EAGLEPICHER TECHNOLOGIES

Lithium-ion COTS cell Batteries for LEO Missions

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2019 NASA Battery Workshop
(Nov 19-21, 2019)

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TECHNOLOGIES

EaglePicher in Space

A SUPERPOWER IN

BATTERY TECHNOLOGY

OUR PRODUCTS

POWERING MISSION SUCCESS

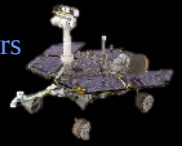
2,720,661,045*

Hours in space without a single failure. Mission accomplished!

*Approximate cell hours.

Lithium-ion Space Heritage

MER Rovers
2003



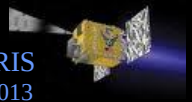
PHOENIX
2007

MSL
2011

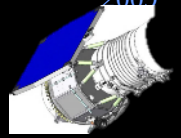
InSiGHT
2018

MAVEN
2013

Mars2020
2020

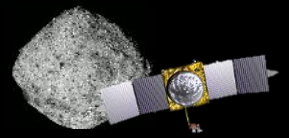


IRIS
2013



WISE
2009

GRAIL
2011

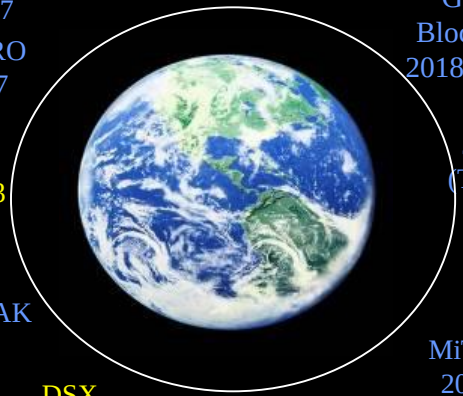


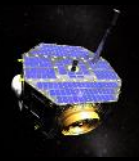
OSIRIS-REX
2016

NEXTSat
2007

ASTRO
2007

GPS
Block III
2018-2022





IBEX
2008

STP/SIV
STPSat 2 & 3

JWSD1
(TacSat 2)
2006

XSS-11
2005

ORION
2014/2019

STP-R1 STREAK
2005

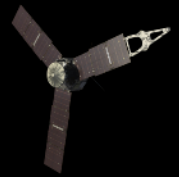
MiTEx
2006

DSX

X-37b
Various

PnPSAT

JUNO
2011



MISSE 5
2005

Planned
Launched

Custom Cell and Battery Designs

- Bespoke cells specific for mission requirements
- Batteries fully designed, qualified, and produced to spec
- Some modification from mission to mission

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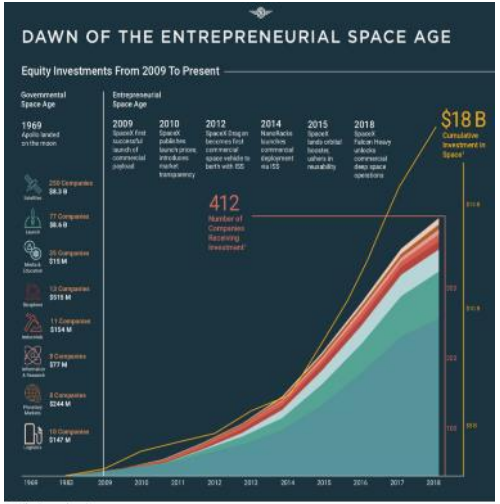
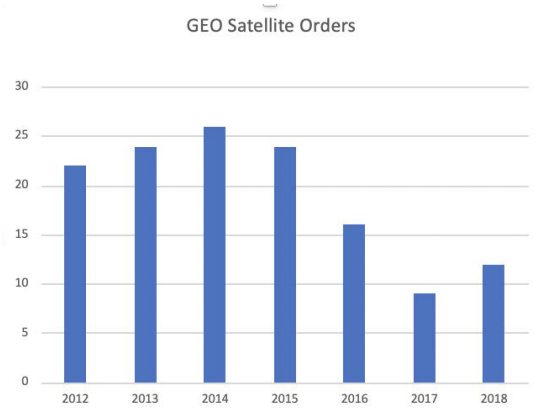
Space Market Trends

- 3 year slump in GEO satellite orders
- Expected increase in LEO activities
  - Constellations will be the dominating factor of this growth, making up over 70 percent of the total market
    - One Web, Telesat LEO
  - EO, SAR
- Other missions (Interplanetary, scientific, etc..)

