2025 NASA Aerospace Battery Workshop

DEVELOPMENT OF ADVANCED HIGH-ENERGY HIGH-POWER LI-ION BATTERIES WITH NEXT GENERATION ZERO-VOLTAGE TECHNOLOGY

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NASA JOHNSON CENTER, TX

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ALE - New Production Site – February 2025

- **American Lithium Energy, with 20 years in Li-ion battery RD and Manufacturing,** is a leading domestic battery solutions provider. ALE offers vertically integrated services in engineering, consulting, and manufacturing battery cells and packs.
- **110+ US and International patents** focused on improving the performance and safety of lithium-ion batteries. 99+ Patents Awarded, including: Safecore™ NTC, Zero Volt, and Solid-state hybrid
- **Production Capabilities:** ALE is committed to US production (see picture of production electrode coater with 110 ft long and 10 feed wide) in a second commercial site to manufacture the cells outlined in this program:
  - **81,000+ SQFT in Vista, California**

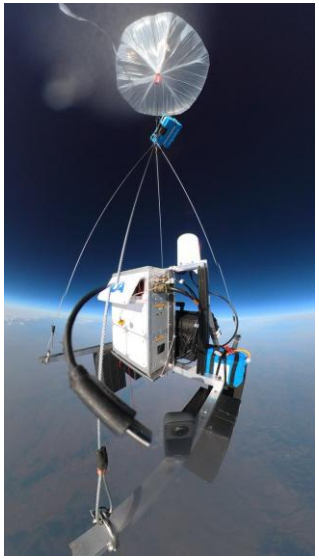
- **Production Lines:**
  - Production line with >300 MWh/year
  - Industrial standard machines –economical and reliable
  - ***Drop-in solutions + new chemistry for advanced applications***
- **Cells Produced:**
  - ***Pouch cells: 2Ah, 7Ah, 14Ah and 19.5Ah for various kinds of markets***
  - ***Cylindrical cells: 21700 cells with 5.5Ah and 18650 cells with 4Ah***
  - ***High energy up to >400 Wh/kg specific energy***
  - ***High power up to 100C rate***

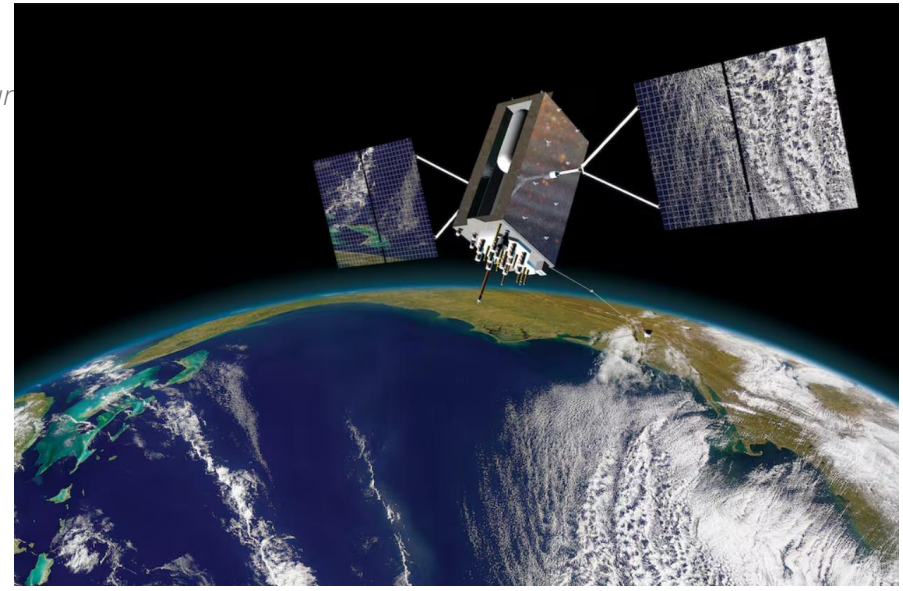
- **Certifications:**
  - AS9100D
  - ISO 9001:2015
  - ITAR

Testing Capability:

- UL 1642
- UN 38.3
- AIAA S144
- Custom

ALE Batteries in sUAS, Near Space Balloon, National Defense Satellite and GPS III Satellite

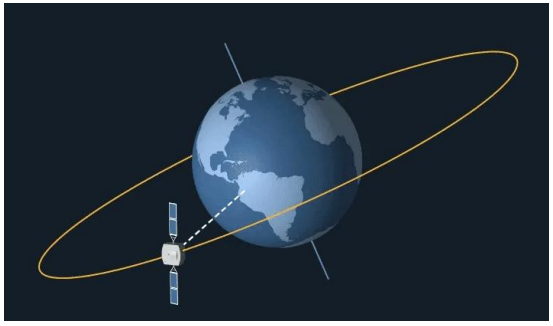


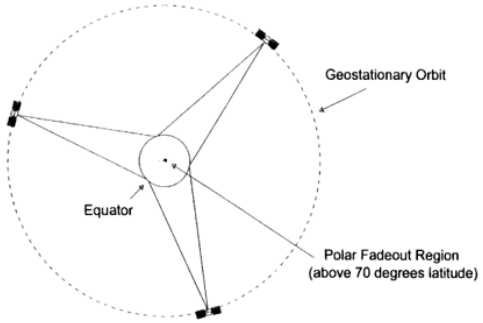


- *ALE 4Ah 18650 cells are powering satellite in space now*
- *ALE 4Ah 18650 cell with TDA electrolyte has been tested in near space ballon*
- *ALE high power and high energy batteries are powering the UAVs at the commercial scale*

