Space Power Workshop
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Li/CFx Technology for Extreme Low Temperature and High Power Applications

EnerSys

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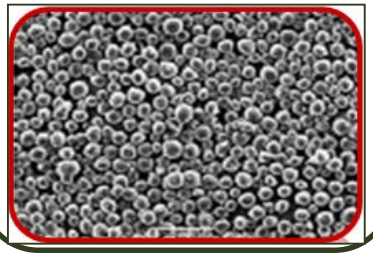
Vertical Integration of Battery Manufacture

Materials

Critical anode and cathode raw materials – production and analysis

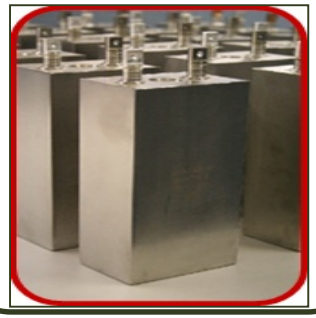
Sylmar, CA
Santa Clarita, CA



Cells

High-performance custom cells in wound, stacked-plate, prismatic, pouch, and 18650 formats from 1 to +100,000/year

Sylmar, CA



Electronics

Custom engineered electronics for battery management and system interface

Sylmar, CA

Battery Pack

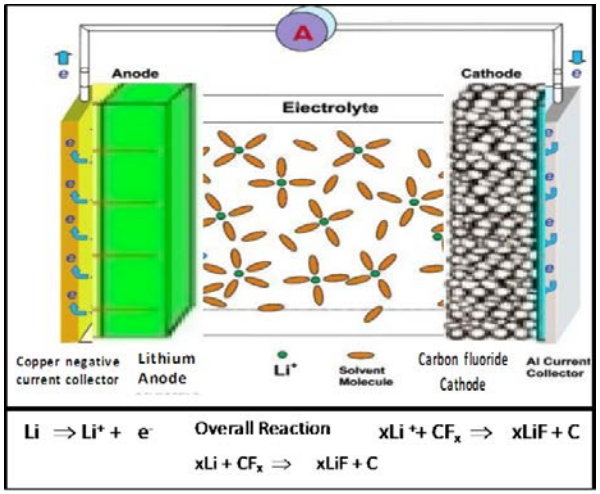
Complete cell packs engineered, manufactured and tested for any high-performance application

Sylmar, CA
Longmont, CO
Culham, UK

> **Unmatched product flexibility and supply-chain stability in one battery partner** <

QUALLION

Li/CFx chemistry



"Attractive for planetary probes and surface missions that require high energy density primary batteries" JPL D-101146

$(CF)_n + nLi^+ + ne^- \rightarrow nC + nLiF$

Theoretical Capacity: 864mAh/g

Pros	Cons
High energy density (>450Wh/kg, >700Wh/L)	Poor low temperature capability • Low ionic conductivity of electrolyte
Low self discharge (<1% per year)	Poor rate capability • Low electronic conductivity of CFx • Slow reduction kinetics of CFx cathode
Long shelf life	Safety concern at high rate and high temperature
Minimal voltage delay	Poor End-of-Life indications

Quallion Li/$(CF)_n$ approaches

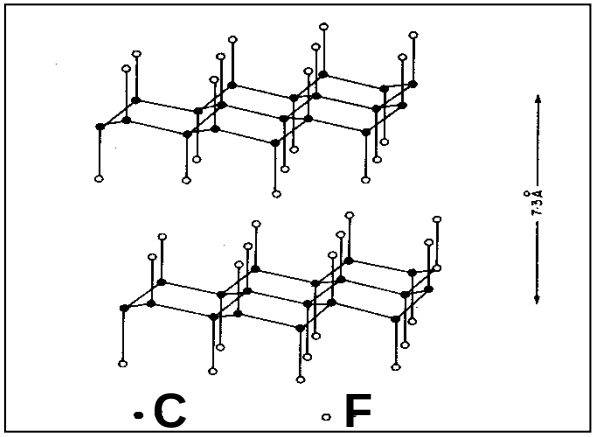
	Current Li/$(CF)_n$ cells	Quallion Li/$(CF)_n$ cells
Material	Conventional CF_x	High surface area CF_x
Electrode	powder pressed electrodes	thin film coated electrdoes
Internal Design	pellet wound	jellyroll
Electrolyte		low visocity electrolyte
Separator	non-woven	microporous thin film separator

Key elements that enable Quallion to build high power, low temperature capable CFx cells.

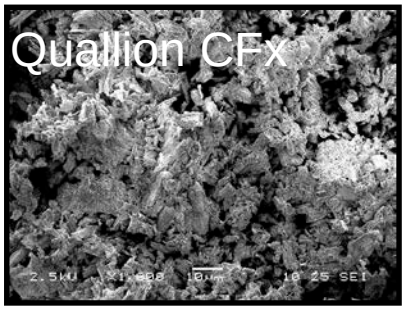
Active Materials

Synthesis of Carbon Fluoride $(CF)_n$

$nC_{solid} + n/2\ F_{2,\ gas} \rightarrow (CF)_{n,\ solid}$ at 400-600°C



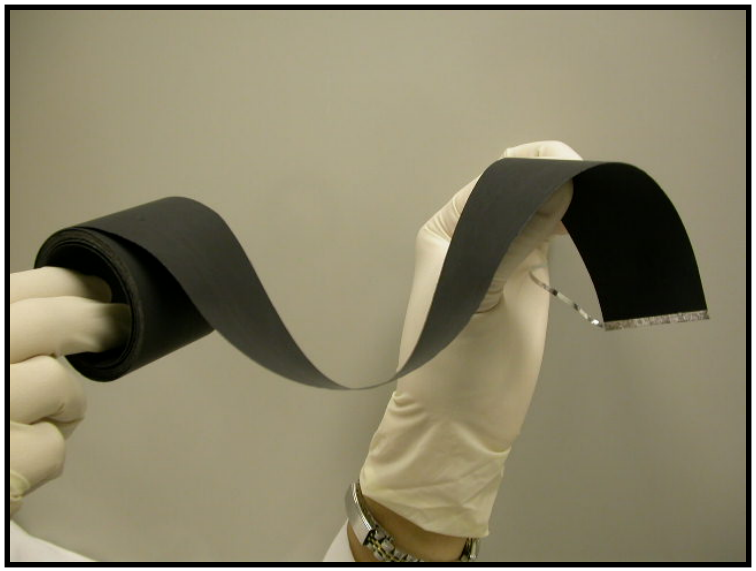
- Crystallinity of carbon
- Particle size / Surface area
- Fluorination degree / condition
- Bonding characteristics