"…the space economy to be worth more than $1 trillion in 2040.." (Source: Morgan Stanley)

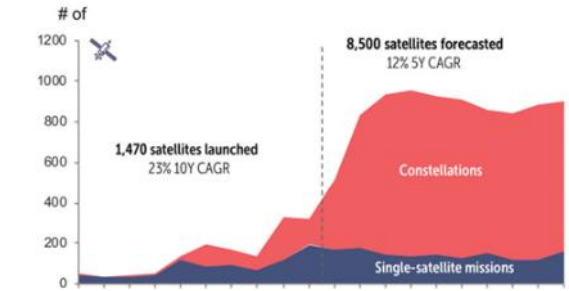


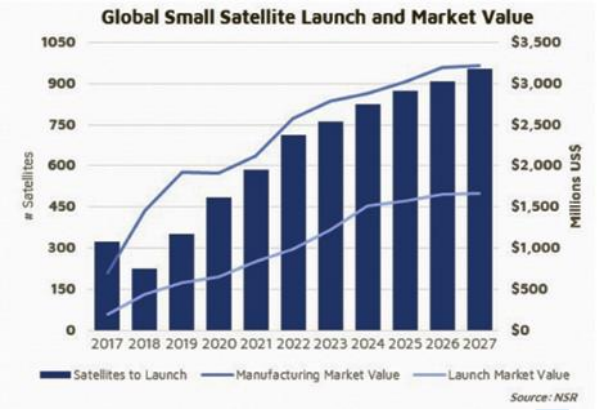
Credit: Space Angels.



Source: Orbital Gateway Consulting

Some 8,500 satellites with a launch mass of 500 kilograms or less stand to launch between 2019 and 2028, according to Paris-based Euroconsult.





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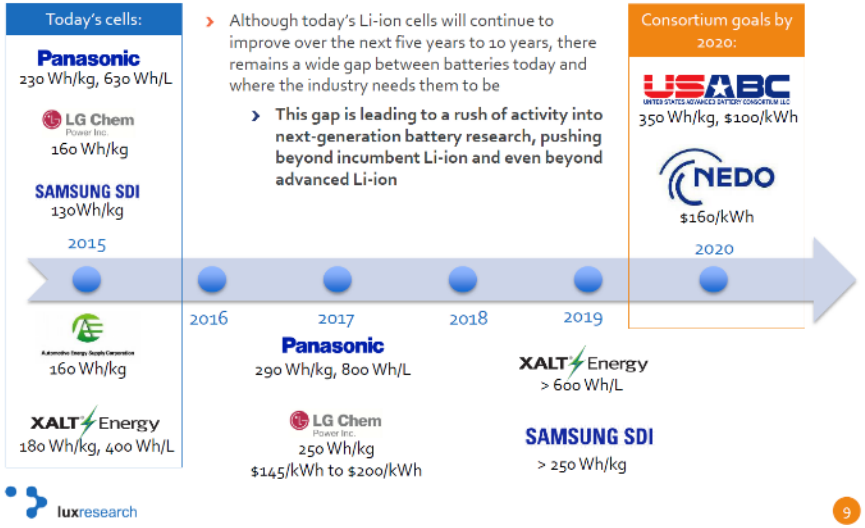
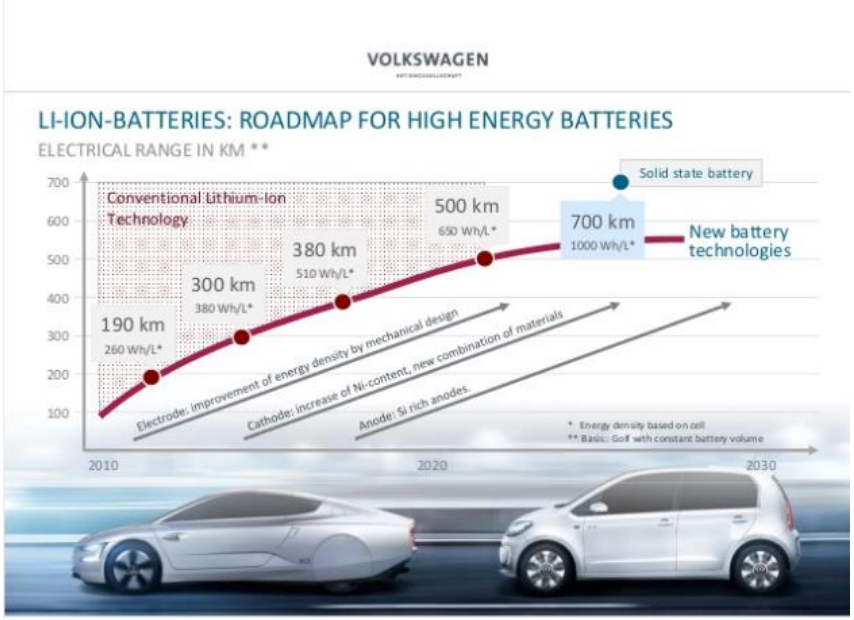
Cell Market Drivers

