High Energy Lithium Primary Batteries for Extreme Conditions

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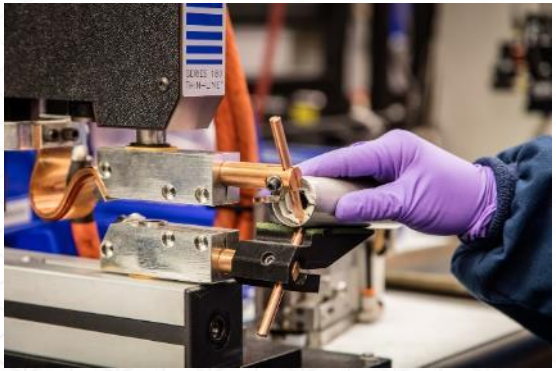
Electrochem

Electrochem manufactures lithium primary batteries for specialized markets, with a focus on extreme operating conditions. Our headquarters is in Raynham, Massachusetts, south of Boston.





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Electrochem, an Integer Company

- Integer is one of the world's largest medical device outsource manufacturers, delivering revenues approaching $1.4B annually with numerous locations throughout the world.

- Electrochem operates as an Integer company while maintaining independent leadership, processes, and decision making. Our heritage for superior quality, reliability, and innovation are deeply rooted in our origins when Wilson Greatbatch invented the first lithium battery for implantable pacemakers.

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Why people choose Electrochem

✓ **Quality & Reliability**

- US manufacturer with state-of-the-art ISO 9001:2015 certified manufacturing facility.
- Design for Excellence (DfX) principles, with comprehensive product/process qualifications and validations.

✓ **Culture of Safety, Compliance & Continuous Improvement**

- Dedicated to the specifications and processes that are critical to the markets we serve (ITAR, NAVSEA, EAR, MIL-STDs).
- Numerous global certifications and compliance measures (UL, CE, IATA, DGR, TCC).
- Fail-safes incorporated into all battery pack designs ensuring user safety.

✓ **Experience**

- 40+ years experience with critical battery applications, where failure is not an option.
- Exceptionally broad range of cell types and sizes, with strong capability for custom cell and pack designs.
- Extensive knowledge of battery chemistries and fundamentals, with proven success in harsh environments.

Electrochem is looking to establish partnerships for new technologies and manufacturing opportunities.

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Extreme conditions

When we say "extreme," what do we mean? Some examples:

- High temperature (>100°C)
- Low temperature (<0°C)
- Physically rugged, high shock (1000g) and vibration (20grms)
- Need for multi-year discharge life
- Explosive atmosphere or similar hazardous conditions

Primary batteries

In a world of rechargeables, when are primary batteries a better choice?

- Charging not available or not practical
  - No energy source available for charging
  - Charging electronics would be too heavy, complicated
  - Very long low-rate discharge where multiple cycles are not needed
  - Low self-discharge important (very long inactive storage)
- Conditions where there is no rechargeable option available
  - High temperatures
  - Low temperatures
- Need to avoid flammable electrolytes
  - Explosive atmosphere conditions (e.g., mining or pipelines)

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Lithium oxyhalide batteries

Lithium oxyhalide primary cells contain:

- A lithium metal anode, and a liquid cathode consisting of a highly oxidizing inorganic compound (thionyl chloride or sulfuryl chloride).
- The liquid cathode also serves as the electrolyte. Because no space is wasted on an inert electrolyte, the energy density of these batteries can be very high (>450 Wh/kg, >1000 Wh/L).
- A layer of LiCl forms immediately on contact between the electrolyte and the lithium, passivating the lithium surface and preventing any further reaction.
- Note that the oxyhalide liquids are non-flammable.

