Batteries for Military Radios

PRESENTED BY GORDON WALLER, PHD

What is a battery?

- A battery is an assembly of electrochemical cells in series and parallel… but colloquially as few as one
- An electrochemical cell is a **transducer** which converts chemical energy to electrical energy through **faradaic reactions**
- A rechargeable (sometimes called a “secondary” battery) can **reverse** the electrochemical reaction with some energy penalty. Rechargeable batteries can in theory have 100% efficiency in terms of capacity (measured in Amp-hours or coulombs) but always have <100% **energy efficiency** (measured in Watt-hours or joules)
- The first rechargeable battery was the lead-acid cell invented in 1859

Benjamin Franklin coined the term “battery” in ca. 1749 in reference to an assembly of **Leyden Jars** (early dielectric capacitors)

The first true **primary** battery was the “Voltaic Pile” developed by Allesandro Volta in 1800 containing Zn and Cu plates with a brine electrolyte.

*Credit Eric Shields
(https://creb.umd.edu/sites/creb.umd.edu/files/EShields.

Battery History

Civil War Telegraph Wagons

WWI Telegraph Stations

WWII SCR-536

Korea AN/PRC-9

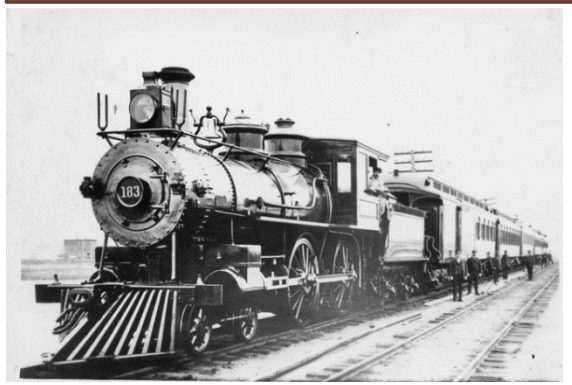
Vietnam AN/PRC-77

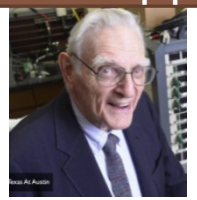
Iraq & Afg. AN/PRC-153

Military Capabilities

1860 1885 1910 1940 1960 1980 2000 Today

Commercial Applications





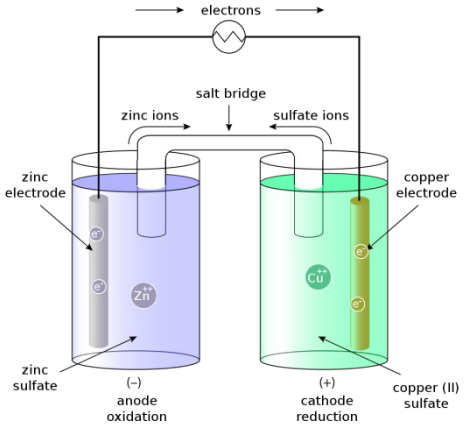
1912-1919
DoD/Commercial Battery Standardization

1991 Dr. John Goodenough invents the li-ion battery

Civil War Telegraph Wagons

U.S. Library of Congress, Petersburg, Va. U.S. Military Telegraph battery wagon, Army of the Potomac headquarters. June 1864

Daniell cells from 1836



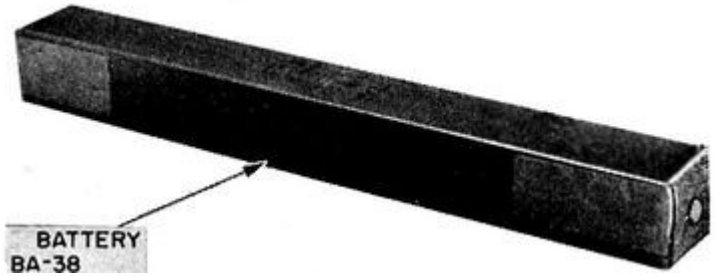
Telegraph wagons utilized non-rechargeable **Daniell Cells**.
"These Daniell Cell batteries made about 1.1 V each, and the number of batteries needed to send a signal a given distance varied on the type of wire it was sending over. Some estimates give 2V per 20 miles, some much more… An average load of batteries for a telegraph battery wagon seems to have been about 100 cells." from *Jalopnik.com*