+ Large increase in specific energy and large reduction on cost required for applications such as electric vehicles



Source: Luxresearch



Electric vehicles and urban mobility markets driving cell industry to increased specific energy cells

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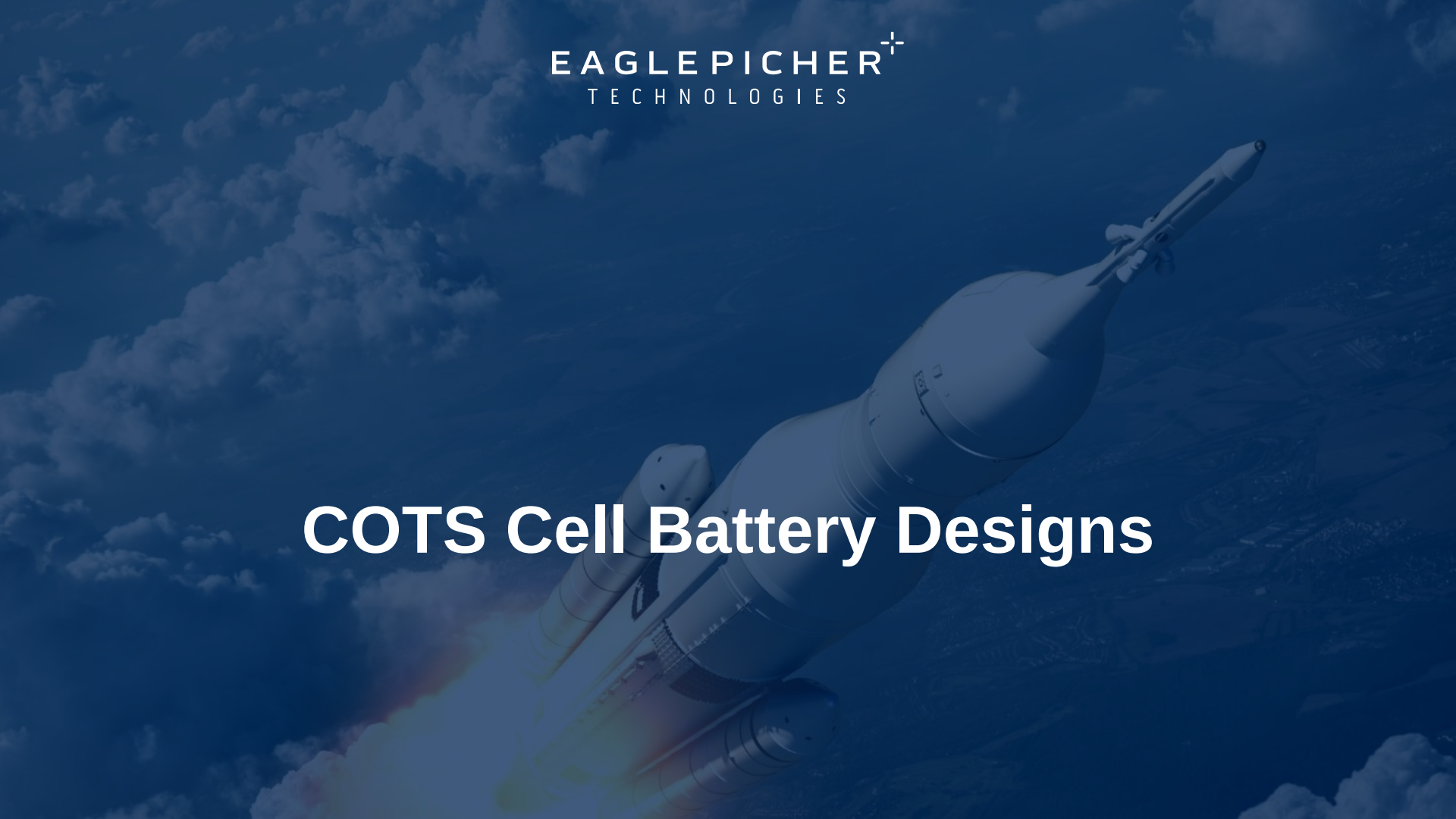
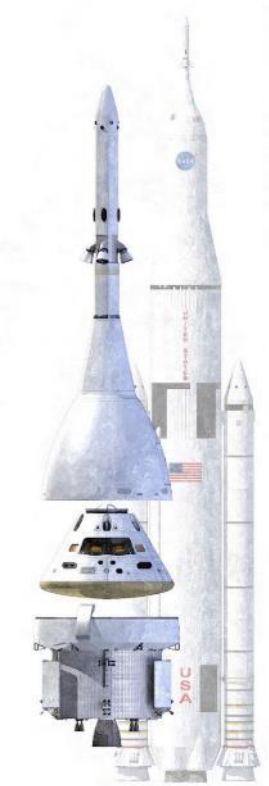


