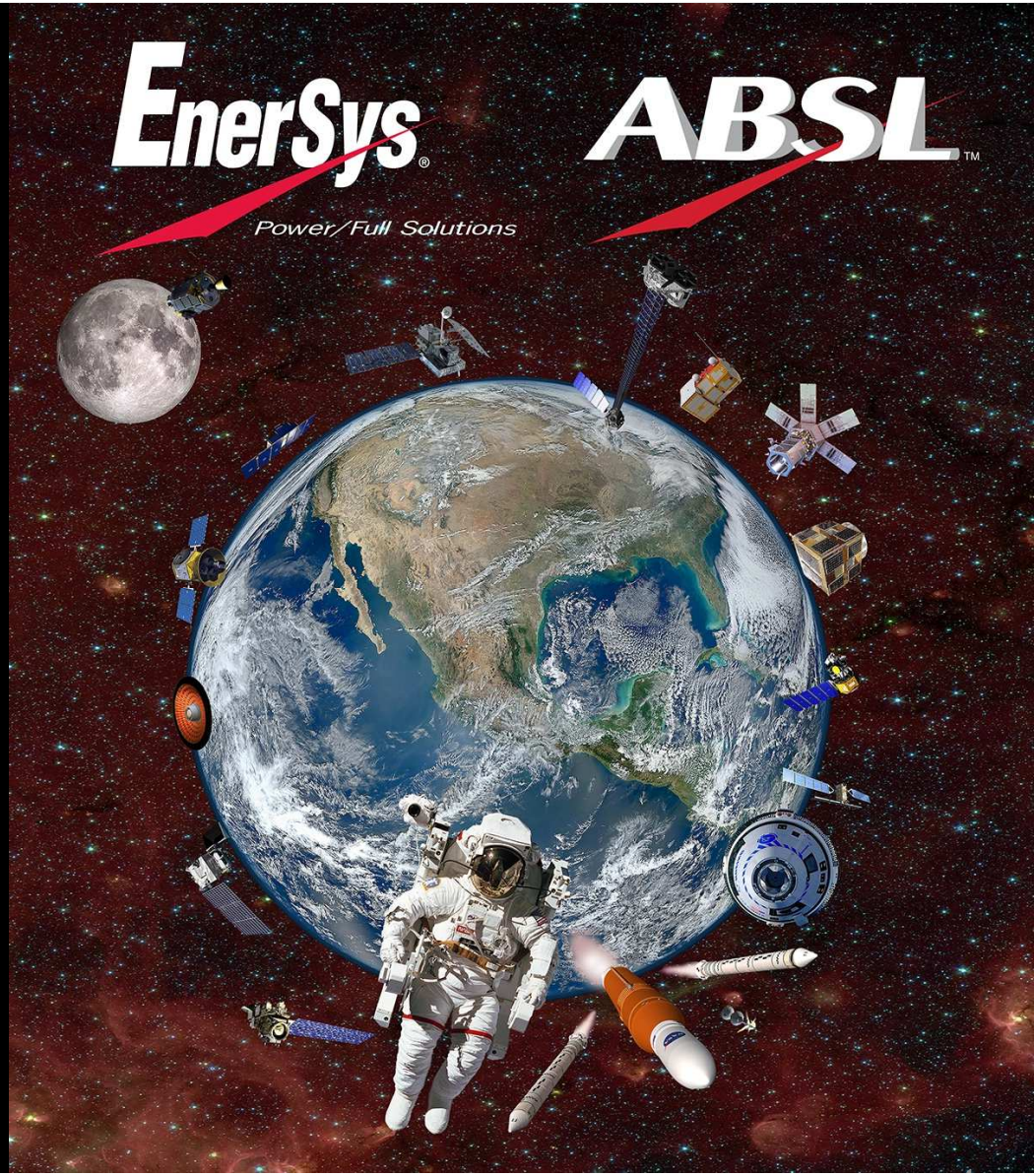
Investigation of COTS Li Ion Cell Performance at Low Temperature