WWII SC-536

- The SC-536 was the first “squad radio” introduced in 1940. Effectively a precursor to the modern walkie-talkie.
- “**The power was supplied by a BA-37 1.5 volt dry battery for the filament supply and a 103.5 V BA-38 battery for plate supply**. Battery life was about one day of normal use. The SCR-536 weighed 5 pounds (2.3 kg) with batteries and 3.85 lb (1.75 kg) without batteries. The unit operated in AM voice mode between 3.5 and 6.0 MHz frequency range on any one of 50 channels. Plug in crystals and coils were used to control the frequency of the receiver and transmitter. The antenna was a 40 inch telescoping rod that slid into the case. **The SCR-536 had an RF output power of 360 milliwatts.** The range of the unit varied with terrain; from a few hundred feet (about a hundred metres), to approximately one mile (1.5 km) over land, and 3 miles (5 km) over water.” from Wikipedia

WWII SC-536

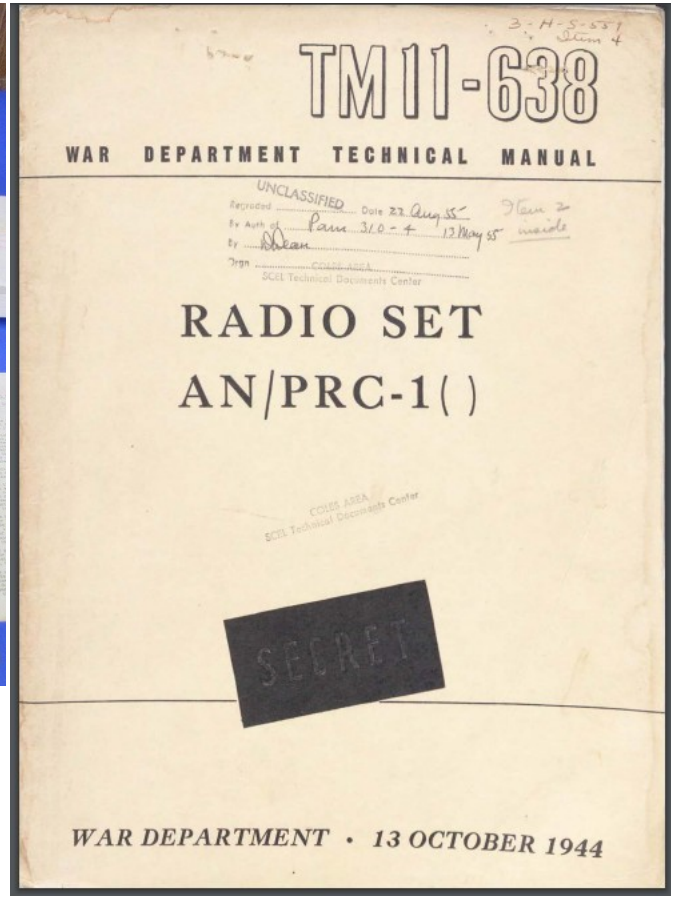
- BA-38 and BA-37 batteries images from “Radionerds.com”



Both the BA-38 and BA-37 are described as “dry cells” (Zn vs MnO2 on Carbon rod in $NH_4Cl/ZnCl_2$ electrolyte) – predecessors to modern alkaline cells (e.g. AA, AAA, D, C, 9V etc.)

Army Navy / Portable Radio Communication (AN/PRC)

AN/PRC 1



- The AN/PRC family of radios have been in use since WWII, starting with the AN/PRC-1. According to the technical manual this operated from AC power. Portable versions in the Korean War and Vietnam War used dry or alkaline cells.