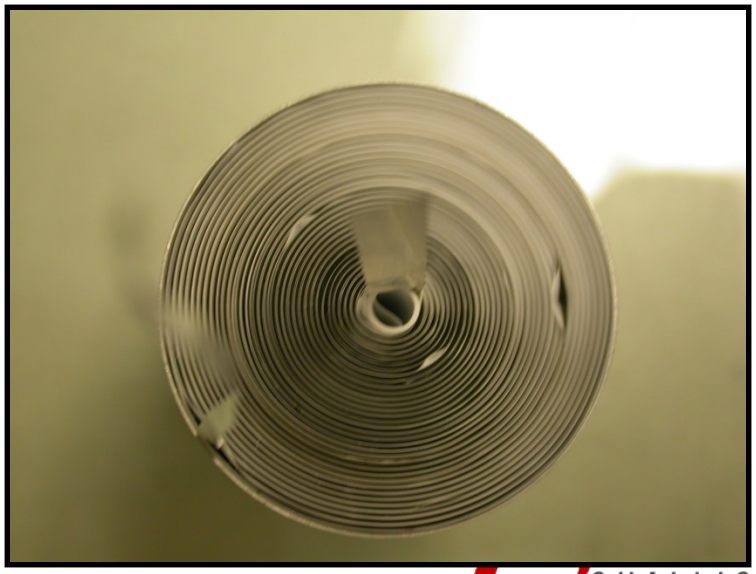
➢All these factors affect the discharge characteristics of CF_x.

Electrode

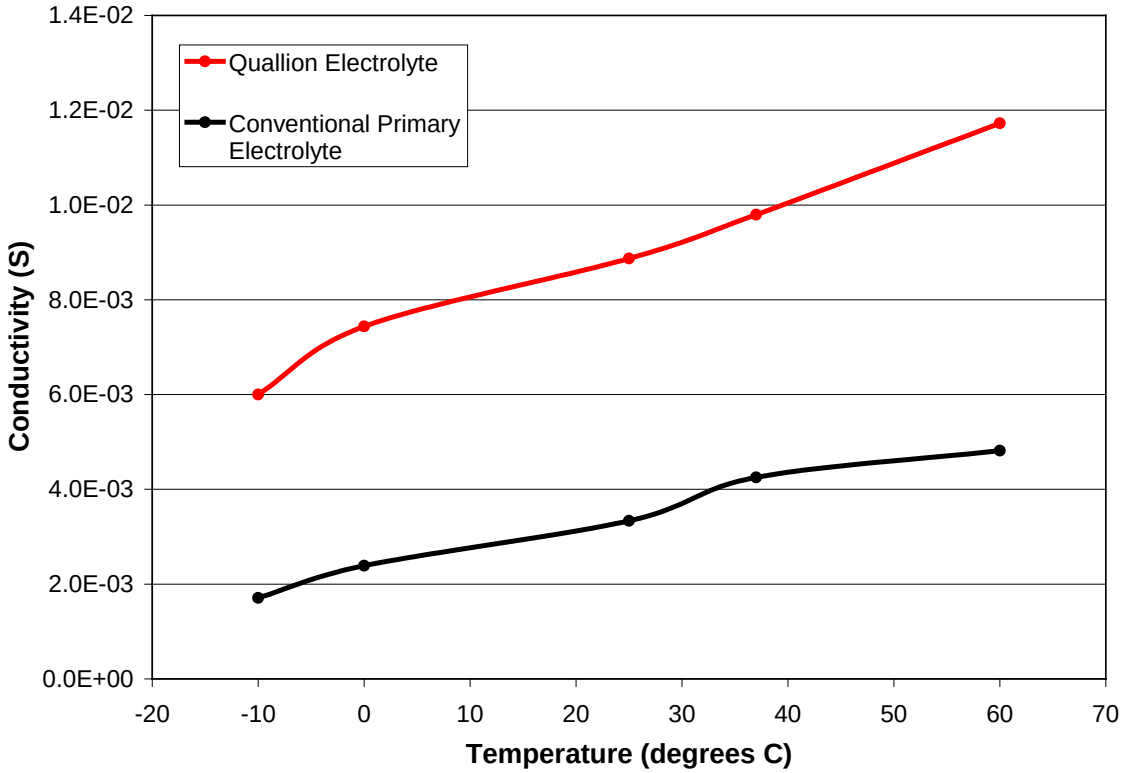
Quallion utilizes a method of thin film coating to create flexible electrodes that can be easily wound into a jellyroll.



The wound jellyroll design enables high power discharge of the cells.