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Three electrolytes, and many cell types

Thionyl Chloride ($SOCl_2$)

- Excellent performance at high and low temperatures
- Leading technology for the downhole market
- Open circuit voltage = 3.67 V

BCX ($SOCl_2$ with BrCl additive)

- Enhanced performance and safety at very low temperatures
- Originally developed for use on Space Shuttle missions
- Open circuit voltage = 3.9 V

Sulfuryl Chloride (SO_2Cl_2) – "CSC" and "PMX"

- Highest energy density
- Most commonly used at moderate temperatures, but also used in some high temperature downhole applications
- Open circuit voltage = 3.93 V

Different cell designs for low, moderate, and high rate capability, sizes ranging from 7 mm to 47 mm diameter

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Lithium – Thionyl Chloride

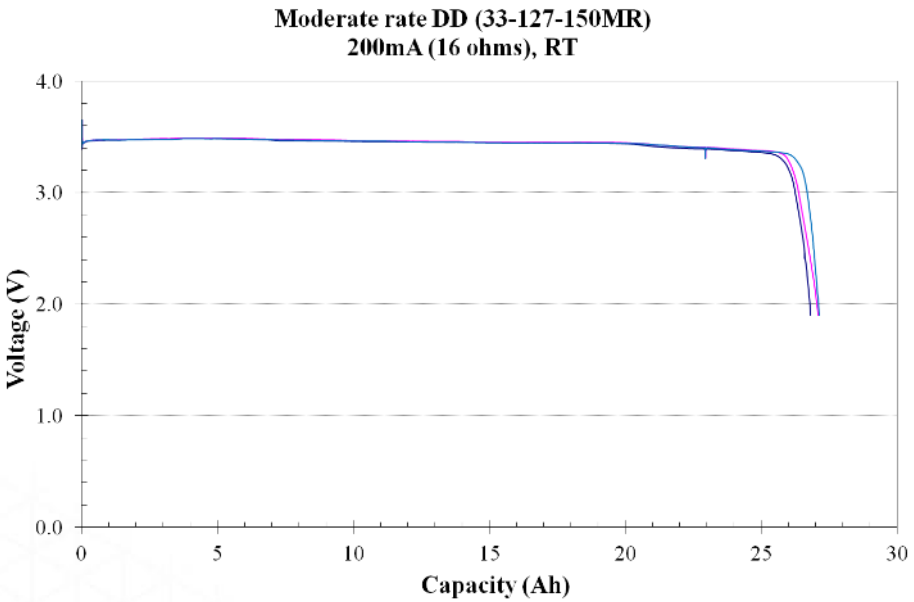
Anode Oxidation:

$$Li \rightarrow Li^{+} + e^{-}$$

Cathode Reduction:

$$2SOCl_2 + 4e^{-} \rightarrow S + SO_2 + 4Cl^{-}$$

Open Circuit Voltage: 3.67 V



- Thionyl chloride is the most widely used of the liquid cathode electrolytes.
- It can be used at temperatures from -40°C to 200°C.