"Originally designed for use by Army Intelligence, some of these radios were used by the Office of Strategic Services. The radio is concealed in a suitcase." from *National Museum of the U.S. Air Force*

Army Navy / Portable Radio Communication (AN/PRC)

AN/PRC-77

AN/PRC-77 with NESTOR voice encryption system

- The AN/PRC-25 and later AN/PRC-77 were utilized in the Vietnam War
- The AN/PRC-77 utilized solid-state transistors, replacing the few remaining vacuum tubes in the AN/PRC-25.
- The AN/PRC-77 had a transmitting power 1-4W with a range of ~5 miles
- Early AN/PRC-77 utilized a “magnesium battery” (presumably a 1.5V Mg//AgCl) which was replaced by a 3V Li-metal Li//SO_2 battery in the early 1970s which is still used today

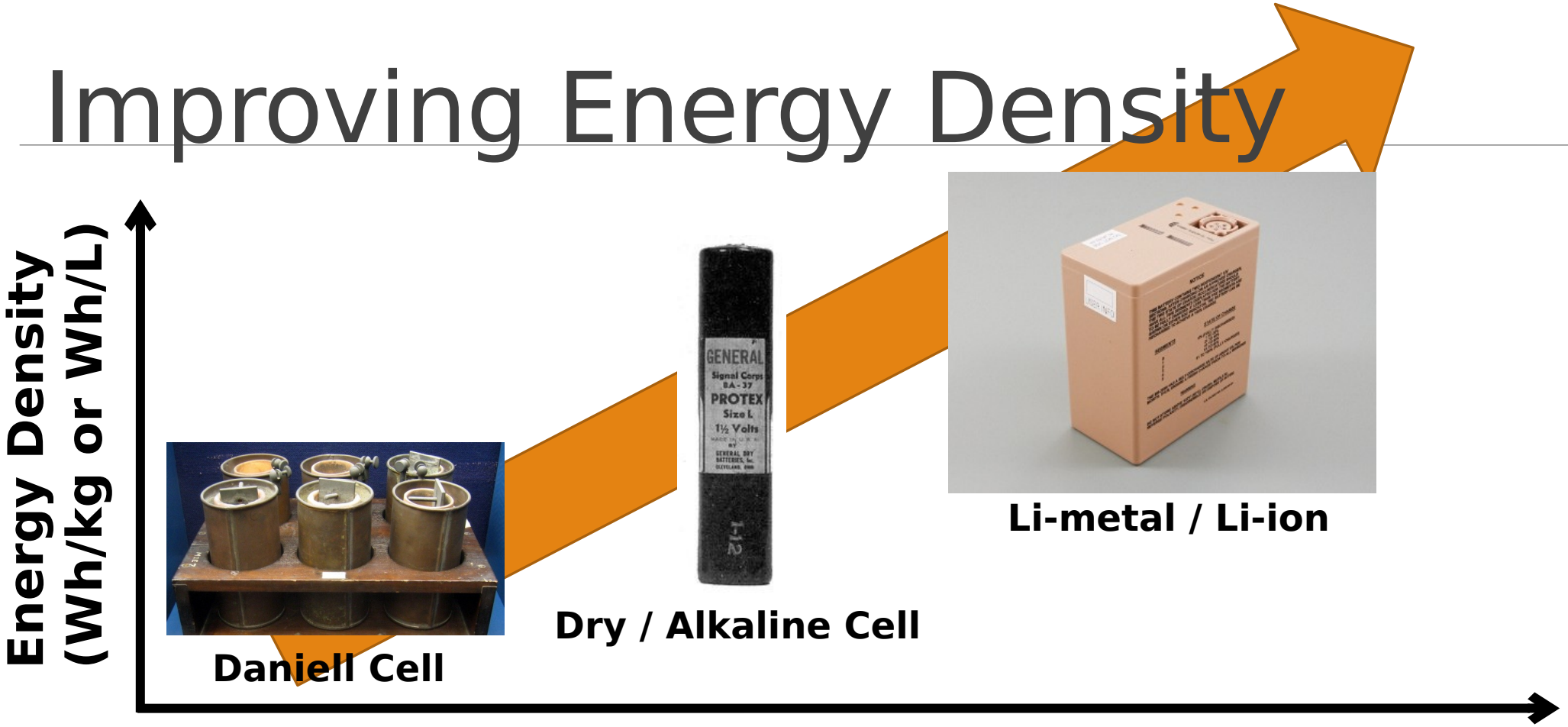
Army Navy / Portable Radio Communication (AN/PRC)