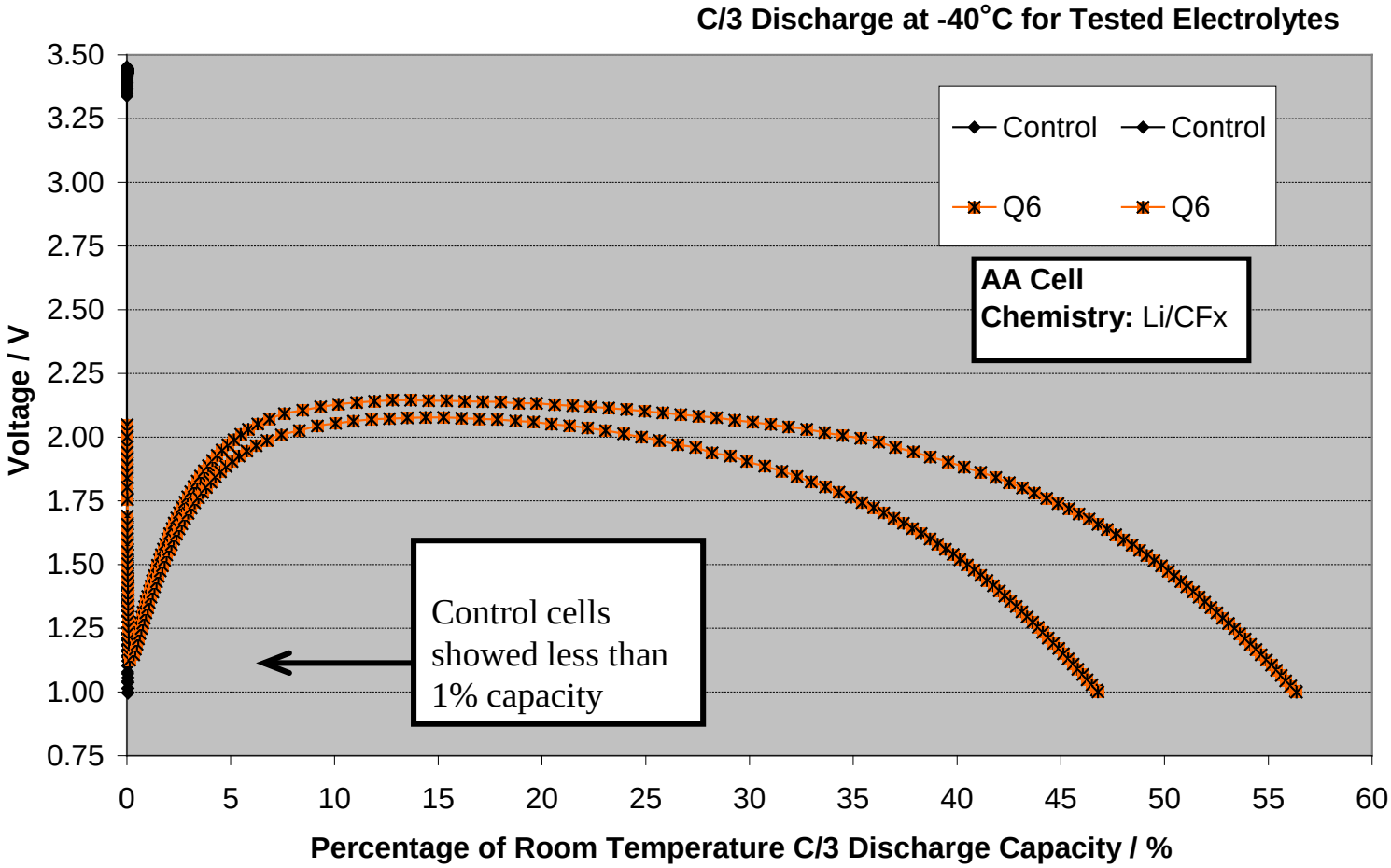


Low Viscosity Electrolyte



High conductivity throughout a broad range of operation temperatures.

C/3 Discharge Curves at -40°C

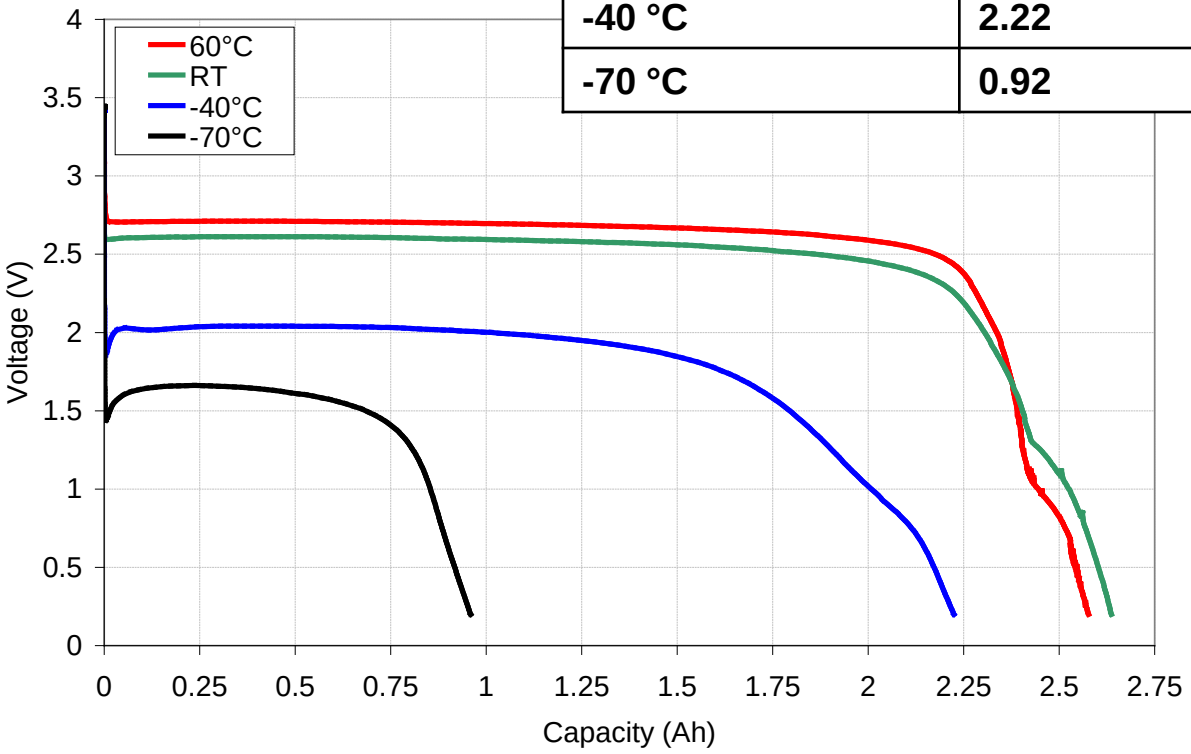


AA-cell
Capacity: 2.5 Ah
Diameter: 13.4 mm
Height: 49.1 mm
Energy Density:
966 Wh/L
385 Wh/kg