Space Power Workshop 2024

Ryan Pritchard
Principal Project Engineer, ABSL Space Products



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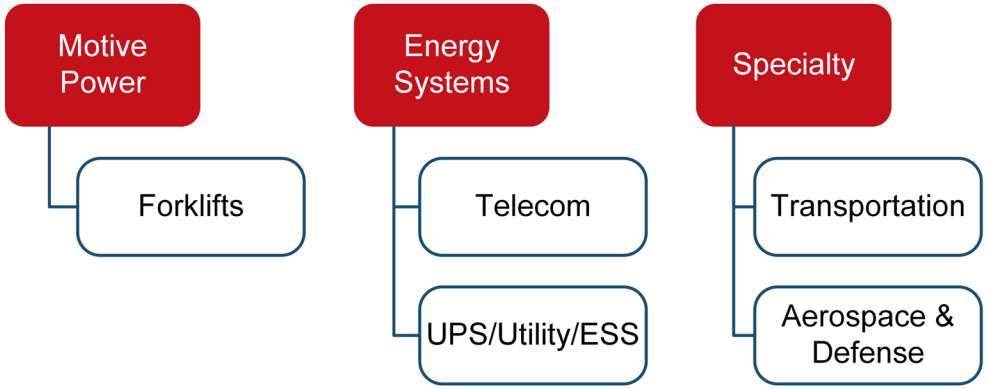
The Power of EnerSys

- World's Largest Industrial Battery Company ~ $4B annual sales
- Leading brands in wide range of end-user markets
- US-owned / Publicly Traded
- Global – Over 10,000 employees with over 30 locations in 18 countries
- Recent acquisition of Alpha Technologies Group, NorthStar Battery

ABSL Longmont, CO

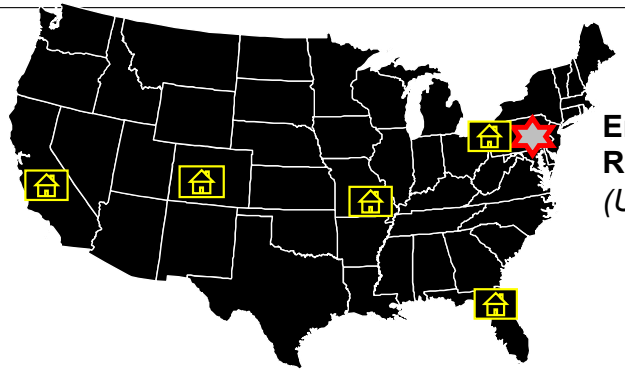


Aerospace and Defense

Facility Locations

Manufacturing Facilities

- Santa Clarita, CA
- Longmont, CO
- Warrensburg, MO
- Horsham, PA
- Tampa, FL
- Culham Oxfordshire, UK



EnerSys Headquarters: Reading, PA
(US Owned Company)

Six Engineering Locations Serving Multiple Markets			
Business Line	Brands	Technology	Location
Space	ABSL/Quallion	Lithium-Ion Materials, Cells, & Batteries	Longmont, CO Santa Clarita, CA Culham, UK
Aviation	Hawker/Quallion	Lead Acid (Thin Plate), Ni-Cd & Li-Ion	Warrensburg, MO
Medical & Space	Quallion	Cells & Batteries	Horsham, PA
Munitions	EAS	Lithium Primary, Liquid Reserve & Thermal Batteries	Horsham, PA Tampa, FL
Land & Sea	Armasafe / Hawker	Lead Acid (Thin Plate & Flooded/Cylindrical)	Warrensburg, MO

ABSL Facilities Overview

Longmont, CO

- ABSL opened its US operations in 2008 to serve all aspects of the US space market
- ABSL joined the EnerSys family in 2011
- 100+ passionate staff members
- Wide range of engineering capabilities
- AS9100 certified & ITAR compliant
- All batteries are assembled and tested on-site

- ABSL cell screening & processing
- Contamination-controlled manufacturing rooms
- Destructive and environmental test laboratories
- Dedicated product development space
- Secured inventory stores including a strategic stockpile of cells
- In house CT Scanner

ABSL Qualified Cell Suite

Cell	Chemistry	Capacity	Max Current	Notable Characteristics
18650 HCM	Cath.: LCO An.: Hard Carbon	1.5 Ah	1.5 A	Long Cycle Life, PTC
18650 P20	Cath.: NMC An.: Graphite	2.0 Ah	20 A	High Rate
18650 I28	Cath.: LCO An.: Graphite	2.8 Ah	5 A	Medium Energy, PTC
18650 E35	**Cath.: NMC An.: Gr-Si**	**3.5 Ah**	**10 A**	**High Energy**
18650 M28	**Cath.: NCA An.: Gr-Si**	**2.8 Ah**	**35 A**	**High Rate, Medium Energy** Cell qual on-going