PRC-117 w/ Satcom antenna

PRC-177g

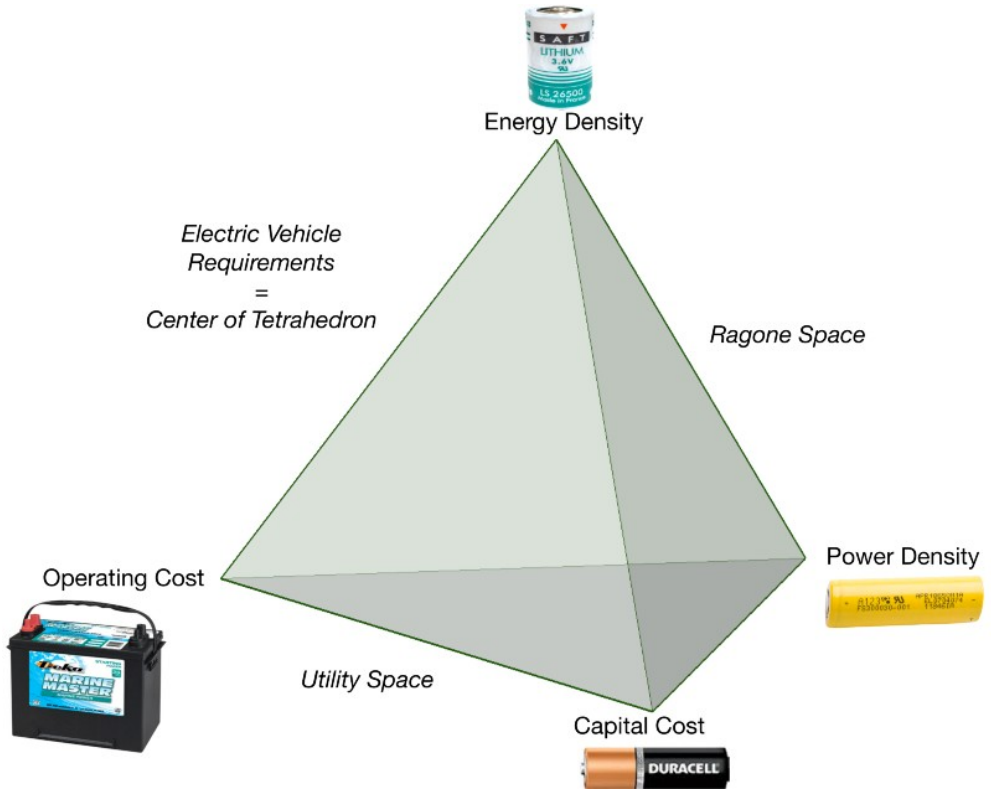
- Modern version of the PRC utilized **Li-metal** and **Li-ion** batteries with MIL-PRF defined formats (e.g. BA-5590 and BB-2590) and utilize software defined signal processing with “over the horizon”/satcom and encryption capabilities
- The PRC-177g weighs 5.44 kg with the battery and **20 W maximum transmitting power**

Improving Energy Density



Greater power demands of radios have driven a shift to greater energy density battery chemistries, but the DOD still uses several types of batteries for radios and other electronic devices.

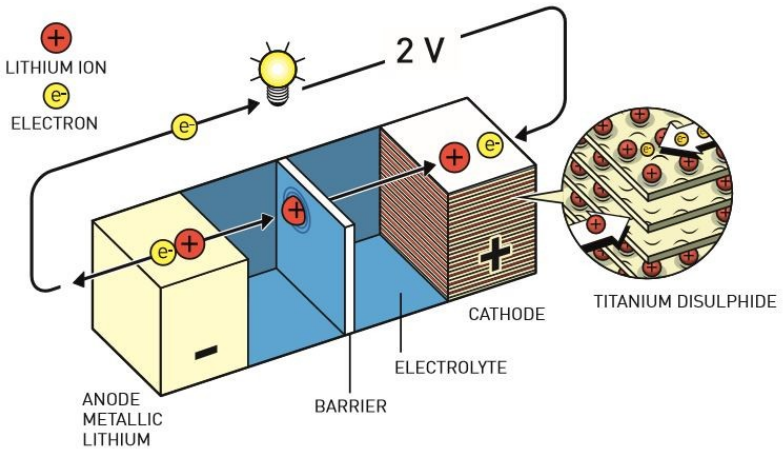
The “Unfortunate Tetrahedron”