With C/3 rate and -40°C, >50% of the capacity was obtained

C/20 Discharge Rate Data of Q6-AA Cell (2.5Ah)

Temperature	Capacity (Ah)	Capacity (% of 2.5Ah)
60 °C	2.58	103
25 °C	2.64	105
-40 °C	2.22	89
-70 °C	0.92	38



AA-cell
Capacity: 2.5 Ah
Diameter: 13.4 mm
Height: 49.1 mm
Energy Density:
966 Wh/L
385 Wh/kg

90% capacity at -40°C and 40% capacity retention at -70°C

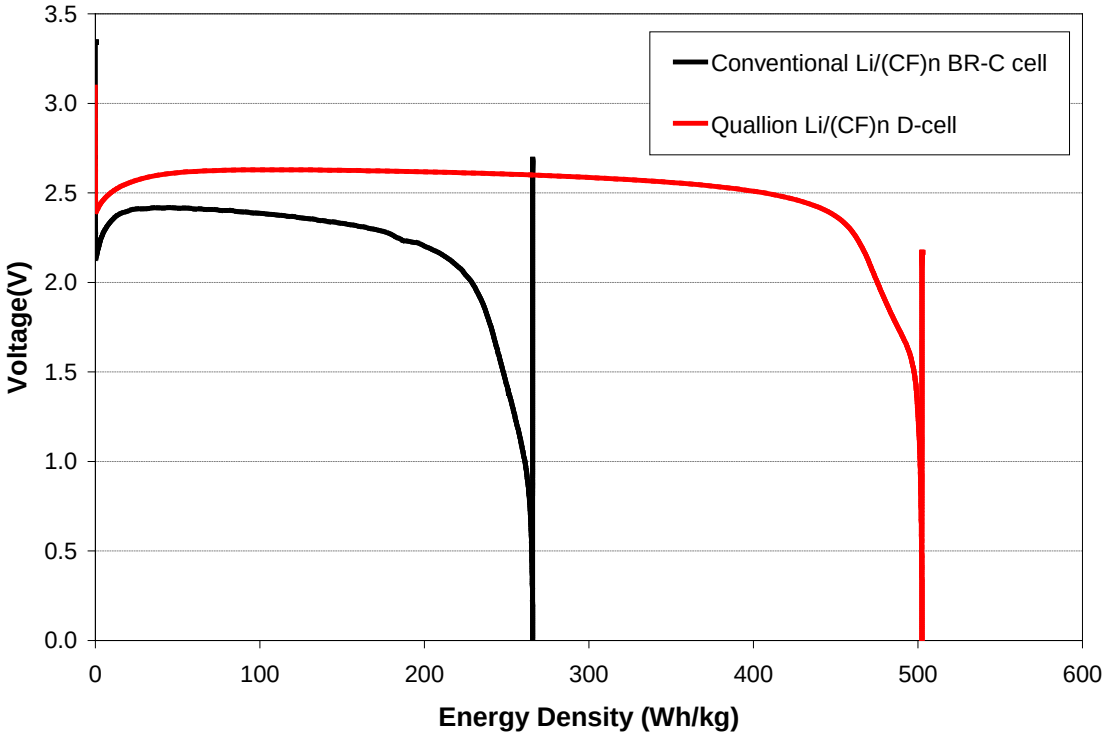
D-cell Comparison

Power and Temperature Tests

- Discharge at varying temperatures.
- Discharge at constant current and constant power.

Capacity: 15 Ah
Diameter: 34 mm
Height: 60.5 mm
Volumetric Energy Density: 680 Wh/l
Weight Energy Density: 520 Wh/kg

Discharge comparison between commercial CF_x cells and Quallion CF_x cells – High rate at room temperature