COTS Cell Battery Designs

NASA Orion – Crew Module Battery



- Nominal 120V, 30Ah (14p32s)
- Baseline NASA JSC Design
  - EP completing design to meet environmental requirements
- Thermal Runaway safety demonstrated – no propagation in testing

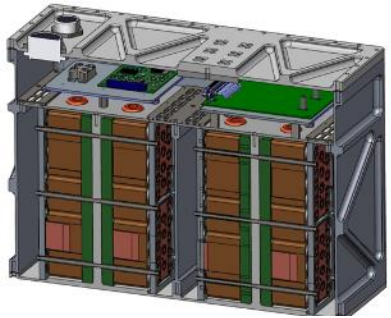
Modular Design

- Cells arranged into 14p sub-bricks
- 8s sub-bricks arranged on a thermal wall – super-brick
- 4s super-bricks arranged in sealed aluminum structure

Cell

14-Cells in Parallel (Sub-Brick)

(8) Sub-Bricks in Series (Super-Brick)



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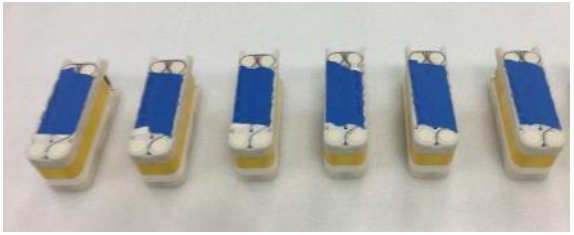
Modular Battery Development

- Several (non-space) applications developed with COTS cells, following similar design pathways
- Performance-based cell selection, driven by application needs
- Module Designs for Scalability
- BMS architecture design to support large systems/arrays
- Design in safety through best practices and demonstrated testing