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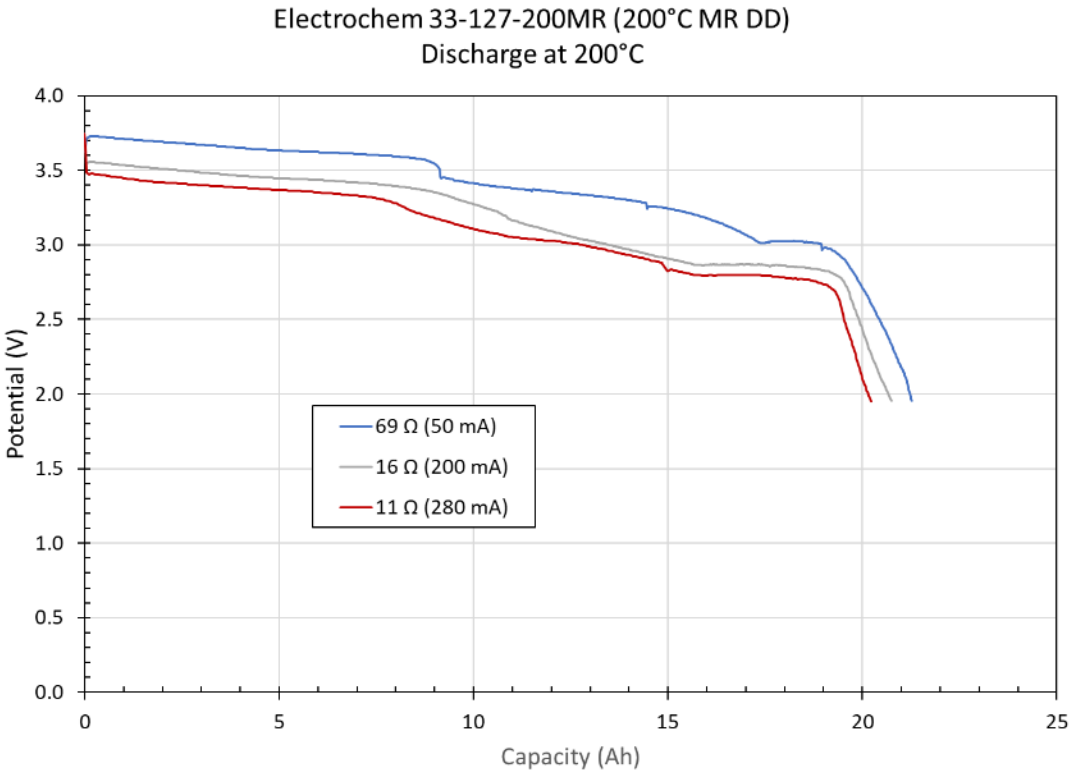
Lithium – Thionyl Chloride

Thionyl chloride cells with lithium alloy anodes can operate at 200°C, higher than the melting point of pure lithium.



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Some thionyl chloride applications

Low to high temperatures, including physically rugged conditions

Remote-Reading Applications:
Low-rate cells for mild temperatures.
Cells can operate for many years.

Downhole Applications:
Very high temperatures, very high shock-and-vibration (1000G shock, 20Grms/5-500Hz vibration), very high energy density.

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Lithium – Sulfuryl Chloride (CSC/PMX)

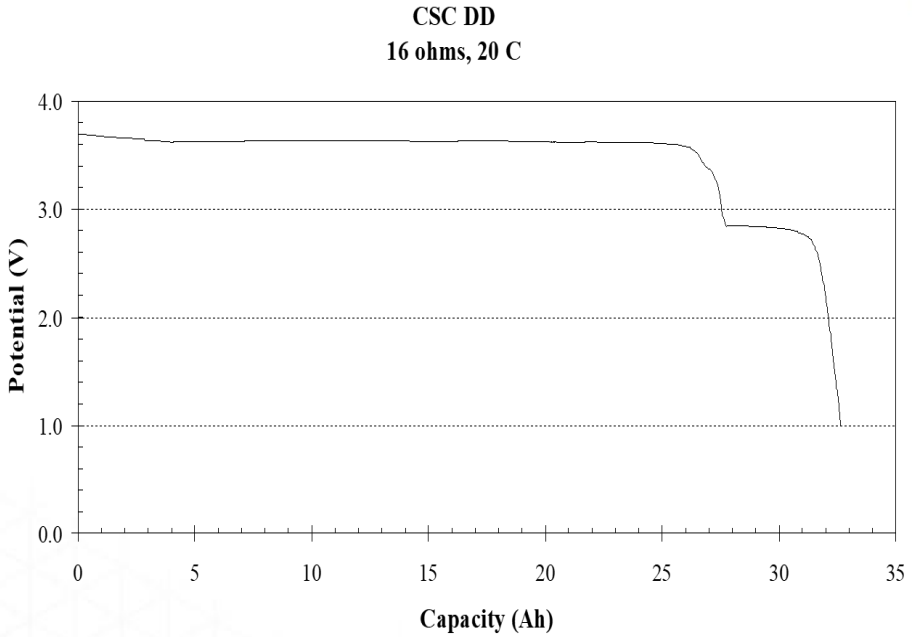
Anode Oxidation:

$$Li \rightarrow Li^{+} + e^{-}$$

Cathode Reduction:

$$SO_2Cl_2 + 2e^{-} \rightarrow SO_2 + 2Cl^{-}$$

Open Circuit Voltage: 3.93 V



- Because of the high voltage, these cells have the highest energy density available.