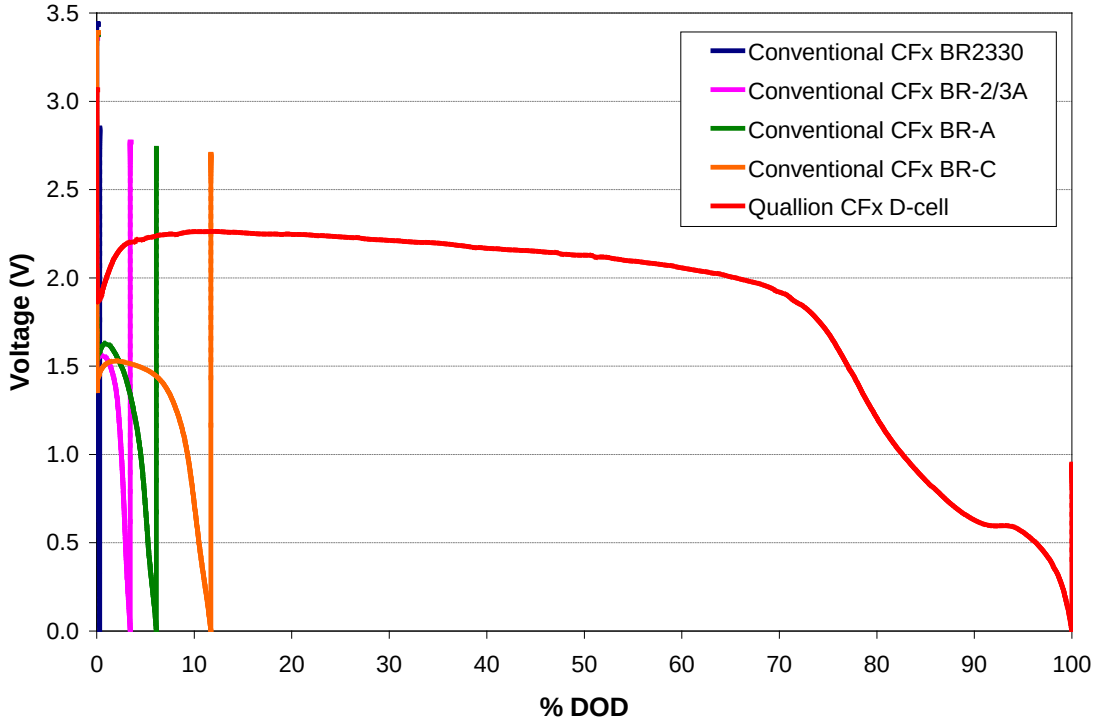


Conditions:

- 25°C
- C/7.5 Constant Current (Typically CFx cells are rated for ~0.02C)

The energy density of the Quallion $Li/(CF)_n$ D-cell is about double that of existing $Li/(CF)_n$ cells.

Discharge comparison between commercial CF_x cells and Quallion CF_x cells – High rate at -30°C

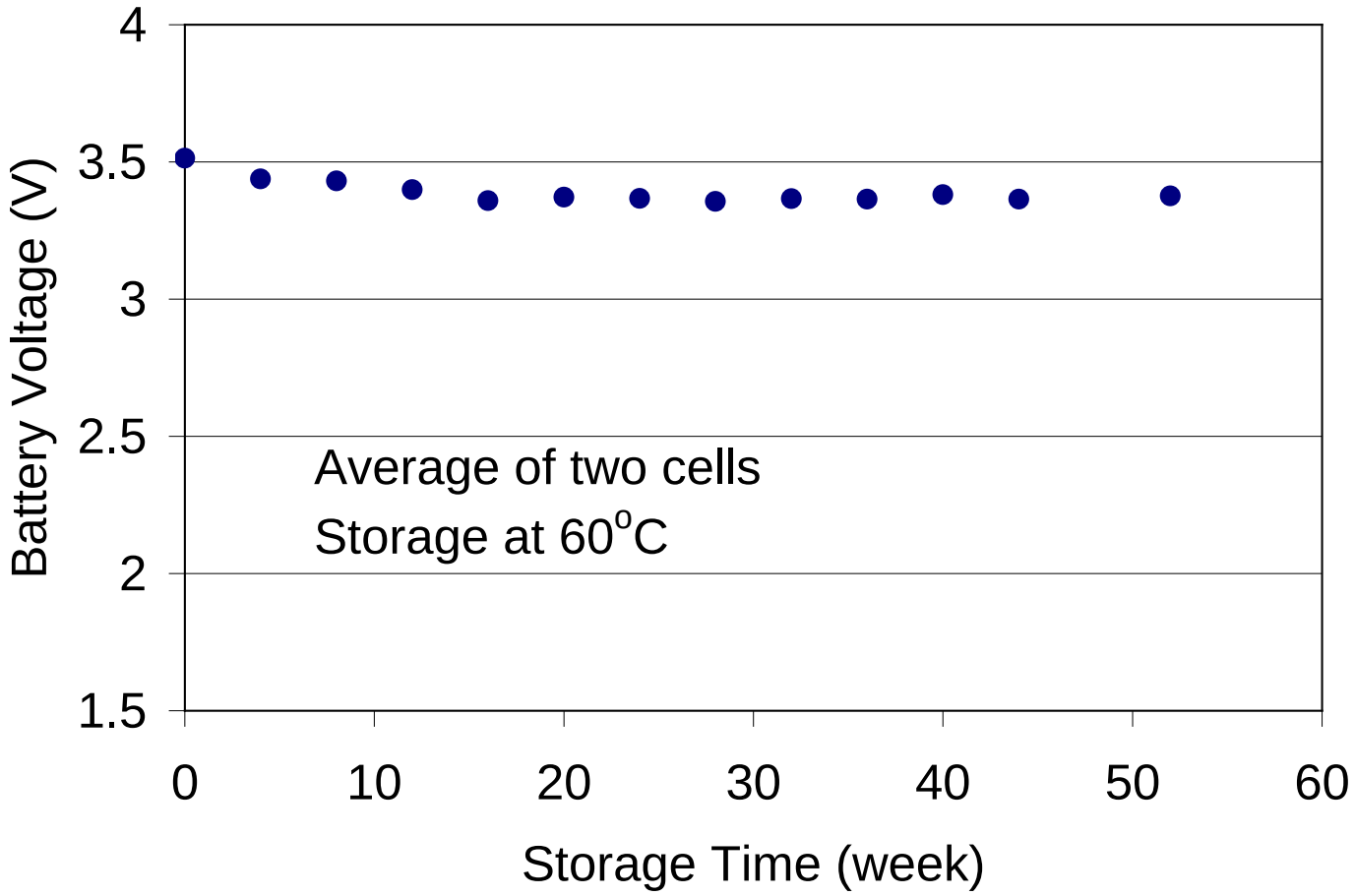


Conditions:

- -30°C
- C/7.5 Constant Current

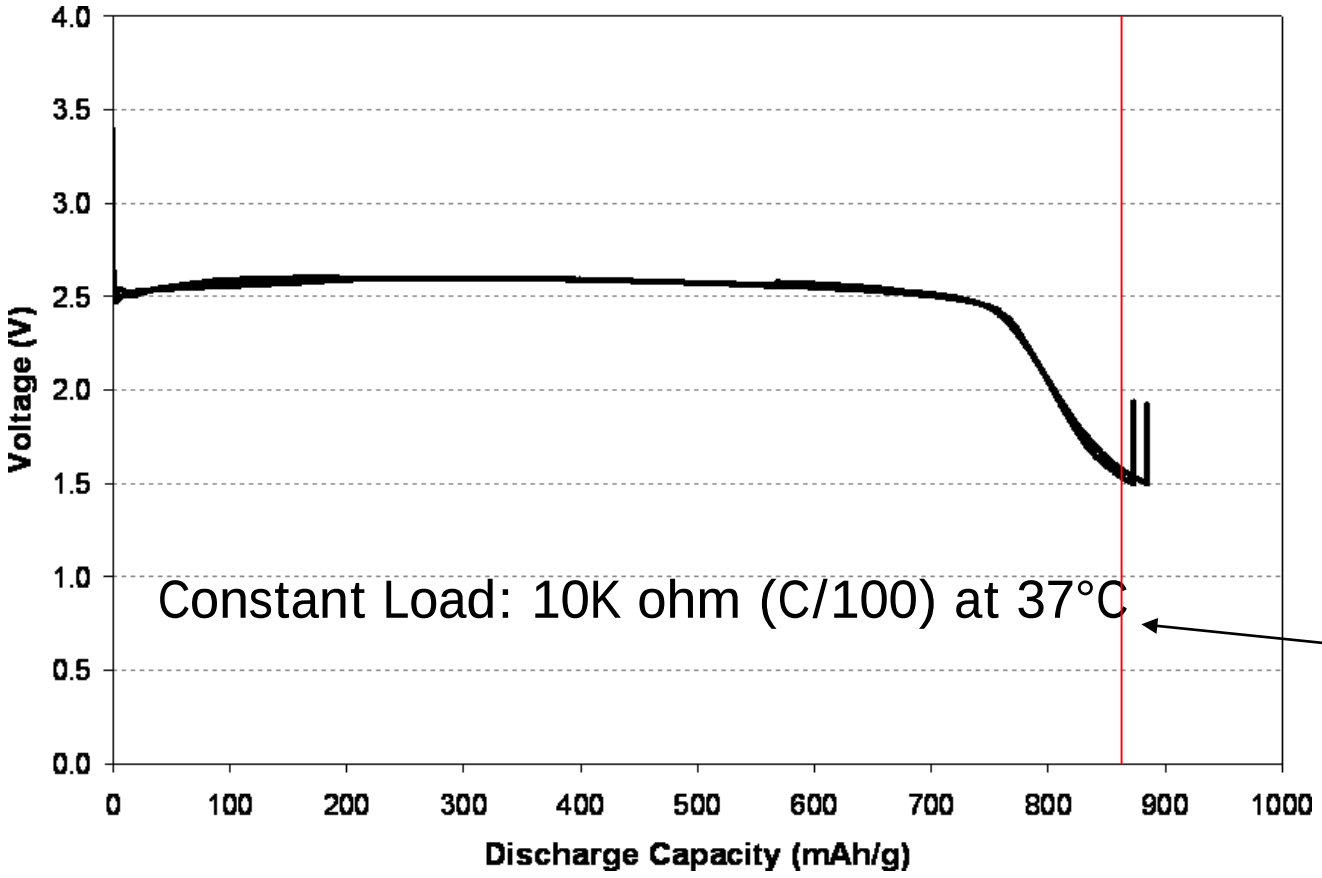
- Existing CF_x batteries are not able to operate efficiently when discharged at high rates C/7.5 at -30°C.
- Quallion CF_x D-cell is operational above a 2.0 V cutoff for 65% of its capacity.