Challenge 1: Space Battery Requirements for Satellites

Satellite Orbit	GEO (Geostationary Earth Orbit)	MEO (Medium Earth Orbit)	LEO (Low Earth Orbit)
Altitude	36,000Km	5,000-20,000Km	500~1,200Km
latency	>500ms	<80ms	<30ms
Earth coverage	Very large	Large	Small
Satellites Required	Three	Six to Twenty	Hundreds to thousands
Time circle earth	24hr	2~12hrs	~90 minutes
Satellites Lifespan	~15 years	~10 years	5-7 years
Application	weather data, broadcast TV, and low-speed data communication	GPS, other navigation applications, and high-bandwidth data service	Real time data service, International Space Station, Star link for global coverage
Battery requirement	Long cycle life; long time storage; high energy density		





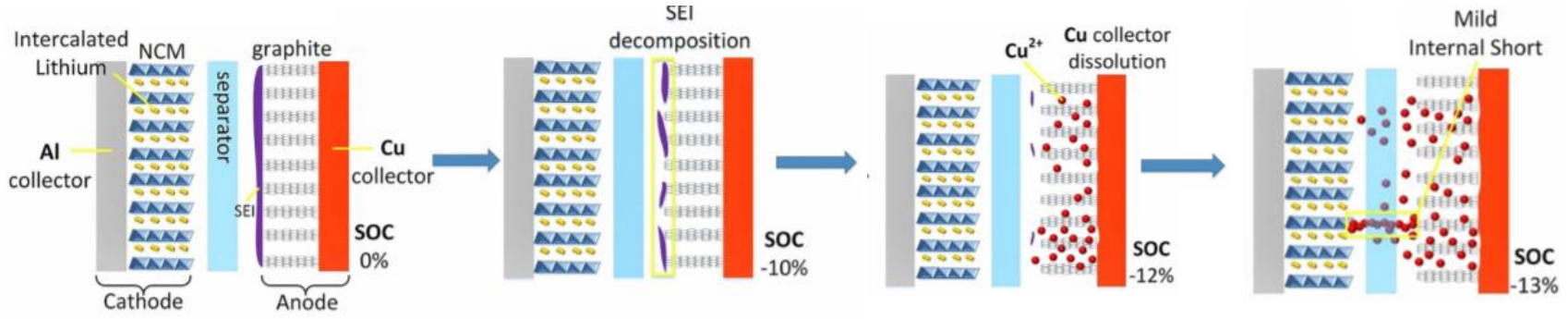
ALE batteries can meet these requirements for GEO, MEO, and LEO satellites

https://www.deepinsecurity.com/geostationary-earth-orbit/

Challenge 2: Dead Bus Recovery: ZV Stability

Battery Complete Discharge → Battery Failure → Spacecraft Power failure → Dead Bus

Battery failure mode



SOC<0

Overdischarge Process: Cu dissolution and dendrites, Internal short

Recovery Battery from Deep Discharge even Zero voltage Exposure

ALE Solutions: Prevent Cu dissolution at low Voltage

Zero Voltage Technology: Technology Map

Replace Cu foil with Ti foil

First

ALE: Sacrificial electrode approach for ZV stability (SBIR Phase II 2021): (FA864921P0869)

Second

ALE: Non-sacrificial approach for ZV stability (STRATFI 2025): (FA8802-25-C-0001)

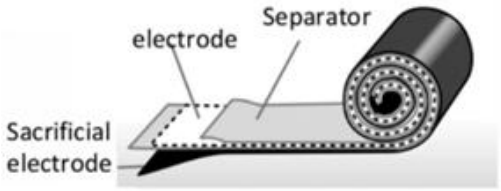
Advantages
- Good Electrochemical Stability
- Good Corrosion Resistance
- High Mechanical Strength

Disadvantages
- High Cost
- 70% Lower Electrical Conductivity
- Processing Complexity

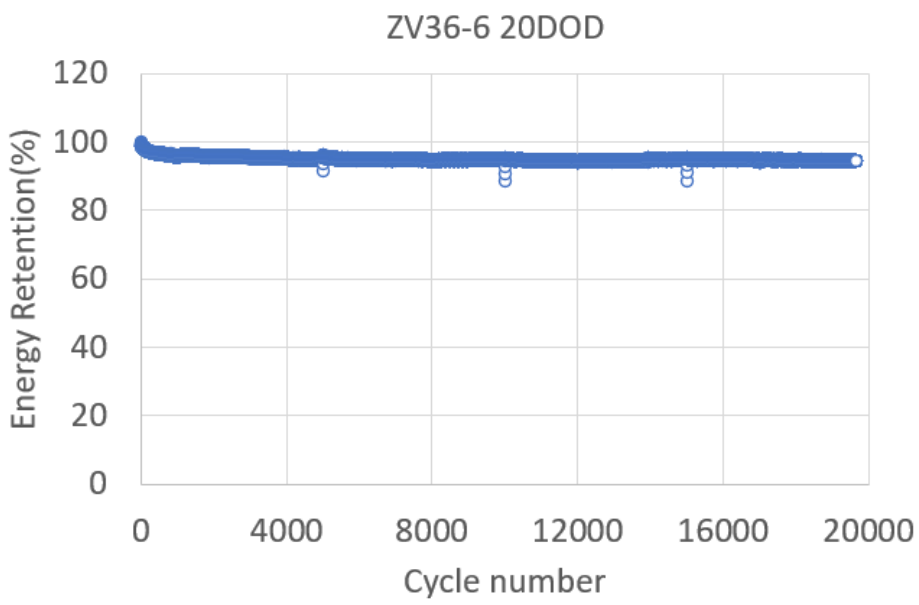
Advantages
- Low cost
- Excellent ZV Stability
- Protect Cu foil from corrosion
- Full performance recovery
- Battery safety
- Battery storage and shipping