Motivation

- Cell exposure below -20°C is not recommended
  - Lunar night is typically -133°C, 14 days long
- Thermal management systems are expensive
  - Mass, power
- Increase mission resiliency to off-nominal conditions
- Recent missions have successfully resumed following lunar night
  - Academic literature shows similar results

Motivation

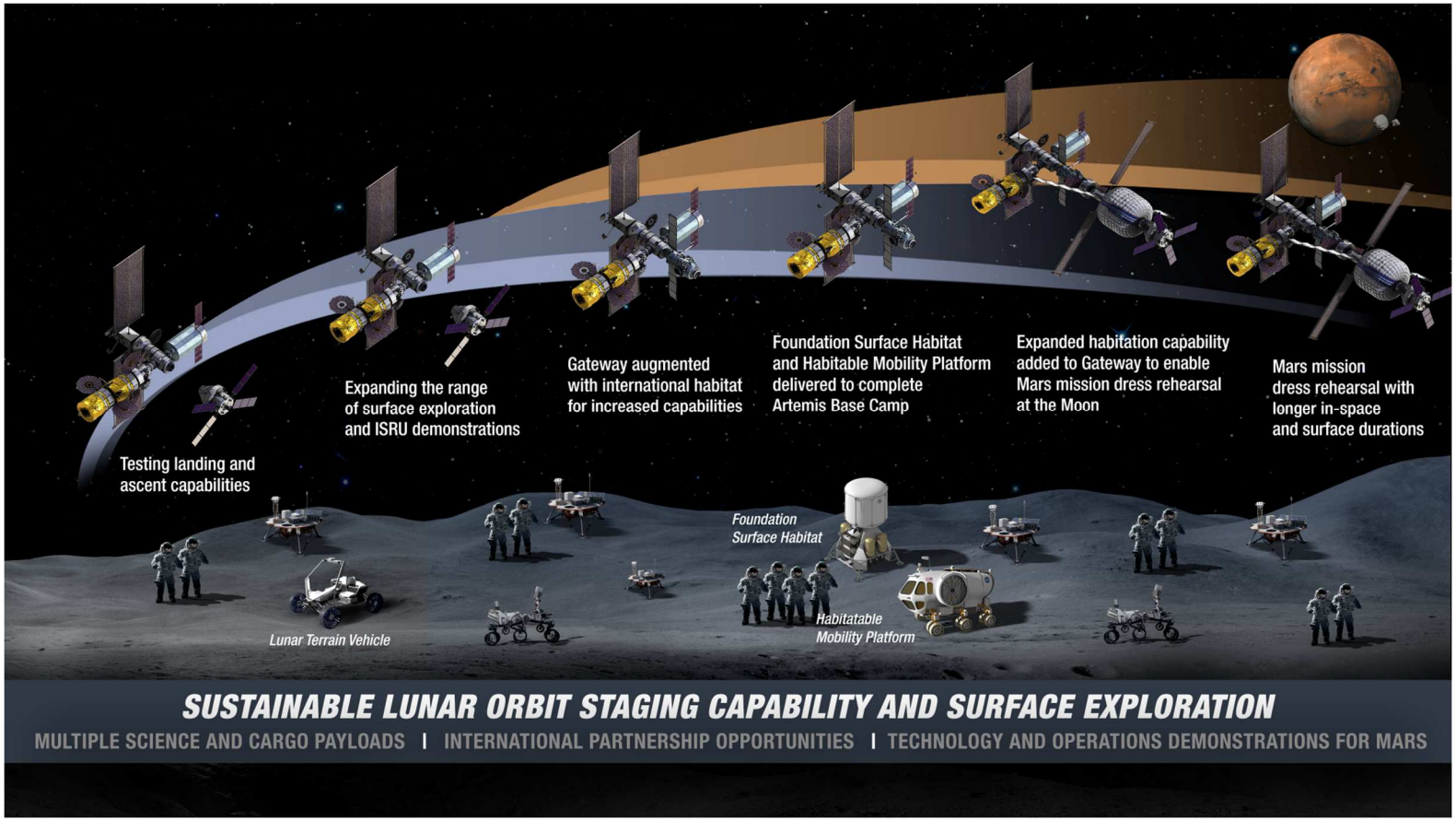


Image Credit: NASA

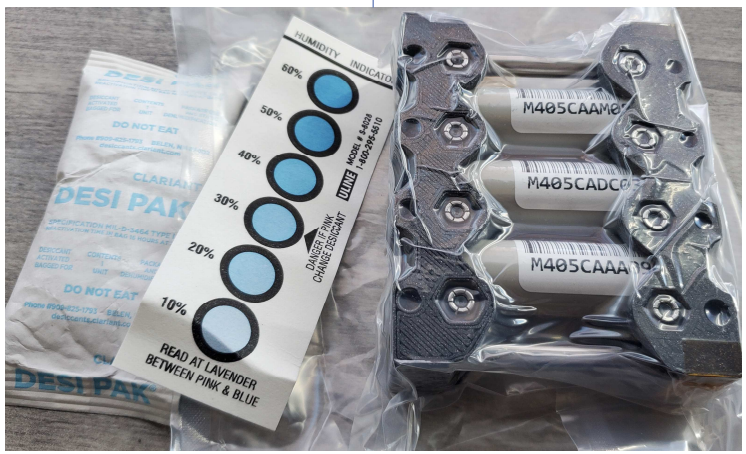
Test Objective

- **Goal:** Quantify the degradation of exposure beyond the rated -20°C limit
- Expect that there is an adverse impact to cell health
  - Characterize the specific impacts to the 18650 E35 & 18650 M28
  - Inform future testing efforts
  - Inform future design development efforts
- Expand acceptable temperature limits to benefit mission operations