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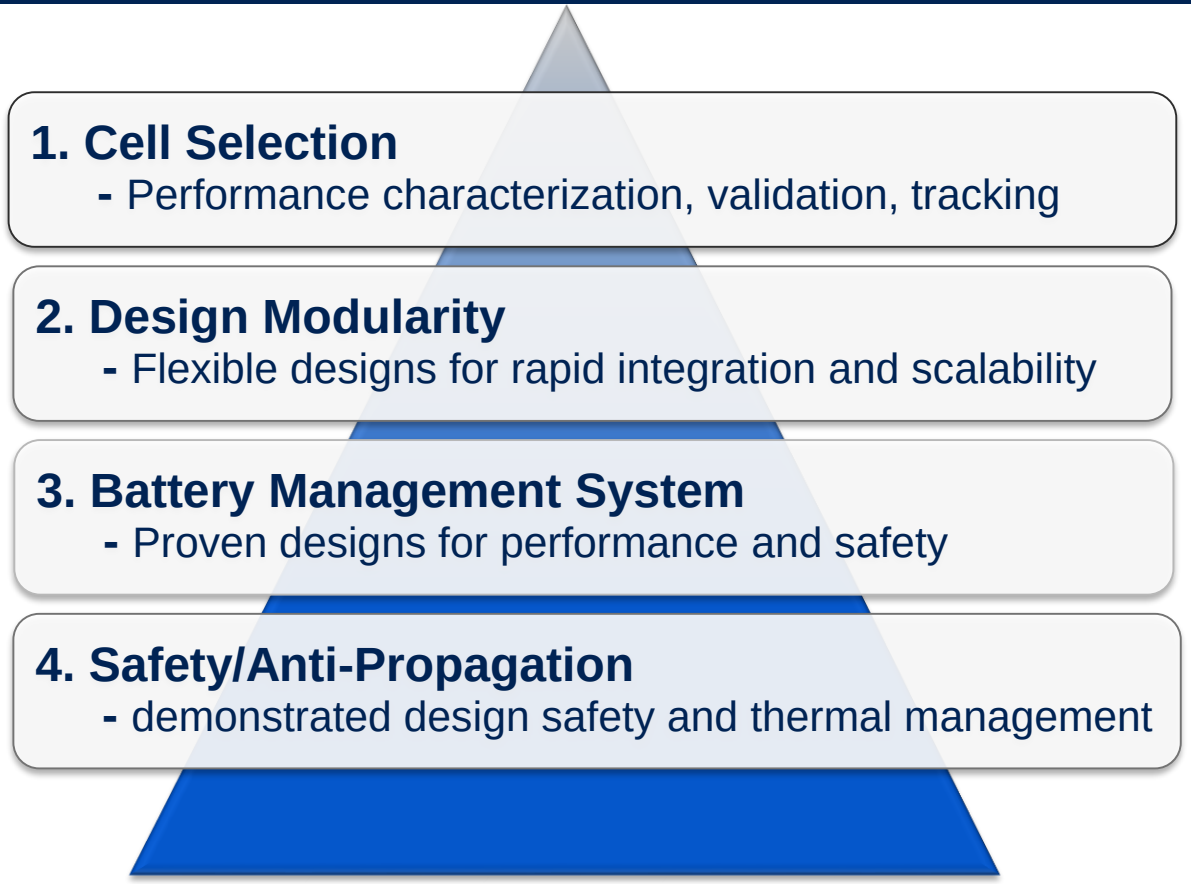
Flexibility and Safety Foundation of Solutions



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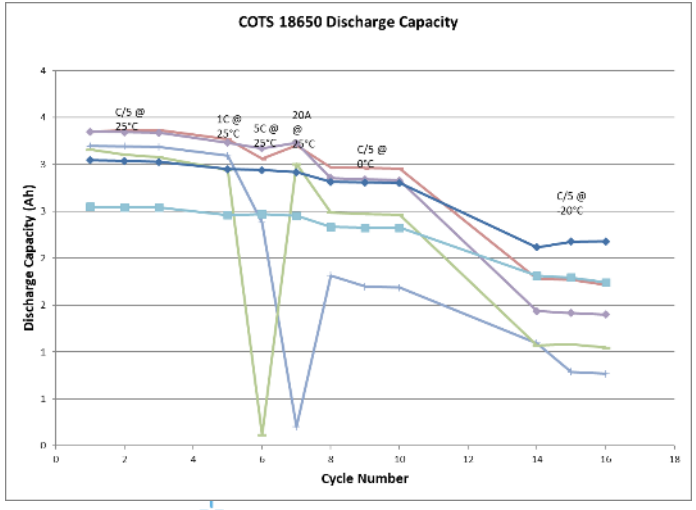
Battery Design/Development Process

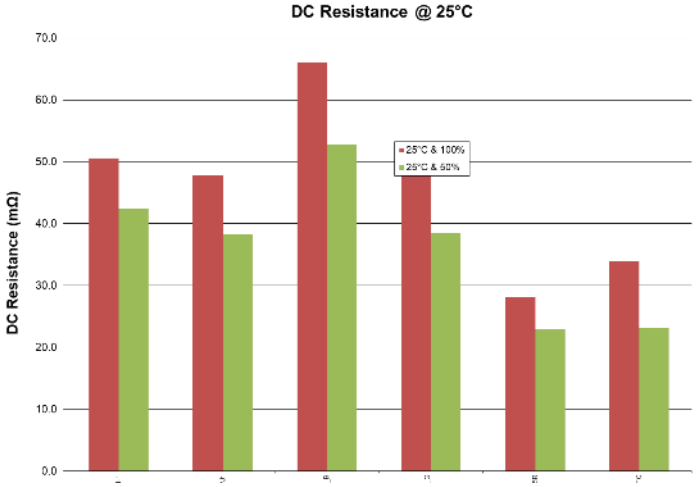
Right Cell for Right Application

- Not all COTS cells perform the same
  - High energy designs
  - Power designs
  - Cycle life and impedance growth
  - Temperature effects
- Different missions need different cells
  - LEO – High Cycle, High Rate – favor higher power capable designs
  - GEO – Low Cycle, High DOD, Lower charge rates – typically favor higher energy solutions
  - Always depends on specific mission parameters…
- Always have to beware of Counterfeit Cells…

