/CFx based at 2.6V

Military Batteries - EPT CFx cells

- EPT has been working on the “EP-5590” format with three approaches:
 - EP-X590 (10 D cells) twice the capacity of the BA-5590.
 - EP-X295 (5 D cells) same capacity, 59% of the size, 58% of the weight of the BA-5590.
 - Half Sized EP-5590 (5 smaller cells) same capacity of the BA-5590.
- The CFx EP-X590 battery was 7.3% heavier but delivered two times the capacity of the SO₂ BA-5590.
- The CFx EP-X295 battery was 59% of the size and 58% of the weight and delivered close to the same capacity as the SO₂ BA-5590.
- The “Half-Sized” BA-5590 with CFx cells delivered 82% of the capacity of a BA-5590 in 50% of the volume and 50% of the weight. Future optimization is on-going.

EPT Li/CFx Batteries

EaglePicher™

EP-X295, EP-X590 and “Half-Sized” BA-5590 Batteries



EP-X590 Batteries - EPT CFx D Cells

- **EaglePicher has made a limited number of EP-X590 batteries with CFx D cells.**
- **EaglePicher evaluated the Li/CFx D cells in the EP-X590 batteries in a similar fashion to a Industry/Government Li:MnO₂/Li:SO₂ evaluation with the exception of the 2A discharges.**
- **The batteries delivered the capacity projected by cell characterization.**

EP-X590 with EPT CFx D Cells Electrical Performance

Test Protocol	Test Temp.	Capacity (Ah)	Running Time (hrs)	Voltage Delay	Specific Energy (Wh/kg)	Energy Density (Wh/l)
Standard ASIP	-20°F	10.21	17.17	1 hour	109.3	127.5
Standard ASIP	95°F	31.16	61.84	Not Observed	393.9	459.3
Heavy ASIP	70°F	30.77	30.28	Not Observed	382.2	445.6
Heavy ASIP	130°F	31.25	31.71	Not Observed	400.2	466.7
RCU (0.825A)	-20°F	20.51	24.73	3.83 minutes	216.9	252.9
RCU (0.825A)	95°F	31.31	37.95	Not Observed	391.0	456.0

Standard ASIP = 20W, 1 minute: 4.6W, 6 minutes: 6W, 3 minutes
Heavy ASIP = 20W 1 minute: 6W, 1 minute

Military Batteries – EP-X295 Battery

- **EPT internally developed the EP-X295 battery.**
- **The EP-X295 is 59% of the volume and 58% of the weight of the BA-5590.**
- **The battery was manufactured in limited quantities for evaluation by Military users.**
- **The EPT EP-X295 battery has successfully passed all the requirements of the UN Transportation testing.**

EP-X295 SINGARS Profile with Storage

Storage	Test (°C)	Voltage Delay	Capacity (Ah)	Run Time (hours)	Wh/l	Wh/kg
None	21°C	None	14.8	28.6	361.1	345.8
None	-20°C	21 minutes	8.1	14.1	176.6	169.1
None	54°C	None	15.4	30.5	385.0	368.7
7 Day DC	21°C	None	14.8	28.4	358.1	343.0
7 Day DC	-20°C	21 minutes	7.5	13.0	163.7	156.7
7 Day DC	54°C	None	15.0	29.8	376.8	360.8
28 Day DC	21°C	None	15.8	28.7	375.2	359.3
28 Day DC	-20°C	31 minutes	6.9	12.0	151.5	145.1
28 Day DC	54°C	None	15.4	30.5	385.0	368.7

**SINGARS (Standard ASIP) = 20W, 1 min.: 4.6W, 6 min.: 6W, 3 min.
Baseline BA-5590 at 21°C provides 247.6 Wh/l and 227.8 Wh/kg.**

EP-X590 and EP-X295 Batteries with CFx Cells - Conclusions

- Under the SINGARS Test Protocol the CFx EP-X590 battery ran for 61.35 hours and the EP-X295 ran for 28.6 hours.
- The BA-5590B/U Li/SO₂ battery tested under identical conditions ran for total of 32.50 hours, specification is 30.5 hours.
- Maximum temperature reached was 41°C for the EP-X590 and 53°C for the EP-X295 under the SINGARS Test Protocol at 21°C.
- The EP-X590 battery is 7.3% heavier but delivers close to two times the capacity of the SO₂ BA-5590. One CFx battery weighing 1030g versus two SO₂ batteries weighing 1920g (960 g each).
- The EP-X295 battery will be 58% of the weight of the Li/SO₂ BA-5590 and deliver 88% of the capacity and 94% of the specified mission requirement.