- Test flow mimics standard cell storage test efforts

Low Temperature Test Flow

Electrical Screening → Group Allocation (3 cells each) → Pre SCM → Packaging (N_2 purge & vac. seal) → Exposure (100% SOC, Cells not cycling) → Inspection & Post SCM

-20°C	1 day
-40°C	3 days
-60°C	1 week
	2 weeks
	4 weeks



Low Temperature Test Groups

Temperature	-20°C		-40°C		-60°C		Lab Ambient*	
Duration (days)	E35	M28	E35	M28	E35	M28	E35	M28
1	TG101	TG201	TG106	TG206	TG111	TG211	N/A	
3	TG102	TG202	TG107	TG207	TG112	TG212		
7	TG103	TG203	TG108	TG208	TG113	TG213		
14	TG104	TG204	TG109	TG209	TG114	TG214	TG116	TG216
28	TG105	TG205	TG110	TG210	TG115	TG215	TG117	TG217

* Lab Ambient: 23±5°C, 30 to 70% RH

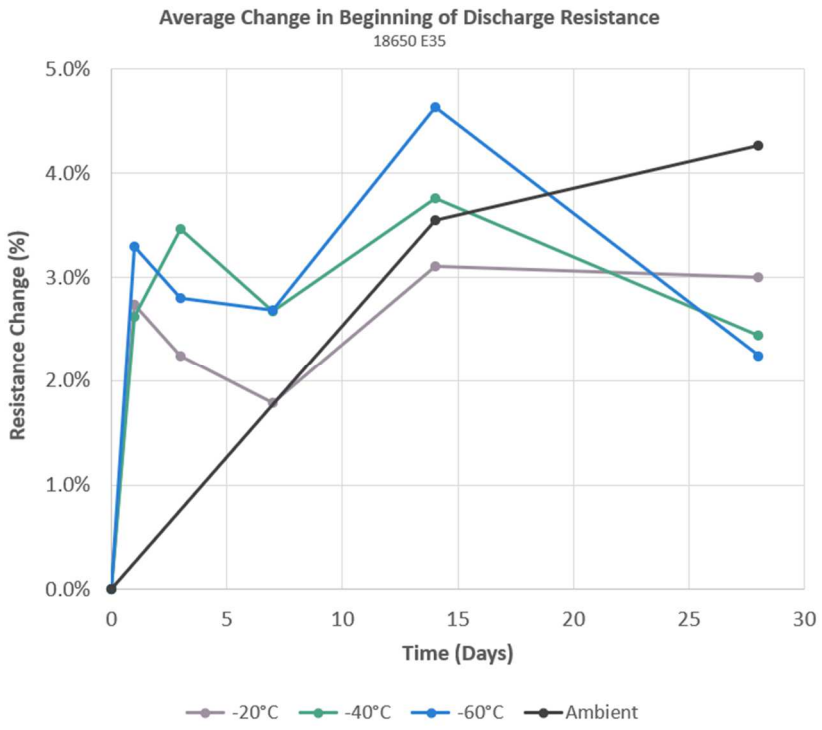
Standard Capacity Measurement (SCM) Profile