Characterization Testing

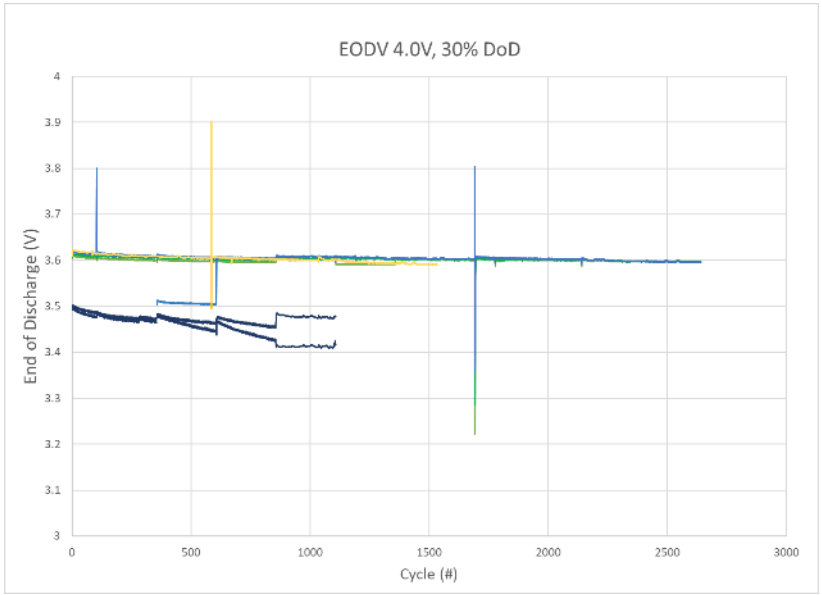
- EP has an on-going evaluation of COTS cell performance
  - Baseline evaluation
    - Capacity/Energy at low charge/discharge rate at various temperature
    - Evaluation of rate capability at constant current and constant power at various temperatures
    - Evaluation of cell impedance at various temperatures and State of Charge
    - Initial evaluations also include safety performance and abuse testing