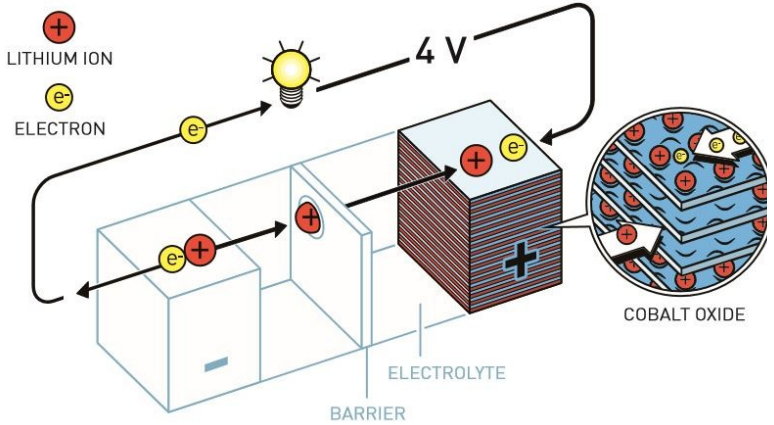
- Power and energy are inversely proportional in electrochemical energy storage systems – both can usually not be optimized at the same time
- Li metal cells offer the highest energy density of any commercial cell (~500 Wh/kg for Li//$SOCl_2$ D-cell compared to ~250 Wh/kg for state-of-the-art LIB 18650) but are generally limited to very low discharge rates
- Cycle life is another consideration for many rechargeable applications and usually results in lower energy. Rechargeable LIB are often used during training instead of costly primary batteries.

*credit to Prof. Dan Steingart | Columbia University

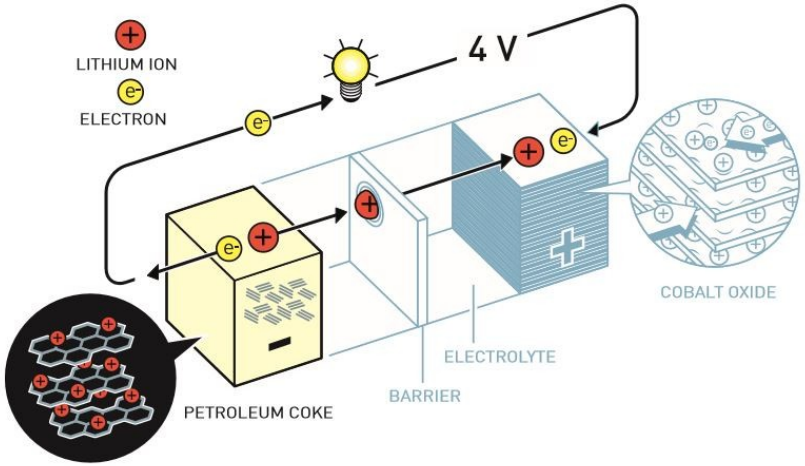
Lithium-ion Battery Nobel Prize



Stan Whittingham developed the Li vs TiS_2 battery while working at Exxon in the 1970s. These cells were commercialized but then discontinued due to major safety issues.



John Goodenough developed a high-voltage cathode ($LiCoO_2$) which raised the cell-level voltage to ~4V vs. Li in the 1980s.



Akira Yoshino identified an intercalation based anode to pair with $LiCoO_2$ in 1986. LIB were commercialized by Sony with this electrode combination in 1991.

Power and Energy in the military

USMC forward operating base

Man-deployable UUV

A squadron of Naval vessels

Power and Energy in the military

Military bases need fuel to power their equipment, but fuel convoys can be subject to attack. Solar power is one alternative option utilized in the DOD.