Background - Goals

Performance Specifications:

- “Half Sized” EP-5590 Li/CFx Battery
- 200 Wh at the SINGARS radio duty cycle of (4.6W : 6.0W : 20W, 6 minutes:3 minutes:1 minute)
- 1.1lb max (400 Wh/kg)
- Dimensions: see drawing below
- 16.8V max, 10V min
- Connector: BA-5590 type
- Fuel gauge
- Operational Temp: -20°C to 55°C
- Storage Temp: -40°C to 70°C
- Prototypes deliverables will be evaluated on electrical performance and their ability to meet IATA, MIL-PRF-47491B, and Safety Assessment Report (SAR) testing. SAR required in FY09 for Soldier use.

“Half-Sized” BA-5590 with Li/CFx Cells

EP-X590 and “Half-Sized” BA-5590 Batteries



Baseline Performance

- **The “Half-Sized” BA-5590 with Li/CFx cells is designed so that the two batteries can fit into the BA-5590 battery enclosure.**
- **The performance goal is quite rigorous since the battery is exactly half the size of the BA-5590 but the connector is unchanged. Therefore, the volume available for the cells is less than 50% of the space available for the cells in the BA-5590 battery.**
- **The “Half-Sized” BA-5590 with Li/CFx Cells weighs 50% of that of the BA-5590.**

Baseline Performance – Cell

- Due to the volume for the cells in the “Half-Sized” BA-5590 being reduced when compared to the BA-5590 a new cell was developed.
- The Electrical Characterization of the cell is shown below:

Temperature (°C)	Discharge Rate (continuous)		
	0.5A	1.0A	2.0A
-20	N/A	6.40-Ah	6.24-Ah
21	13.37-Ah	13.47-Ah	12.78-Ah
55	13.90-Ah	13.35-Ah	13.49-Ah