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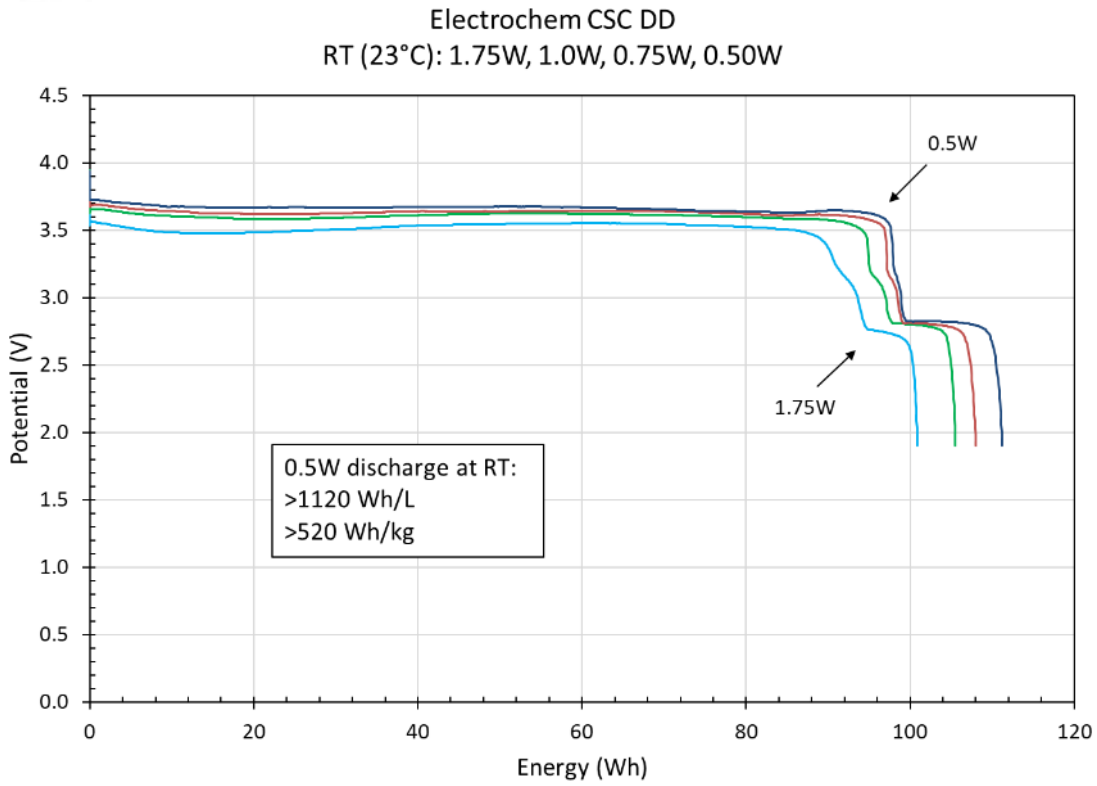
Lithium – Sulfuryl Chloride (CSC/PMX)

Extremely high energy density and specific energy are possible under the right conditions.