OCV Change during Storage



High temperature storage has no effect on the capacity

Discharge Profile after 1year storage at 60ºC



No capacity loss

Li/CFx – LVO Hybrid Cathode Development

Li/(CFx + LVO) Cell

-Rechargeable cathode additive improves pulse capability-

$(CF)_n + nLi^+ + ne^- \rightarrow nC + nLiF$

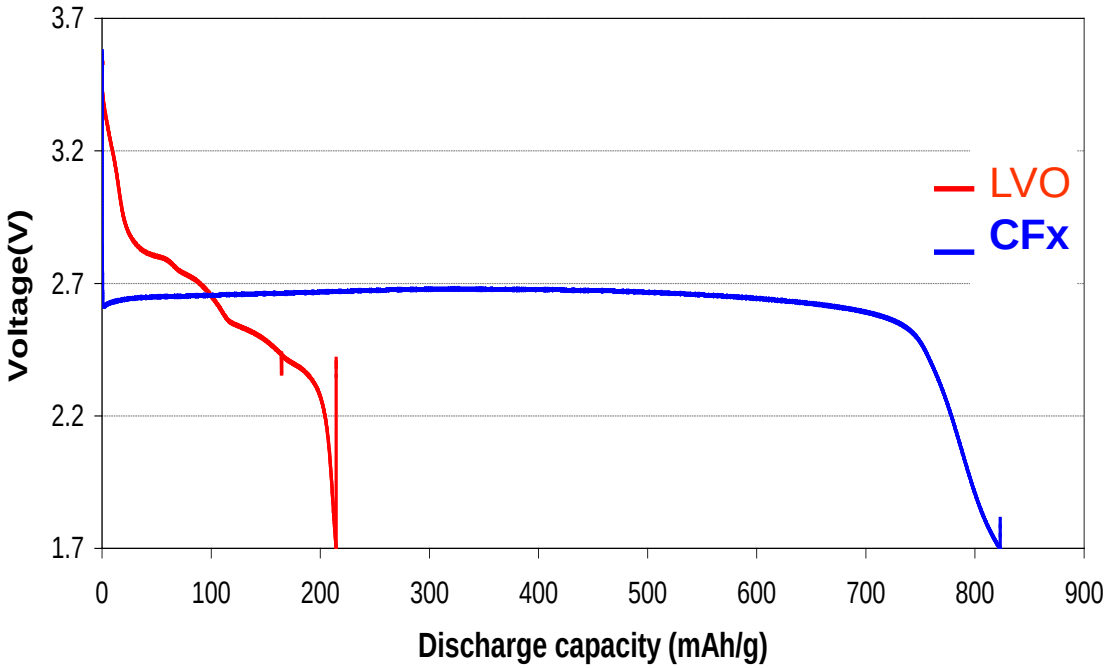
Theoretical Capacity: 864mAh/g

Primary

$Li_{1.1}V_3O_8 + 3.9Li^+ + 3.9e^- \leftrightarrow Li_5V_3O_8$

Theoretical Capacity : 362.4mAh/g

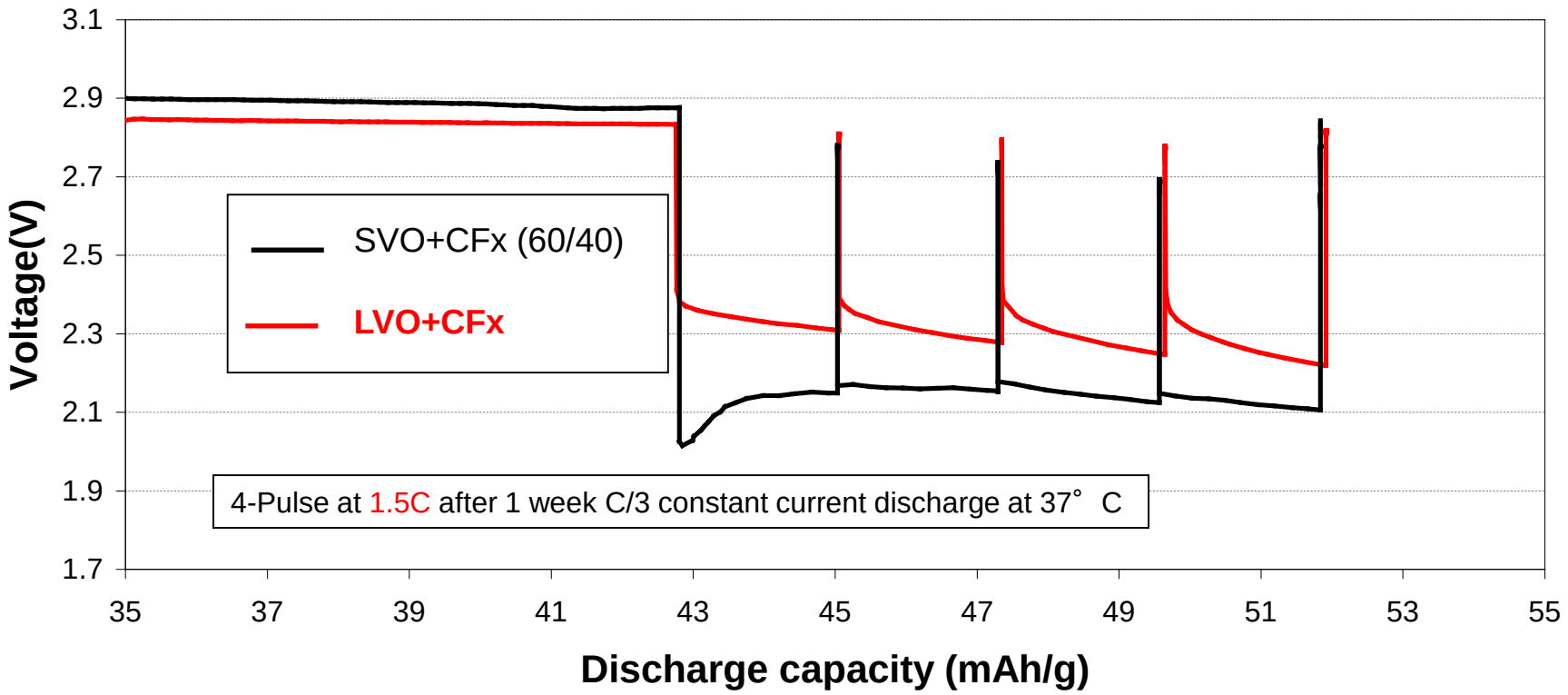
Rechargeable



- Much less resistance than CFx
- At low SOC, LVO voltage is lower than CFx → recharged by CFx internally