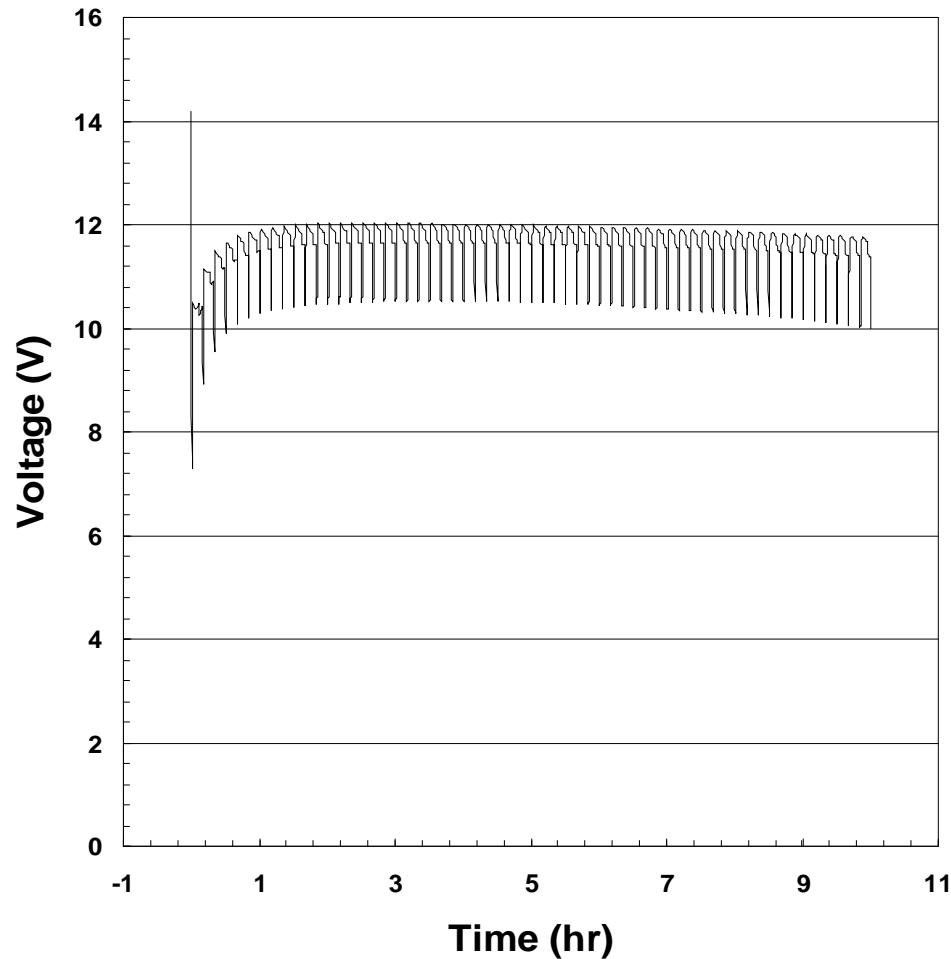
Baseline Performance

“Half-Sized” BA-5590 with Li/CFx Cells

- **The development of the battery focused on the SINGARS Test Protocol.**
- **The batteries were characterized at -20°C, 21°C and 55°C as specified.**
- **In addition the battery was also discharged at -29°C to determine performance limitations.**
- **In all cases the battery discharged at every temperature with some Voltage Delay noted at -20°C and -29°C.**

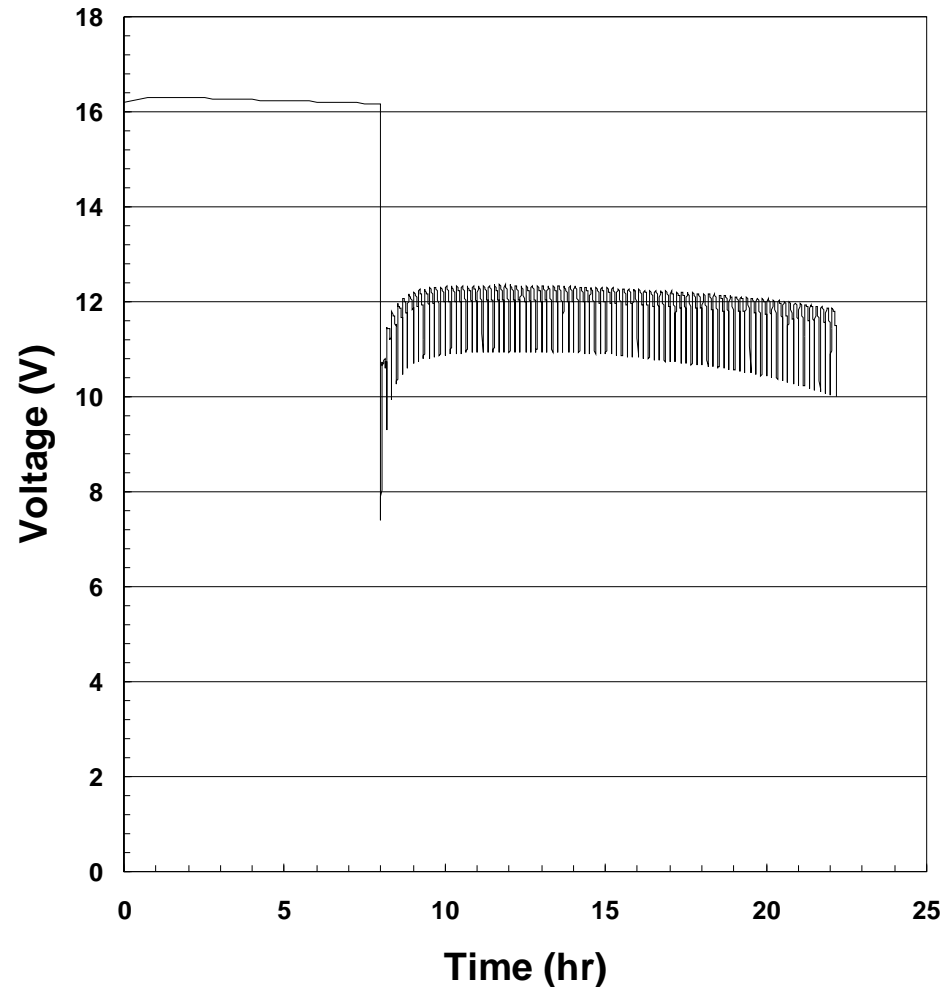
“Half-Sized” BA-5590 with Li/CFx Cells

SINGARS Test Protocol (– 29°C)