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Lithium – BCX (Bromine-Chlorine Complex)

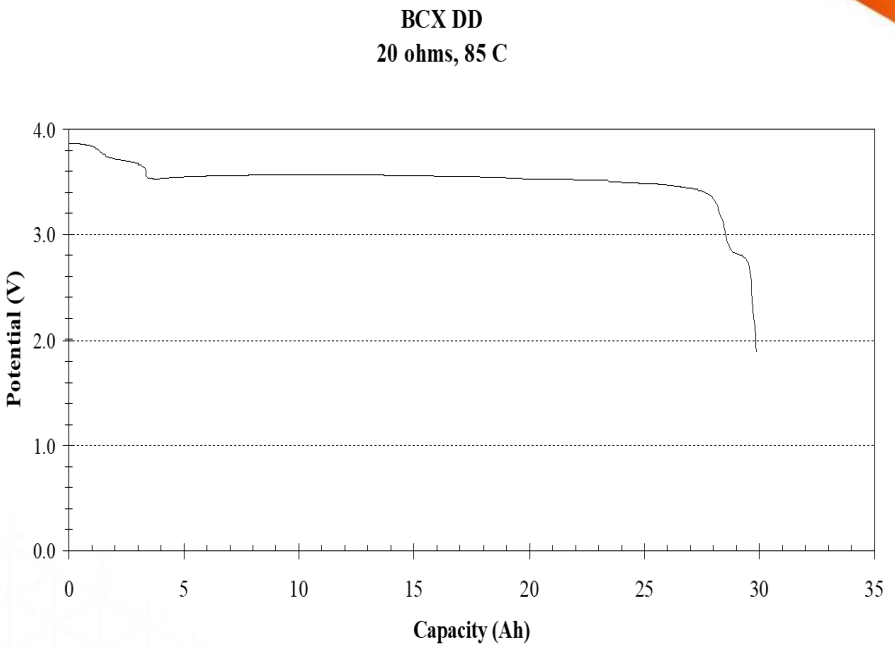
Anode Oxidation:

$$Li \rightarrow Li^{+} + e^{-}$$

Cathode Reduction:

$$BrCl + 2e^{-} \rightarrow Br^{-} + Cl^{-}$$

$$2SOCl_2 + 4e^{-} \rightarrow S + SO_2 + 4Cl^{-}$$



Open Circuit Voltage: 3.9 V

- The BCX electrolyte is a thionyl chloride electrolyte with a BrCl complex added.
- BCX cells operate well at the coldest temperatures.
- The electrolyte was developed for improved safety in the case of deep discharge and over-discharge.

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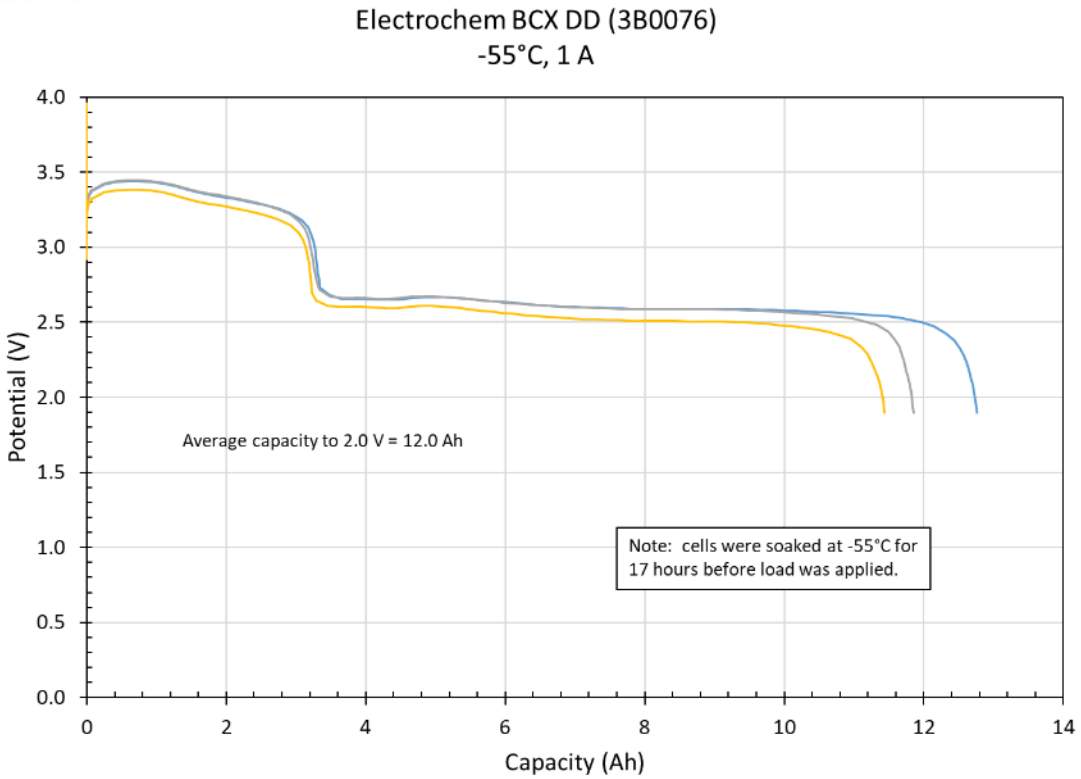
Lithium – BCX (Bromine-Chlorine Complex)