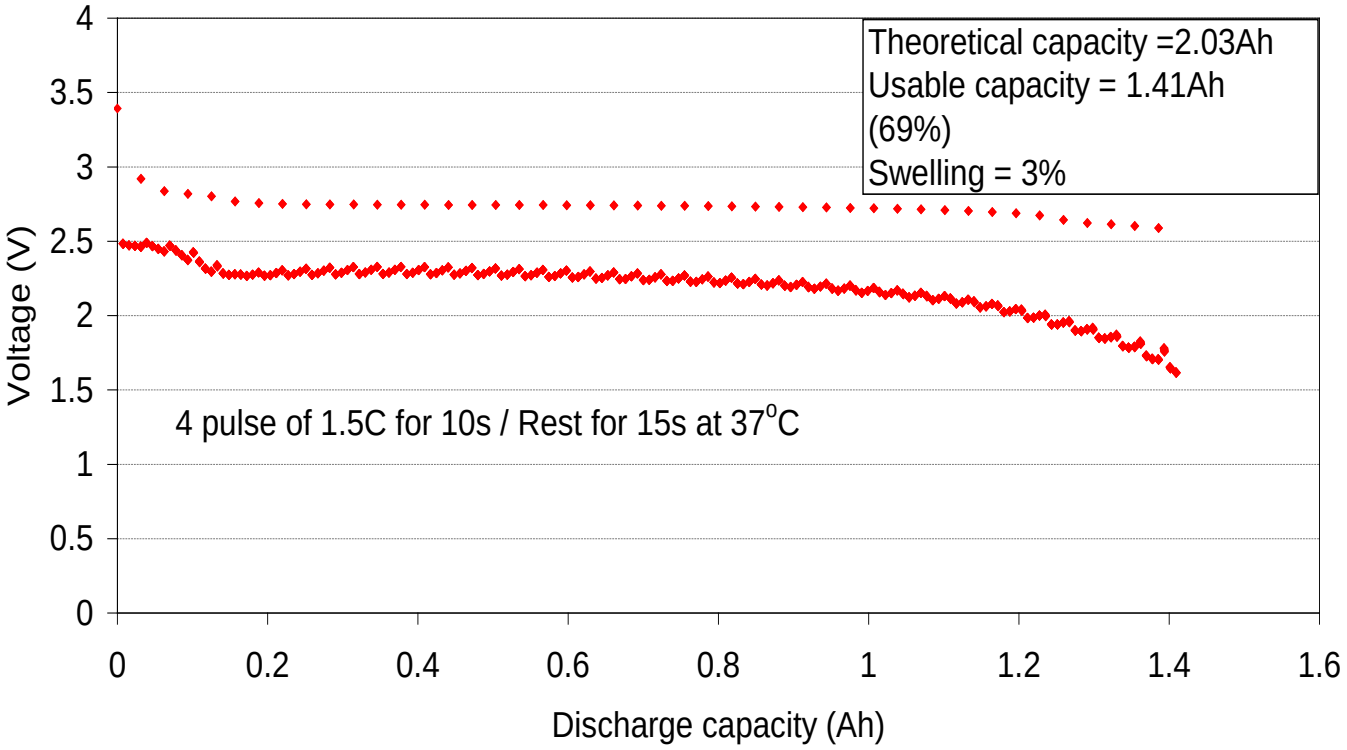
→ **High rate capable CFx**

Li/(CFx+LVO): No Voltage Delay



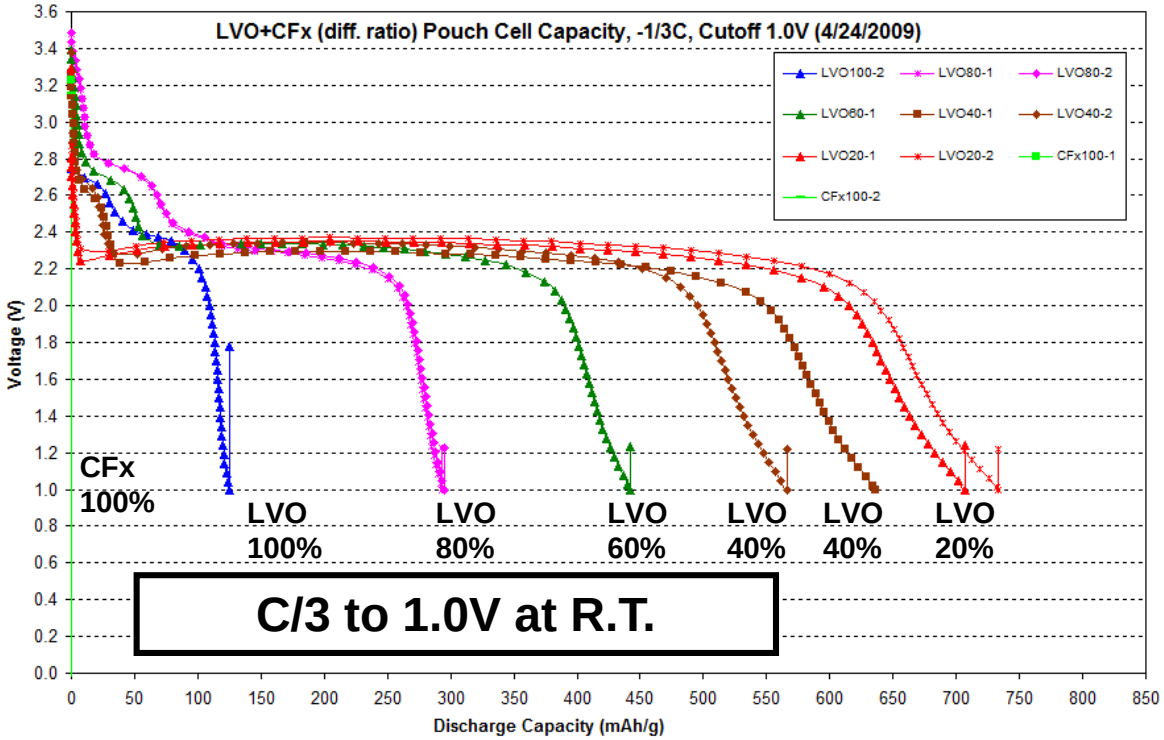
No voltage delay was observed during pulse test

Pulse Discharge Profile



Effect of LVO/CFx ratio

Different amounts of an additive are blended with CFx to give improved high rate and low temperature performance



• CFx 100% cells shows no capacity due to the voltage drops below 1.0V at the beginning of discharge

Quallion Li/CFx cells

AA-cell
Capacity: 2.5 Ah
Diameter: 13.4 mm
Height: 49.1 mm
Energy Density: 966 Wh/l
: 385 Wh/kg

D-cell
Capacity: 15 Ah
Diameter: 34 mm
Height: 60.5 mm
Energy Density: 680 Wh/l
: 520 Wh/kg

Pin type cell
Capacity: 25mAh
Diameter: 2.9 mm
Height: 22 mm
Energy Density: 345 Wh/l
: 111 Wh/kg

Summary

- Quallion prepared high power (C/3 constant or 1.5C pulse) and low temperature (-70℃) capable CFx cell
- Quallion unique technologies:
  - Large surface area and small particle size CFx
  - Low temperature electrolyte
  - High porous separator
  - Flexible thin film coating electrode
  - LVO+CFx chemistry