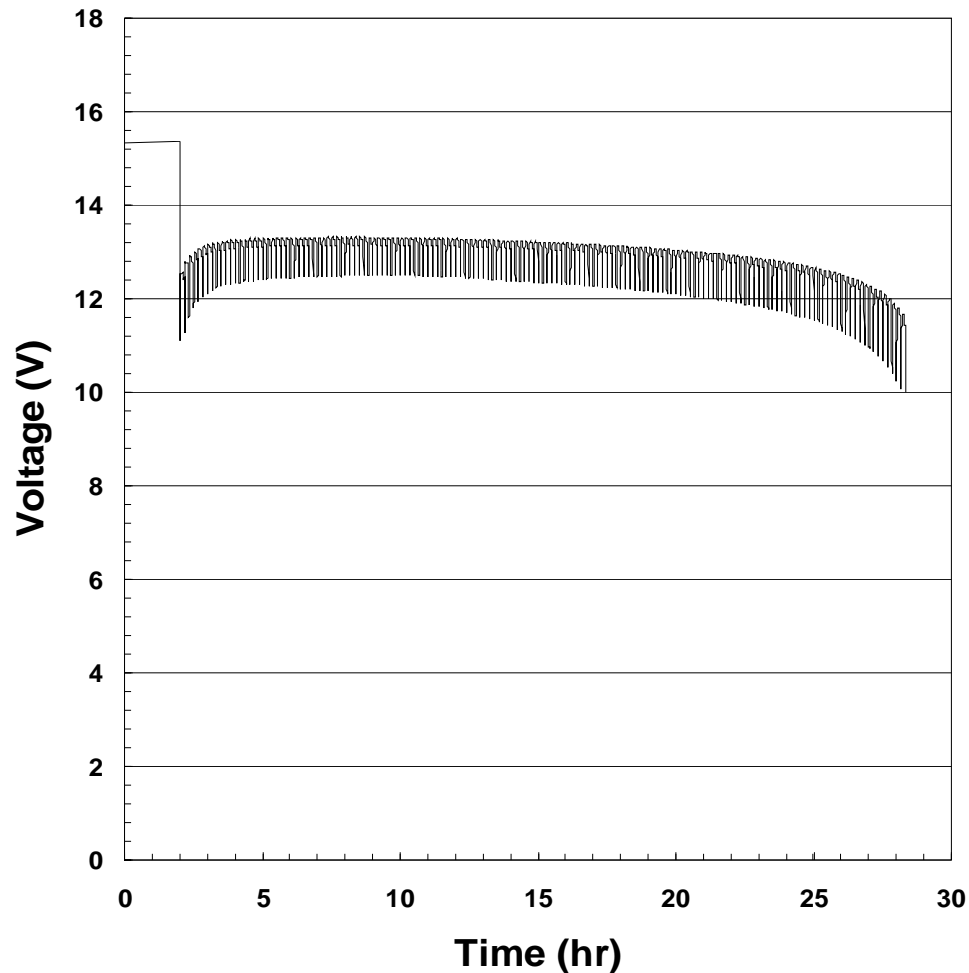
“Half-Sized” BA-5590 with Li/CFx Cells

SINGARS Test Protocol (– 20°C)