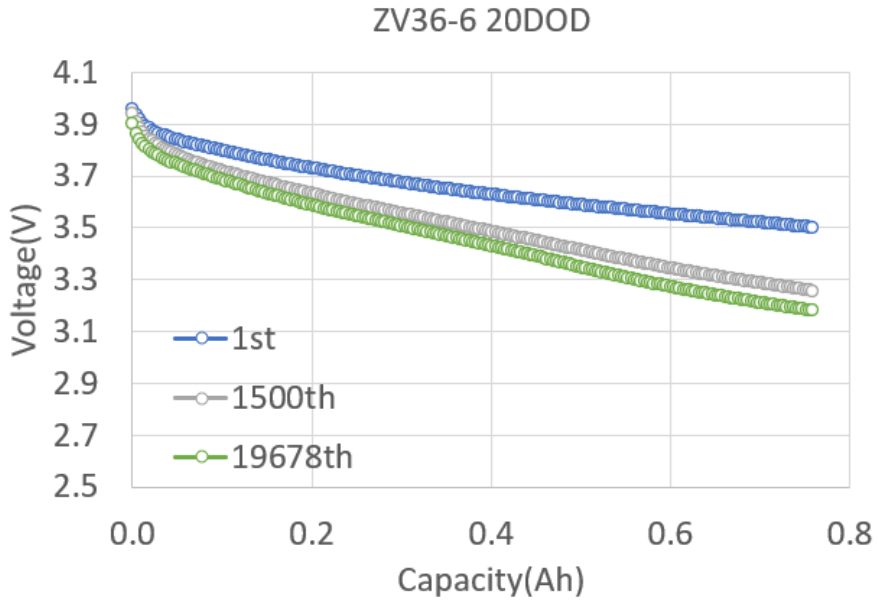
Advantages
- Protect Cu foil from corrosion
- High electrical conductivity
- Middle Cost
- Easy Mass Production

US Patent App. 18/553,463
US Patent App. 18/753,854



20DOD: Cycle life (First Generation)