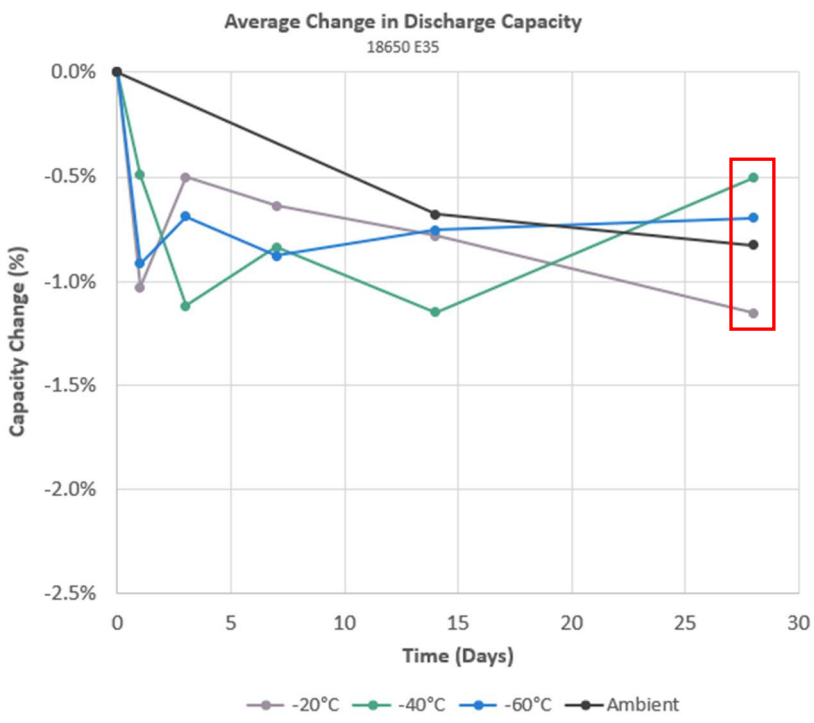
Pre-/Post-Exposure SCM

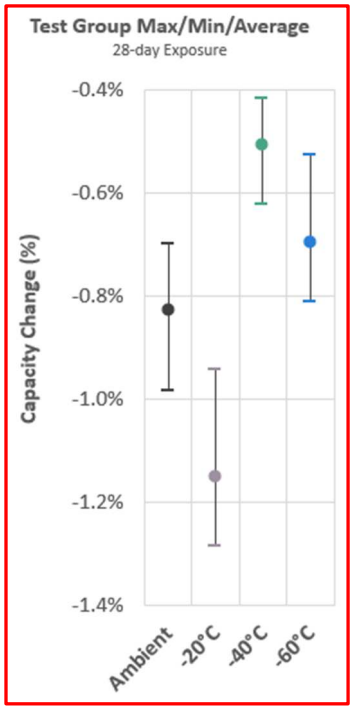
Step	Process
1	Charge at C/5 to 4.2 V Taper to C/100
2	Discharge at C/2 to 2.5 V
3	Charge at C/5 to 4.2 V Taper to C/100
4	Repeat 2 & 3 Three total cycles

- Profile also includes rests to calculate EOC/EOD DCIR
- SCM ends at 100% SOC
- C-rates:
  - E35: 3.5 A
    - C/2 = 1.75 A
    - C/5 = 0.7 A
  - M28: 2.8 A
    - C/2 = 1.4 A
    - C/5 = 0.56 A
- SCMs performed at 20°C