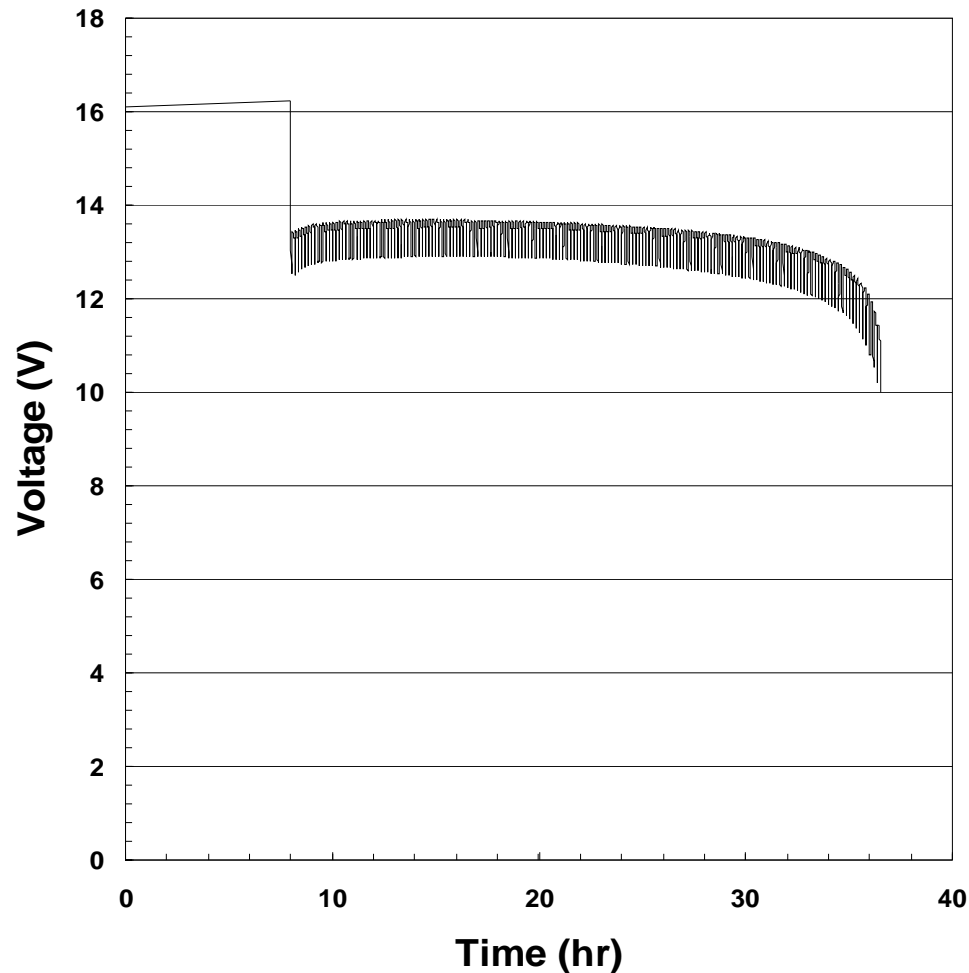
“Half-Sized” BA-5590 with Li/CFx Cells

SINGARS Test Protocol (21°C)



“Half-Sized” BA-5590 with Li/CFx Cells

SINGARS Test Protocol (55°C)



“Half-Sized” BA-5590 with Li/CFx Cells Electrical Performance – SINGARS Protocol

Temp. (°C)	Voltage Delay	Capacity (Ah)	Discharge Time	Watt Hours	Wh/l	Wh/kg
-29°C	30.6 min.	5.3-Ah	9.1 hours	59.5	136.41	122.68
-20°C	20.3 min.	7.6-Ah	13.4 hours	88	201.75	181.44
21°C	0	13.6-Ah	26.2 hours	172.3	395.02	355.26
55°C	0	14.1-Ah	28.0 hours	183.8	421.39	378.97

Baseline BA-5590 at 21°C provides 247.6 Wh/l and 227.8 Wh/kg.

“Half-Sized” BA-5590 with Li/CFx Cells - Conclusions

- **There are still performance issues associated with the CFx batteries when tested at low temperature.**
- **The voltage delay was greater than allowed.**
- **The performance of the EPT Li/CFx batteries have demonstrated the potential of the electro-chemistry.**
- **The “Half-Sized” Ba-5590 battery delivered 355.26 Wh/kg at 21°C and 378.97 Wh/kg at 55°C.**
- **On-going developments have shown 400 Wh/kg is within reach.**
- **The CFx batteries provided by EPT will allow the user to select the proper capacity as governed by the mission and not have to carry unwanted weight.**

“Half-Sized” BA-5590 with Li/CFx Cells Recent Developments

- **Recent Internally Funded Research and Development at EPT has shown that the cell impedance can be greatly reduced to limit or eliminate Voltage Delay under Low Temperature conditions.**
- **The lower cell impedance will also reduce thermal issues at higher discharges rates (2A). The thermal issues are not an issue under the SINGARS Test Protocol.**
- **Presently, different cell designs are under investigation to increase Specific Energy.**