Battery Scaling

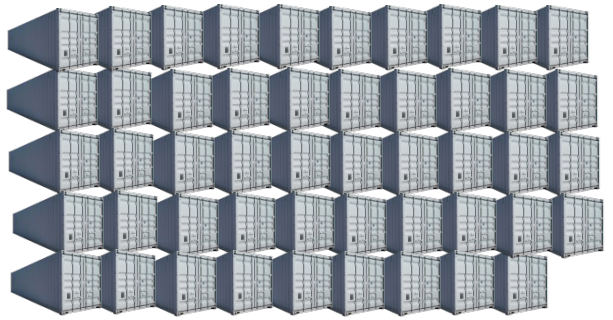
AA Cell
~3.5 Wh

=

18650 Cell
~10.5 Wh

=

Large UUV
~200,000 Wh



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Largest DoD Battery
2019
~98,000,000 Wh

=

BB-2590
~250 Wh

=

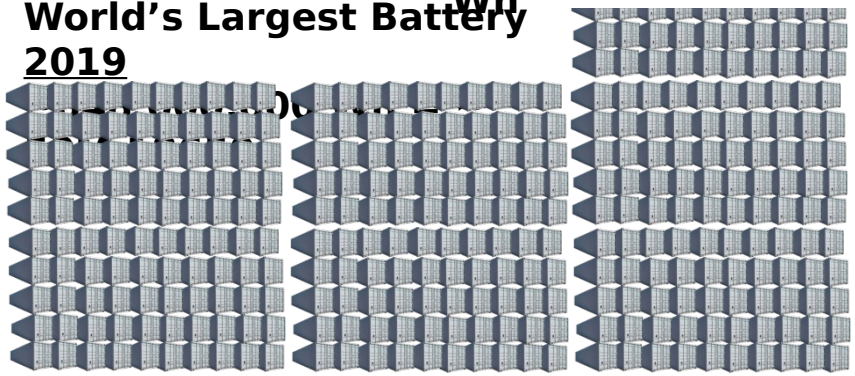
Lithium 6T
~2,000 Wh

=

40’ ISO Container
~2,000,000 Wh

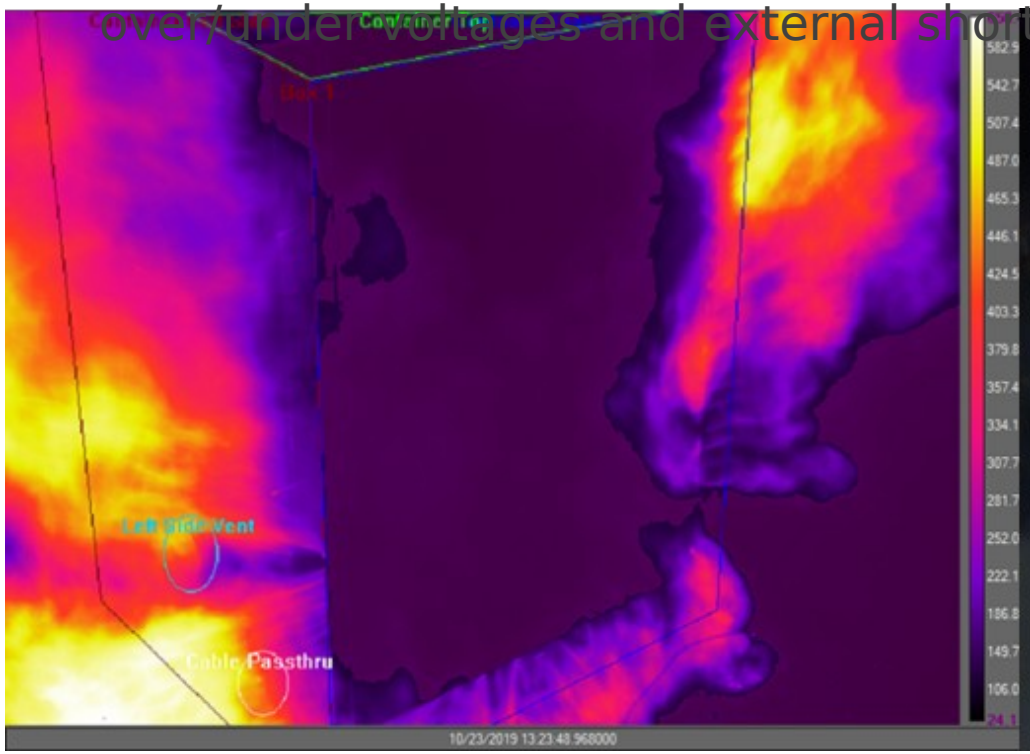
Tesla - World’s Largest Battery
2018
~129,000,000 Wh