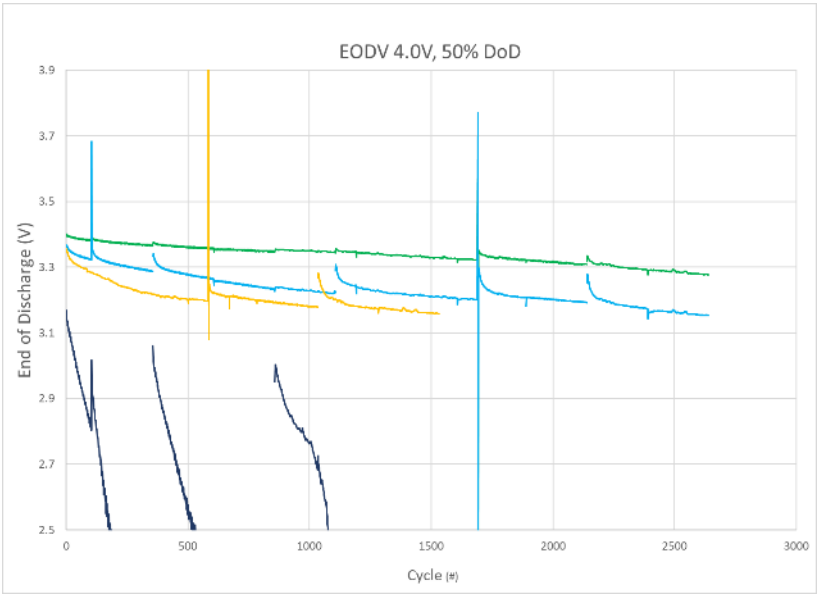




Life Testing

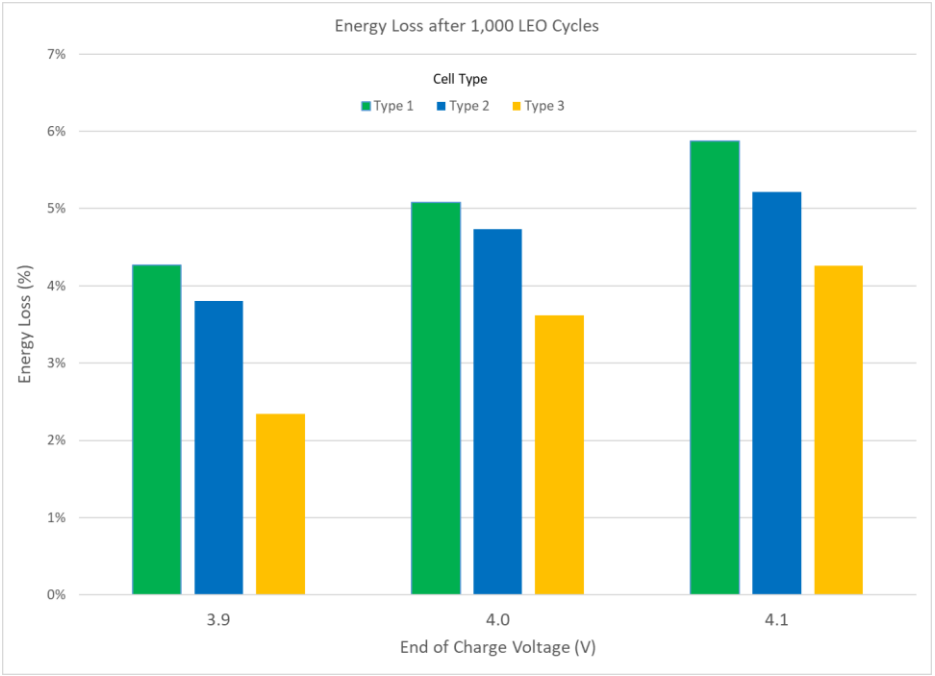
- LEO and GEO testing at different max Charge Voltages, Temperatures and Depth of Discharge
  - Capacity and DC Impedance checks every 1,000 cycles.





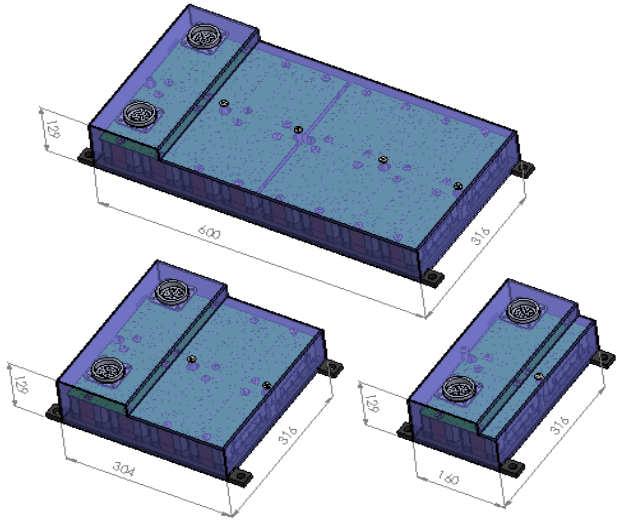
Life Characterization and Modeling

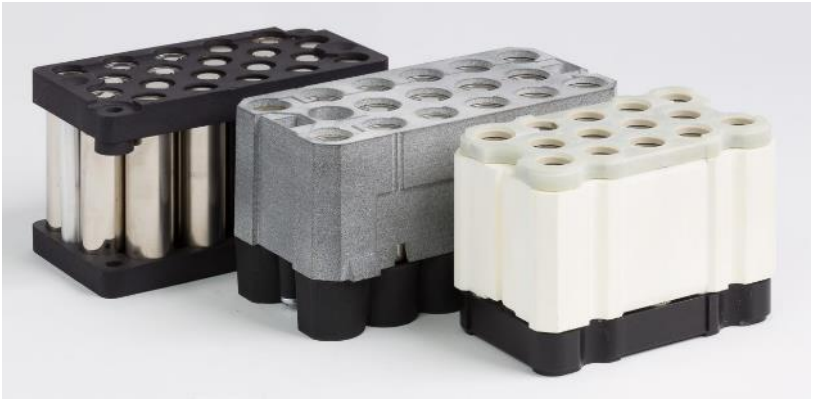
- Life characterization and predictive modeling utilizing multiple data sets
  - Capacity and Energy loss and DC Impedance growth on cycling
  - Effects of temperature, DOD and EOCV characterized
  - Impacts of storage at temperature
- Models compared with historical data on large format cells
  - Chemistry and construction effects
- Cell performance under different conditions used in selections for specific application performance requirements
- On-going testing to increase database and validate models



Modular designs for scalability

- Cells arranged into modules or Bricks
  - Can be connected in series or parallel
- Bricks assembled into next-higher groupings as needed by application
  - Connections in series and/or parallel
- Commonality of features allows for Qualification by Similarity
- Module design (thermal management) critical for system safety