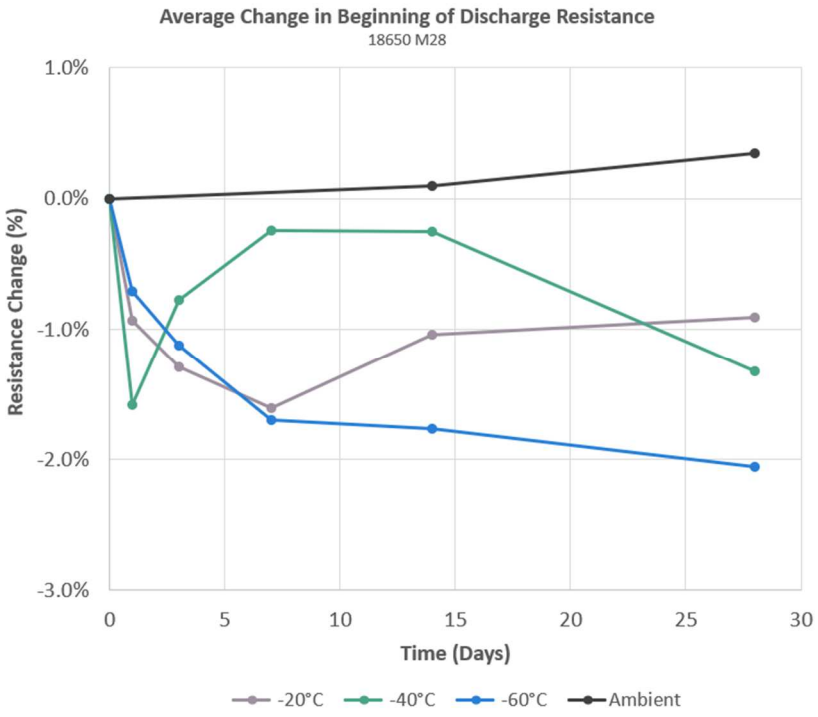
Results – 18650 E35

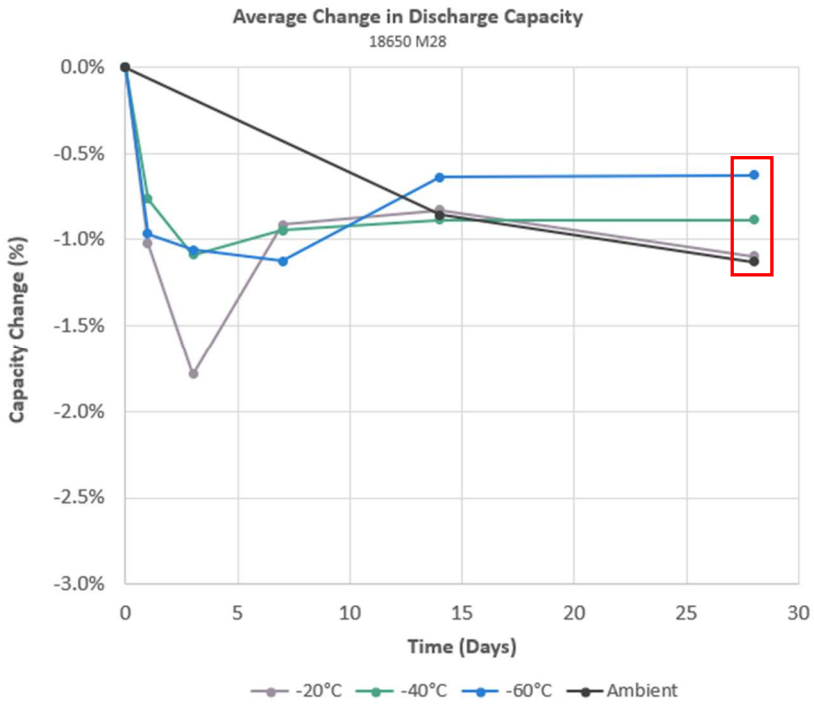


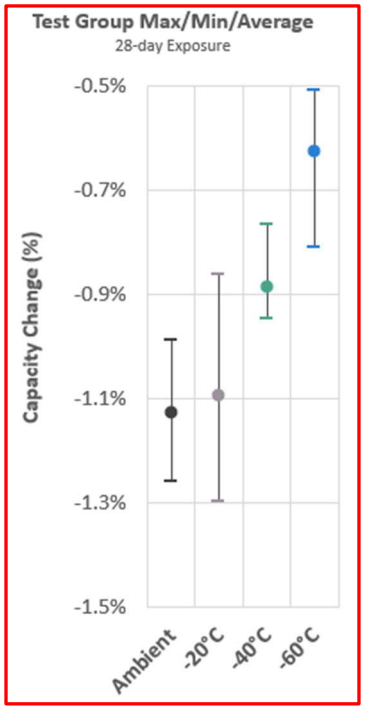




Results – 18650 M28







Results Discussion

Average Change in Discharge Capacity

Temperature	-20°C		-40°C		-60°C		Lab Ambient	
Duration (days)	E35	M28	E35	M28	E35	M28	E35	M28
1	-1.028%	-1.021%	-0.491%	-0.764%	-0.914%	-0.968%	N/A	
3	-0.501%	-1.783%	-1.117%	-1.085%	-0.688%	-1.058%		
7	-0.637%	-0.912%	-0.835%	-0.947%	-0.878%	-1.124%		
14	-0.783%	-0.829%	-1.147%	-0.887%	-0.755%	-0.638%	-0.679%	-0.855%
28	-1.152%	-1.094%	-0.505%	-0.886%	-0.696%	-0.627%	-0.826%	-1.128%

No Adverse Impact to Cell Performance

Results Discussion

Potential Future Work:

- On-going life cycle testing
  - 14 days at 20°C, continuous cycling at C/3
  - 14 days at -40°C, discharge C/560
- Longer exposure to tested temperatures
- Exposure to further extreme temperatures
  - Nighttime lunar surface: -133°C
- Rate characterization at colder temperatures
- Community feedback

Standard Designs

Configuration		Capacity	Cont. Current	Physical	
Battery	**Cell**	**(Ah)**	**(A)**	**Dimensions (mm)**	**Mass (kg)**
8s3p	I28	8.4	16.8	176 x 96 x 98	1.66
8s10p	E35	35	14*	260 x 210 x 103	5*
8s16p	E35	56	25	364 x 204 x 98	7.8
8s44p w/ Relays	I28	105	52.8	432 x 257 x 164	22.9
8s72p	E35	252	50	532 x 326 x 245	36.4