World’s Largest Battery
2019

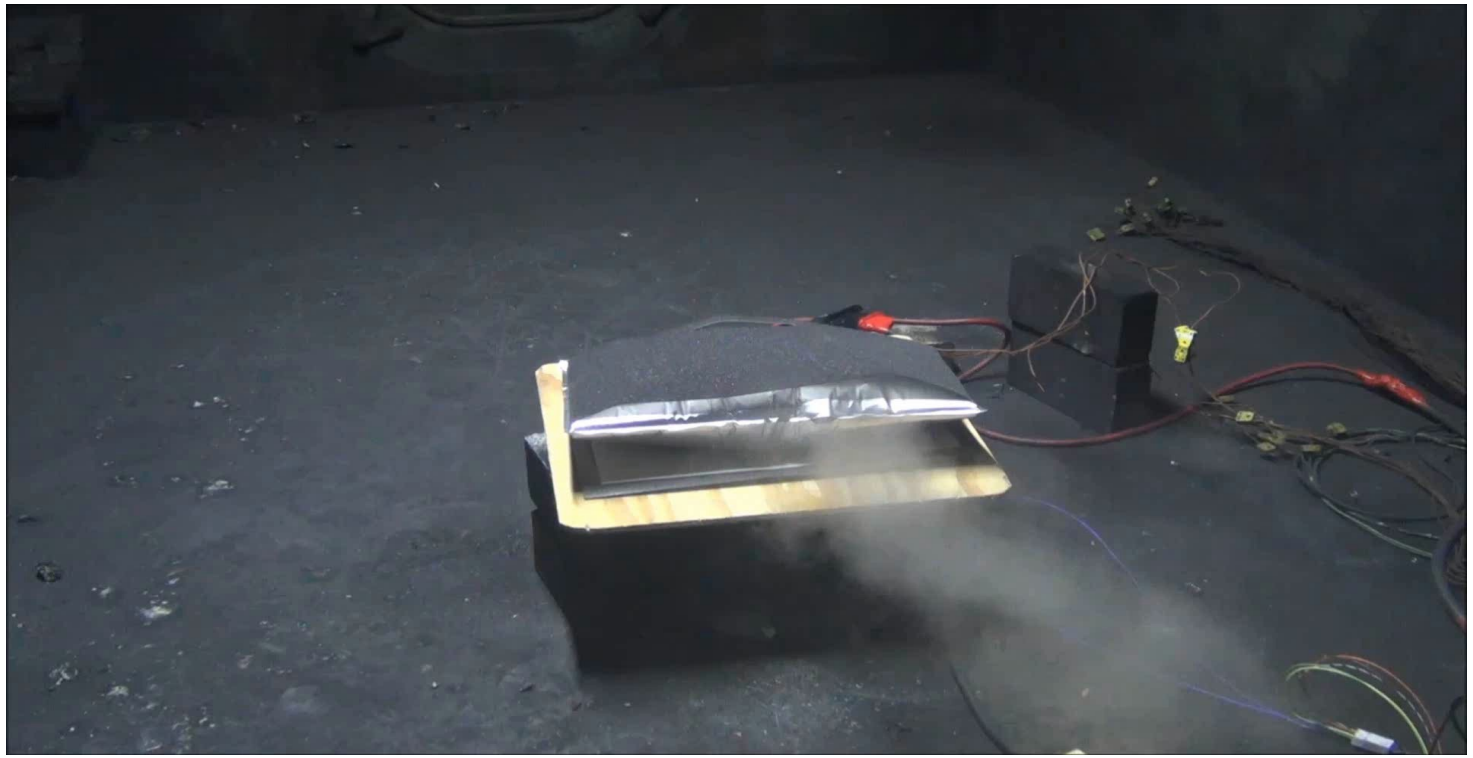


Battery limitations

- High **energy density** is greatly desired for batteries, but this can lead to energetic failures.
- Some cells and batteries have integrated safety features to protect against over/under voltages and external short-circuits. Many consumer devices do not.