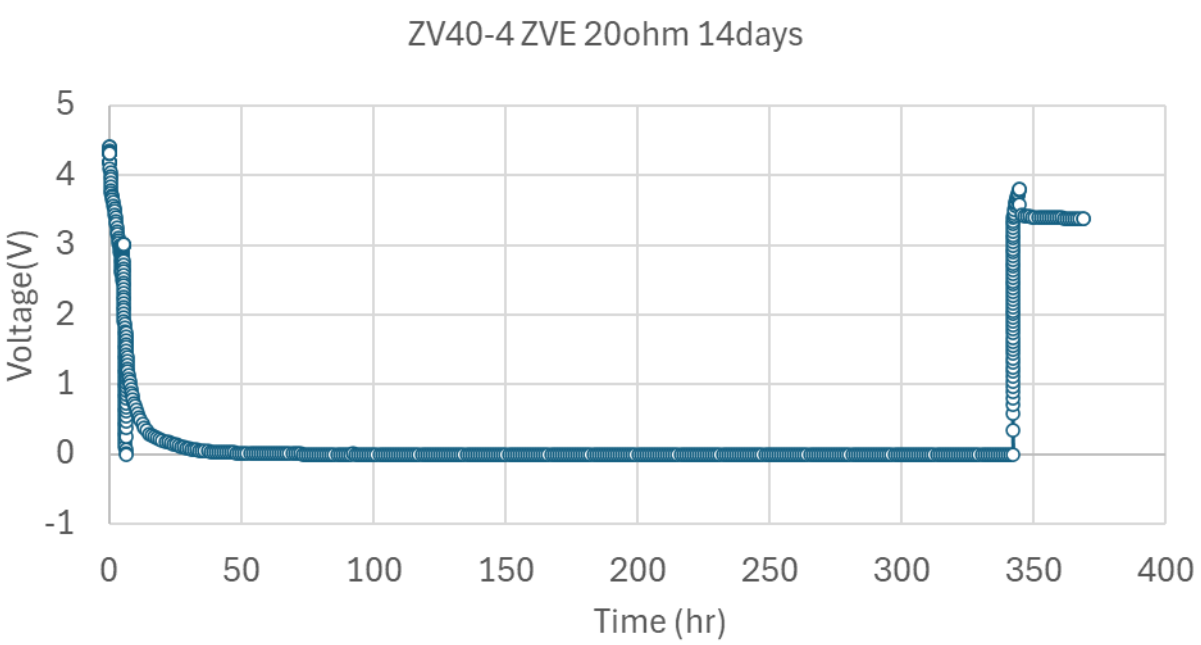


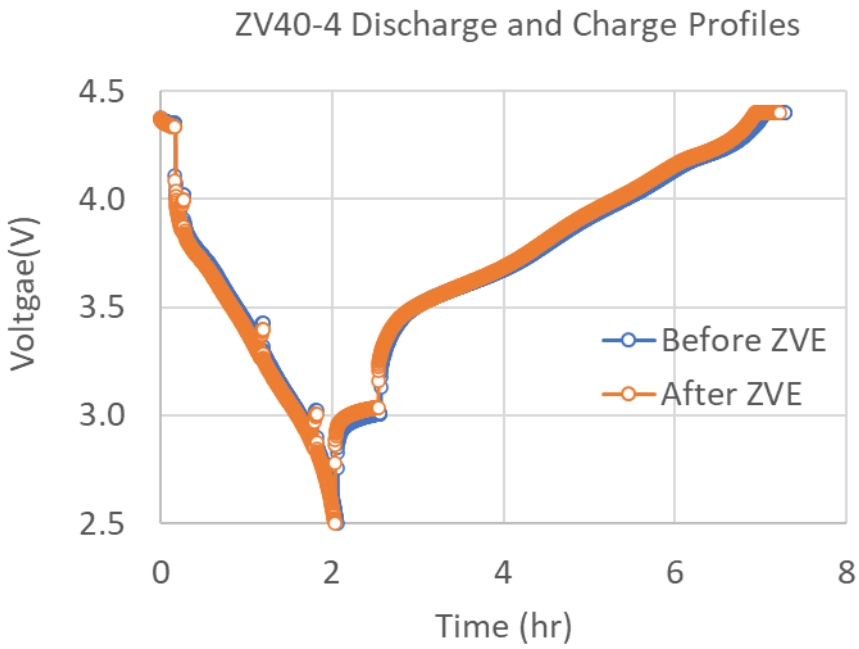
Cycle number	1	1500	19678
End voltage	3.5038	3.2596	3.1825
Energy retention	100%	96.04	94.48

Test Procedure:
Discharge C/3: 35 minutes
Charge C/4.5 to 4.1V cut off C/20: 65minutes

- ~3.96% reversible discharge polarization energy reduction from 1st to 1500th cycle (equilibrium state to steady state)
- ~1.56% discharge loss from 1500th to 19678th cycle.
- Projected cycle life from *four years plus real-life testing data*: >>75,000 cycles (15 years).

ZVE 14days: before cycle life (First Generation)



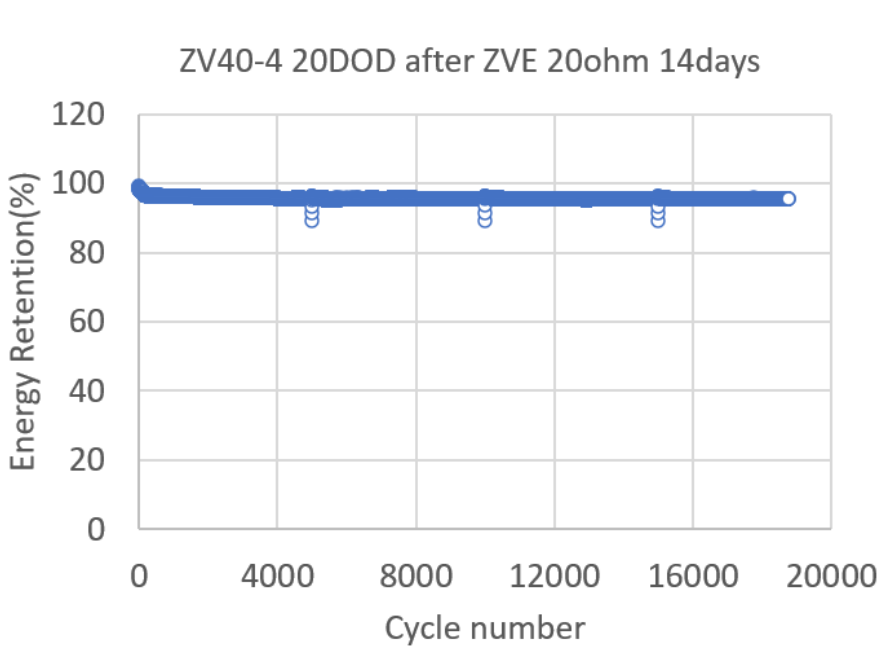


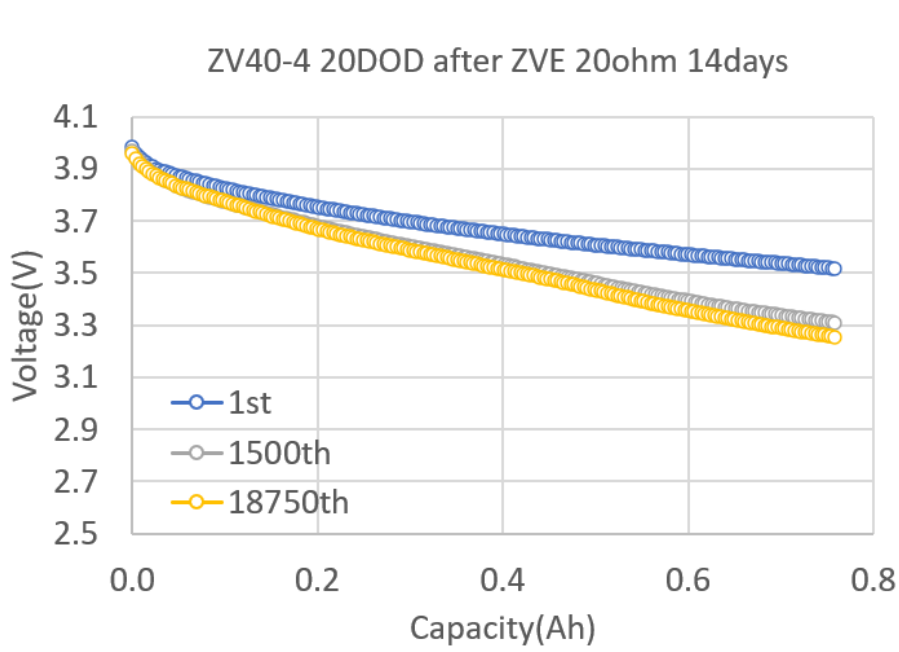
Voltage (V)	2.5V	0V	0V 14days
Capacity(Ah) ZVE	3.47	0.68	0.48
Capacity(Ah) Before ZVE	3.59	-	-
Capacity(Ah) After ZVE	3.53	-	-