Excellent performance even at extremely low temperatures.



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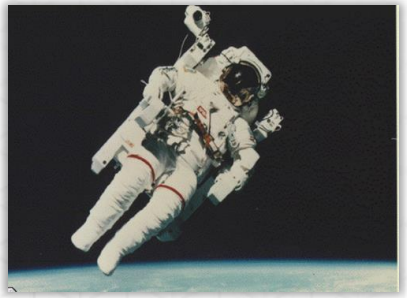
Some CSC & BCX applications

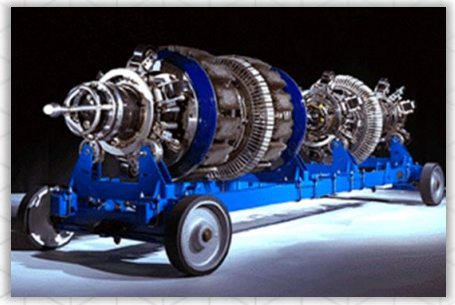
Low to moderate temperatures, very high energy density

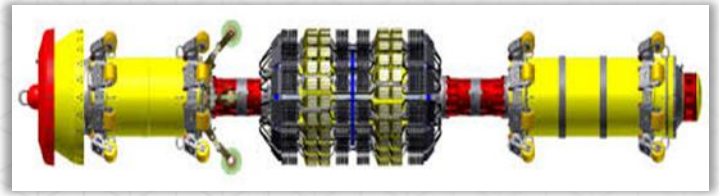
Aerospace



Oceanographic Research

Pipeline Inspection





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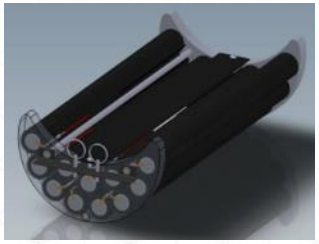
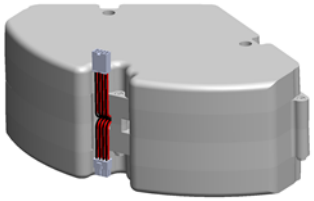
Custom pack designs for extreme conditions

Pack design must take the operating conditions into account:

- Physical robustness of potting, shrink
- Electrical connections (cabling, tabbing, solder, welding, etc.)
- Compatibility with intrinsic safety (explosive atmosphere) requirements








Summary

There are three basic lithium-oxyhalide primary chemistries, available in a variety of cell designs and a range of sizes.

These chemistries have very high energy density and specific energy.

Lithium-oxyhalide primary cells and batteries can operate under a variety of extreme conditions, including:

- Very high temperatures
- Very low temperatures
- High shock and vibration
- Extremely long discharge
- Hazardous environments

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Thank You!

Many thanks to the meeting organizers for the invitation to speak, and special thanks to Prof. Esther Takeuchi.

Questions?

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