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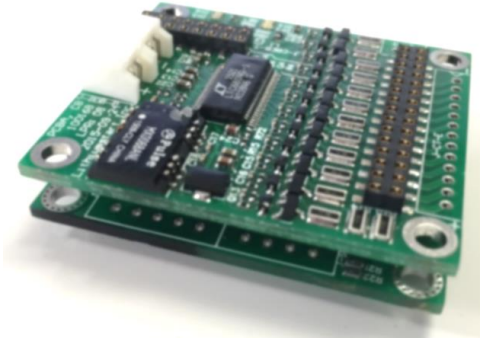
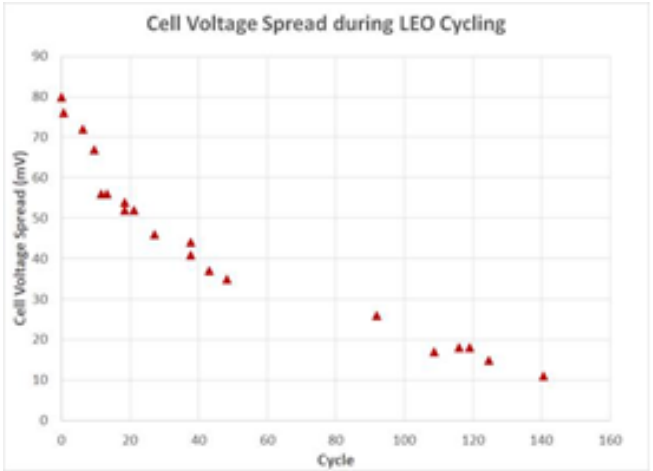
Battery Management System Options

- Simplified cell balancing approach for COTS cells
  - Multiple cells in parallel minimize divergence
- Space Qualified MEQ for 4-32s
  - Demonstrated >10years on orbit
- Field demonstrated BluFlex system for higher voltage systems
- Simplified approach for low cost





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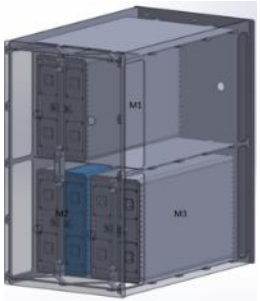
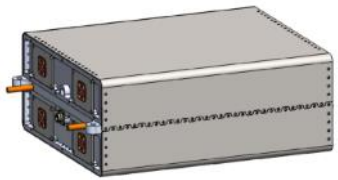
Anti-Propagation Design Pattern Re-use

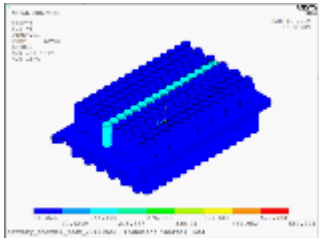
- Safety is critical
  - Electrical Propagation
  - Thermal Propagation
  - Mechanical Propagation
  - Smoke control!!!!
    - Collect and direct!
    - Fuel/Air mixture understanding
- Proven capabilities demonstrated over multiple projects
- Demonstrated in-house NAVSEA 9310 equivalent testing
- Reuse of learnings and continued refinement

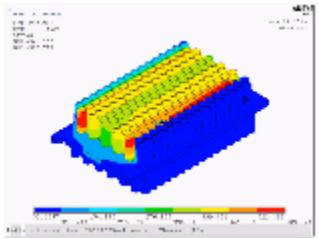


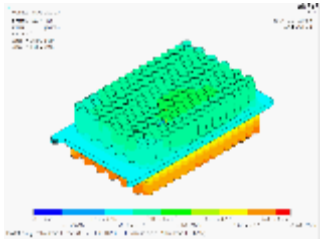
In-house test capabilities demonstrated NAVSEA 9310

Post-test results met propagation requirements









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Conclusion/Summary

- EaglePicher has an extensive heritage in space applications
  - Over 2 Billion Cell-hours operating in space, Over 14 years operational on Mars
  - Deep knowledge-base on how to design for long endurance, high reliability missions
- Shift in space markets to smaller/lower cost systems driving need for more flexible, lower cost battery systems
  - Improving performance and quality of COTS cells enabling higher utilization for longer life missions
    - Not all COTS cells perform alike…
- Characterization, life testing, and modeling provide reassurance of predicted performance for mission needs
- System-level design philosophy ensures mission success

Thank You!




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