Test Procedure:
Discharge C/5: 2.5V
Discharge C/5 to 0V
Discharge at 20ohm
Charge to 3.8V and rest

- 98.5% Capacity Retention after ZVE 0V 14days 20ohm

20DOD: Cycle life after ZVE 14days (First Generation)





Cycle number	1	1500	18750
End voltage	3.5672	3.3110	3.2557
Energy retention	100%	96.14	95.51

Test Procedure:
Discharge C/3: 35 minutes
Charge C/4.5 to 4.1V cut off C/20: 65minutes

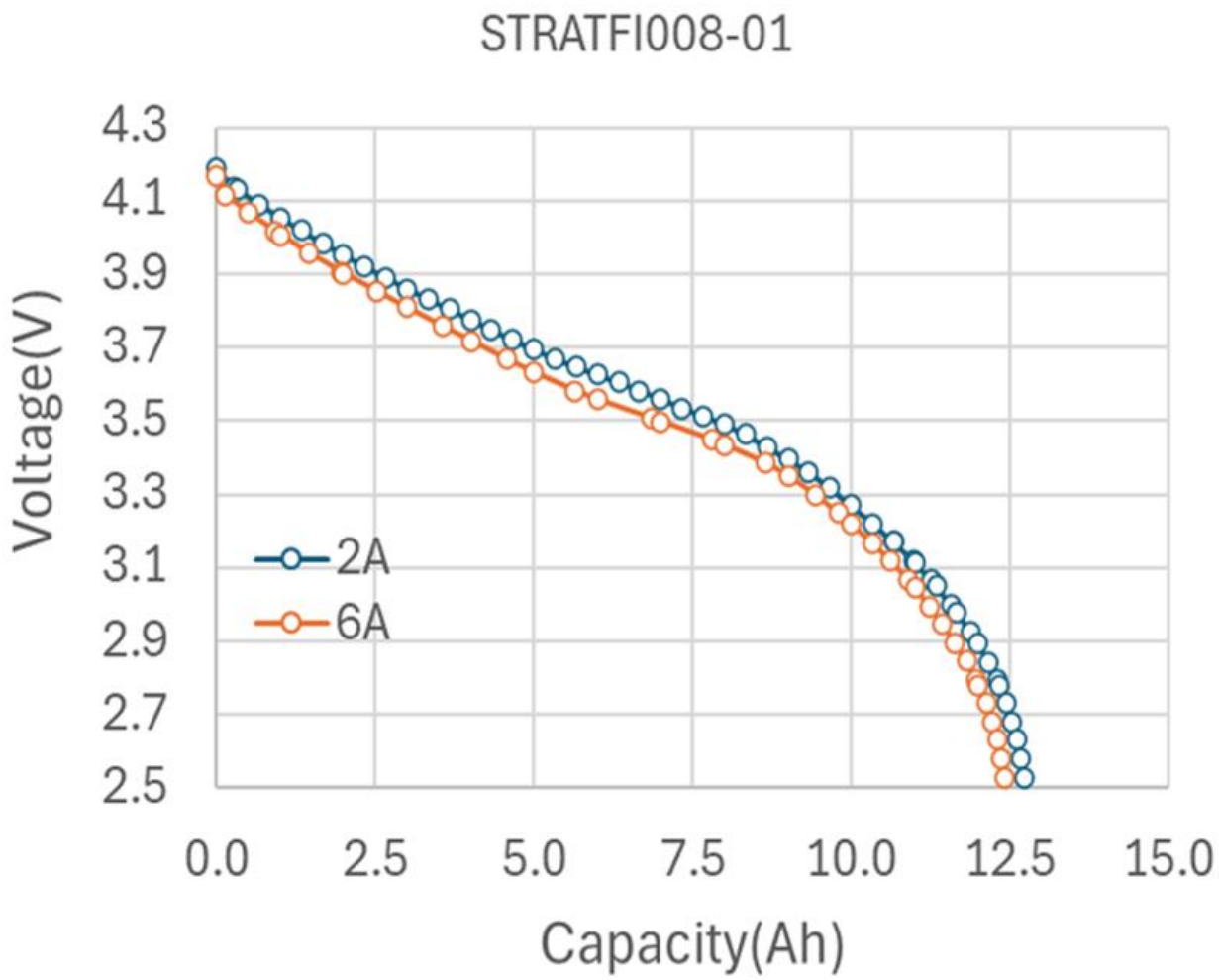
- ~3.86% reversible discharge polarization energy reduction from 1st to 1500th cycle (equilibrium state to steady state)
- ~0.63% discharge energy loss from 1500th to 18750th cycle.
- Projected cycle life from *four year plus real cycle life data*: >>75,000 cycles (15 years).
- No impact on the cycle life from 14 days at ZV