8s84p	I28	180	42	713 x 310 x 181	49.6

*Estimated value. Qual ECD Jan 2025

8s3p I28

8s44p I28

8s10p E35

8s72p E35

8s16p E35

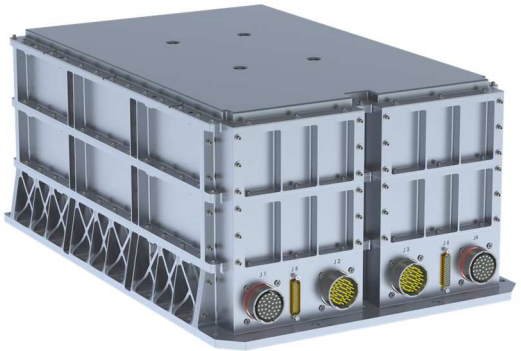
Snake Series High Energy Designs

Configuration		Capacity	Cont. Current	Physical	
Battery	Cell	(Ah)	A	Dimensions (mm)	Mass (kg)
8s32p	E35	112	112	603 x 402 x 97	31
8s72p	E35	252	252	371 x 371 x 230	48
8s80p	E35	280	280	603 x 402 x 177	68
8s128p	E35	448	448	603 x 402 x 256	100

8s32p Boa

8s80p Python

8s128p Anaconda



Further Offerings

- Heritage HCM designs
- High voltage battery designs
- Human-rated applications
  - Thermal runaway mitigating features
  - Integrated monitoring electronics
- Custom designs
  - Restrictive volume requirements
  - Magnetically clean designs
  - Unique mission parameters
- Large format 72 Ah cell applications

High Voltage 28s4p E35
Completed Mid-2023

Contact Information

- Ryan Pritchard – Principal Project Engineer
  - Ryan.Pritchard@EAS.Enersys.com
- Roger Carlone – Senior Business Development Manager
  - Roger.Carlone@EAS.Enersys.com
- Gerard Herbert – Business Development Representative
  - Gerard.Herbert@EAS.Enersys.com

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- Alex Saldana, Product Engineer
- Rachel Garman, Product Engineer
- Andres Medina, Product Development Test Technician