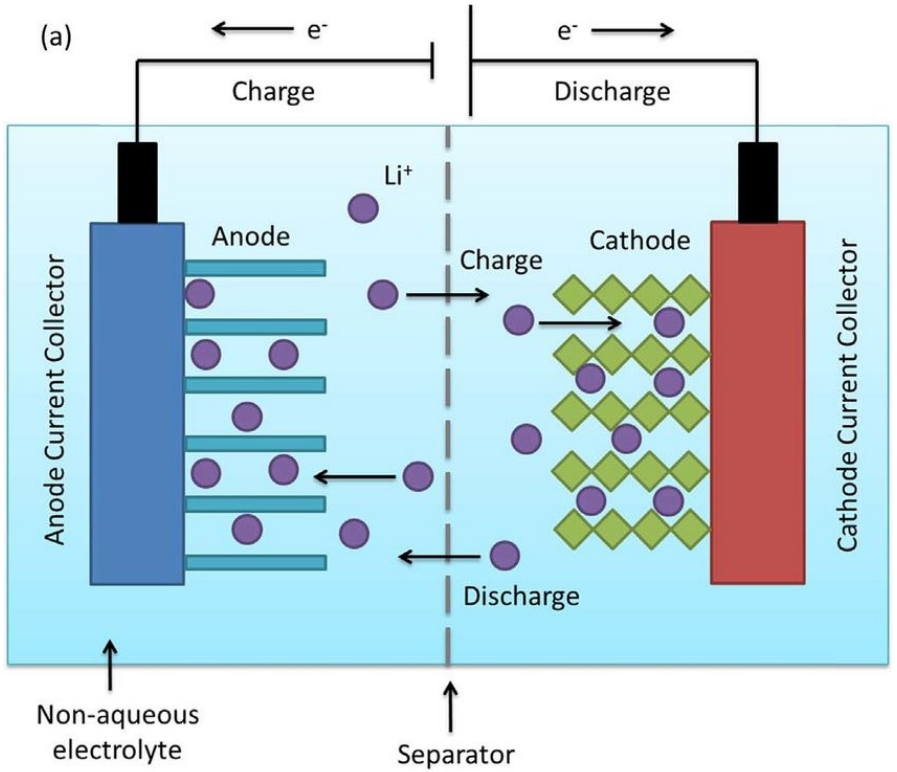
Overcharging an LIB



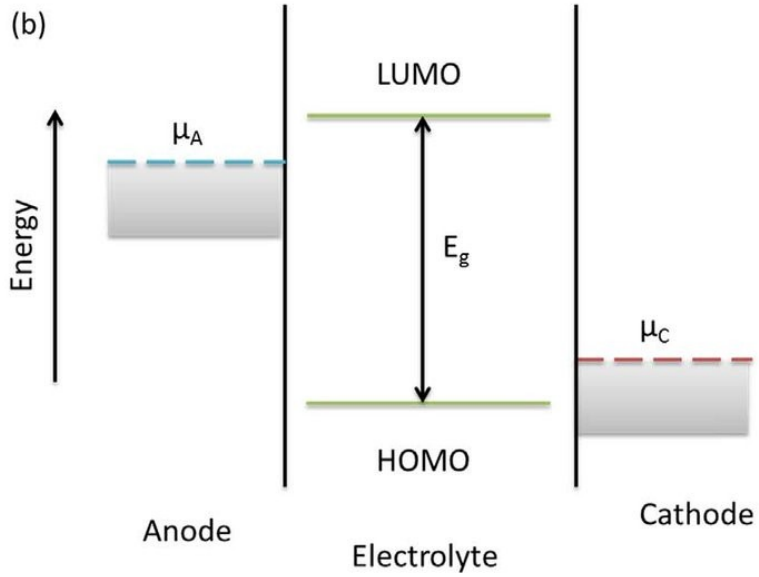
What happens when a battery is forced to accept more energy than it was designed for?

QUESTIONS?

Intercalation and electrolyte stability



LIB store Li^+ by **intercalation** into a host structure. This greatly improves reversibility.



The high cell voltage of LIB requires an electrolyte with a wide stability window. Water based electrolytes are limited to ~2V.