5781173 Battery with Second Generation of ZVT technology

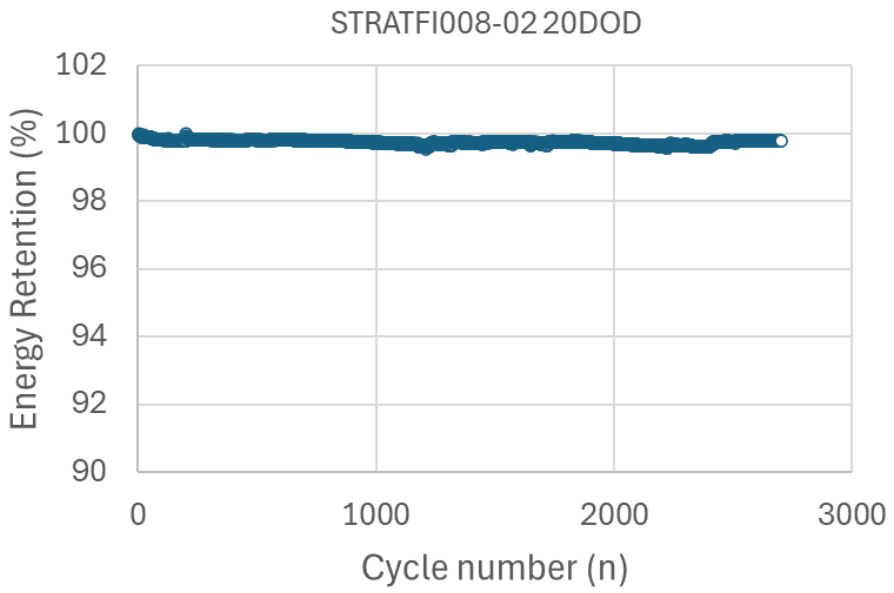
	Sole Source (battery)	ALE (battery)	ALE (1 cell)
Capacity (Ah)	75	100 (33% improvement)	12.5
Energy (Wh)	270	360~370 (33% improvement)	45~46.3
Specific Energy (Wh/Kg)	147	220 (50% improvement)	>270
ZV Stability Requirement (negative voltage)*		-1V, 10 cycles/ and constant C/2 discharge abuse*	-1V, 10 cycles/ and constant C/2 discharge abuse*
Cycle Life (20DOD)/LEO		>75,000 (15 years)	>75,000 (15 years)
Cycle Life (50DOD)/GEO		>1500 (15 years)	>1500 (15 years)
Cycle Life (40DOD)/MEO		>3000 (15 years)	>3000 (15 years)

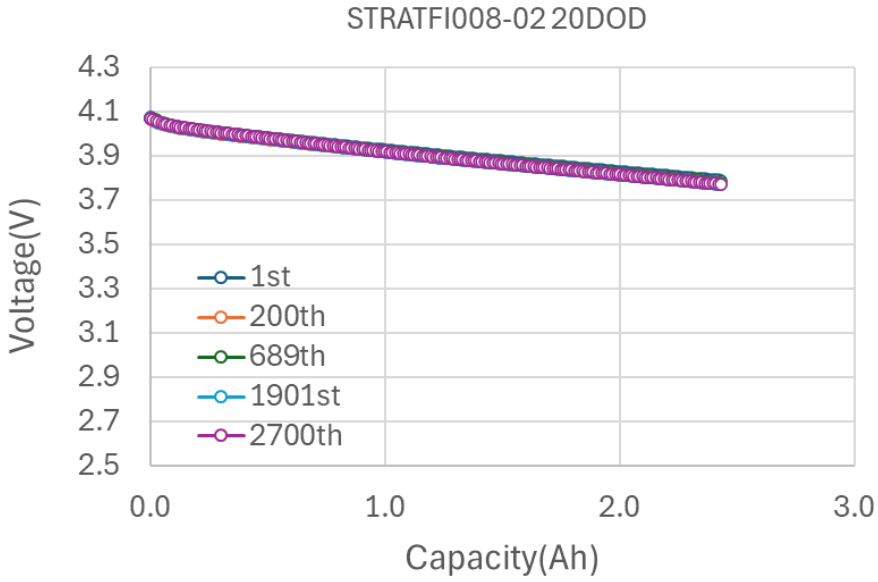
*: S-144 maximum discharge C/2 rate: can reach -1V, but can't < -1V owing to this limitation

12.5Ah Pouch Cell



S-144 TEST: 20%DOD (LEO Test)



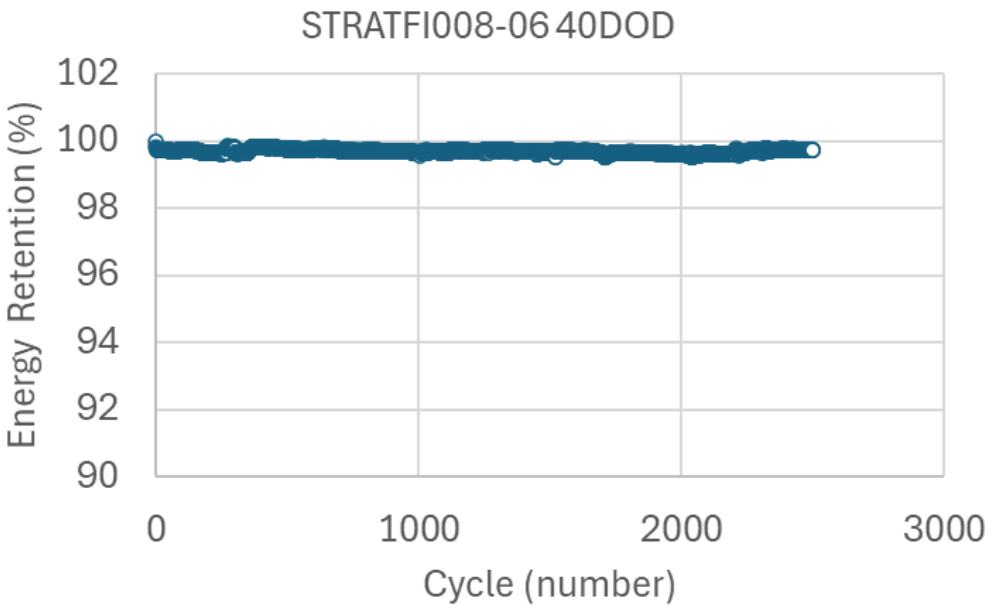


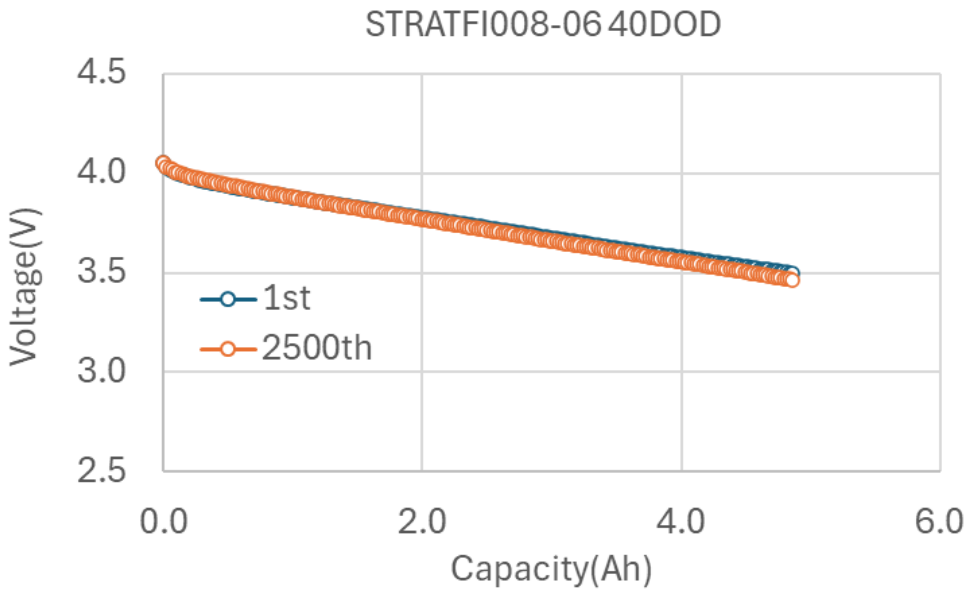
- Test Procedure:
- Charge C/4.5 to 4.1V cut off C/20: 65minutes
- Discharge C/3: 35 minutes

Project cycle life: 360,441 cycles
Target cycle life: >75,000 cycles

Cycle number	1	200	201	400	1901	2700
End voltage (V)	3.7890	3.7769	3.7870	3.7766	3.7713	3.7726
Energy retention (%)	100	99.78	100.0	99.80	99.74	99.79

S-144 TEST: 40%DOD (MEO Test)





- Test Procedure:
- Charge C/2.25 to 4.1V cut off C/20: 65minutes
- Discharge C/1.5: 35 minutes

Cycle number	1	2500
End voltage (V)	3.4986	3.4653
Energy retention (%)	100	99.76

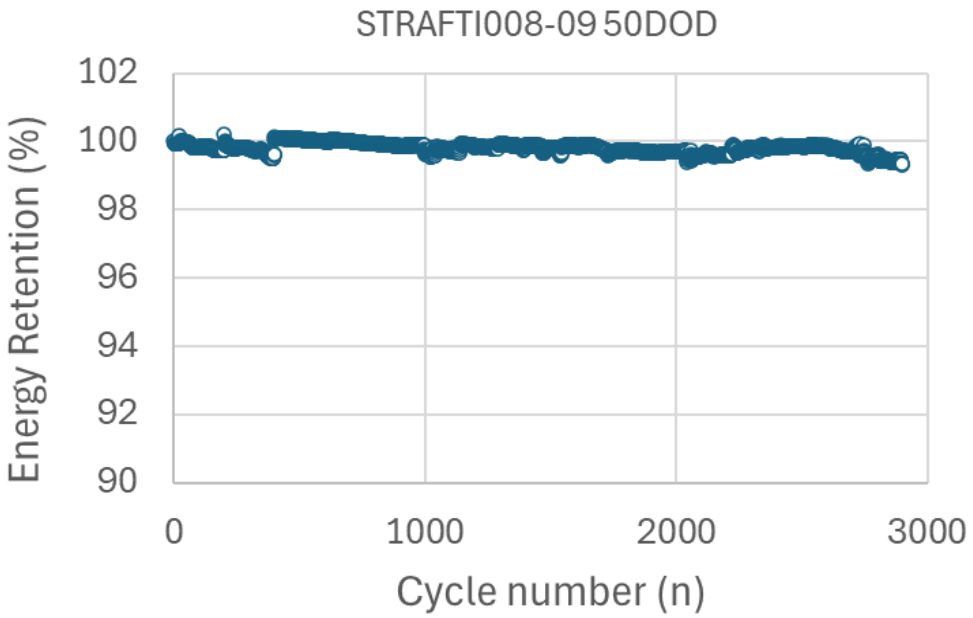
Project cycle life:
72,470 cycles

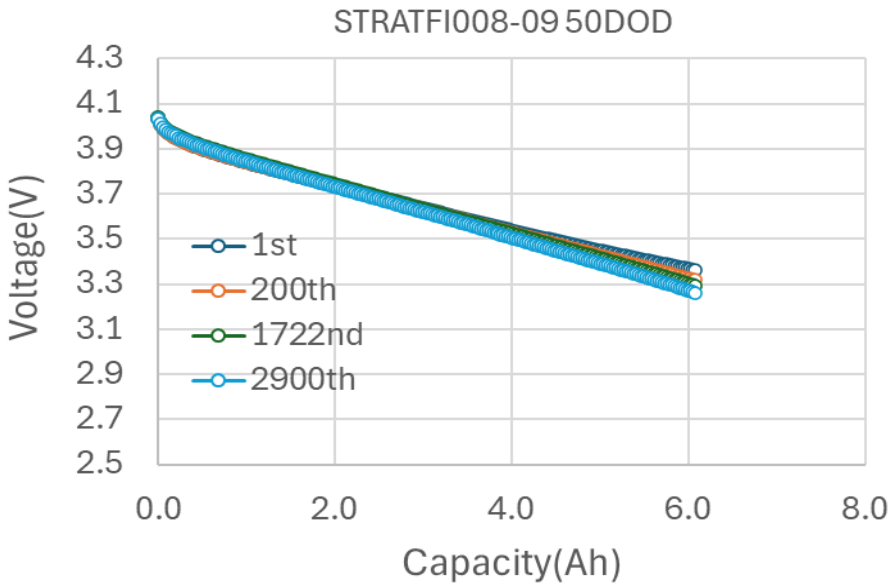
Target cycle life:
>3000 cycles

Only 0.24% loss after 2500 cycles

Very stable chemistry

S-144 TEST: 50%DOD (GEO Test)





- Test Procedure:
- Charge C/1.8 to 4.1V cut off C/20: 65minutes
- Discharge C/1.2: 35 minutes

Cycle number	1	200	1722	2900
End voltage (V)	3.3617	3.3176	3.2935	3.2628
Energy retention (%)	100	99.74	99.72	99.35

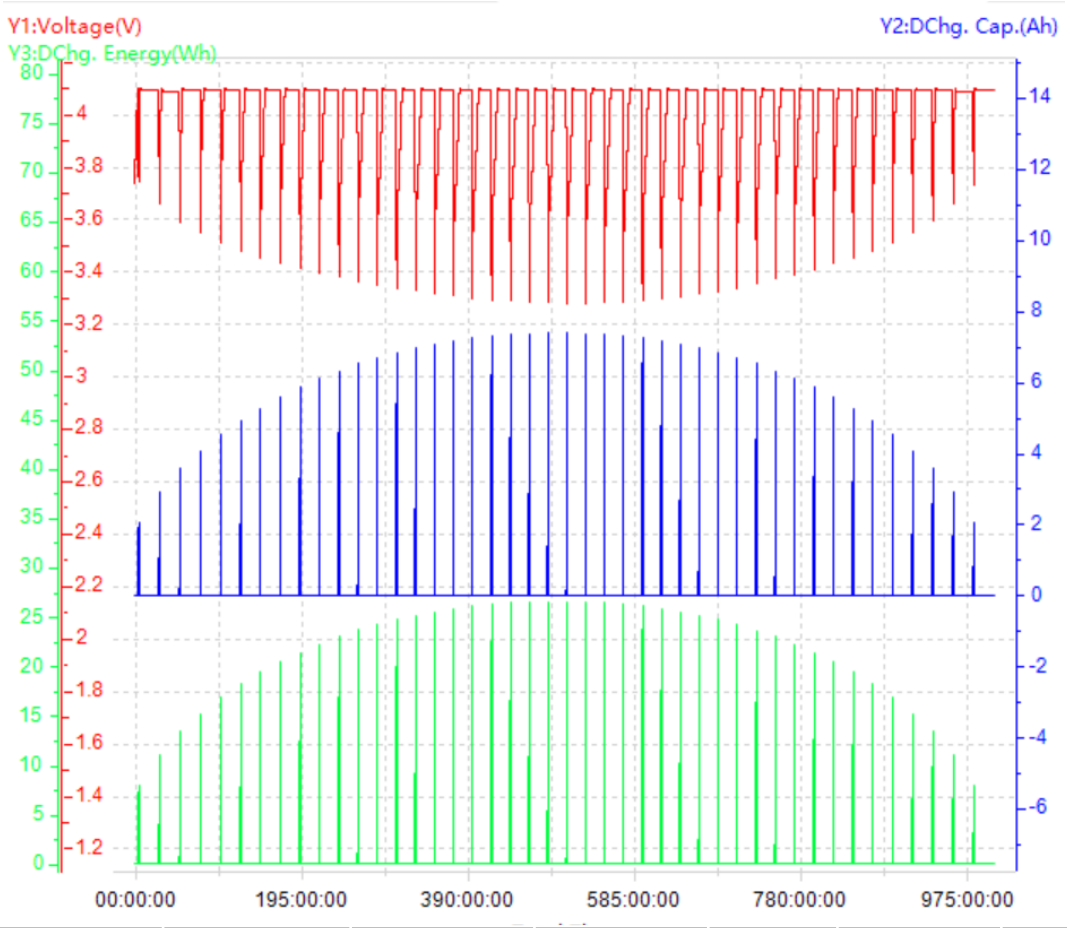
Project cycle life: 31,000cycles

Target cycle life: >1500 cycles

Only 0.65% loss after 3000 cycles

Very stable chemistry

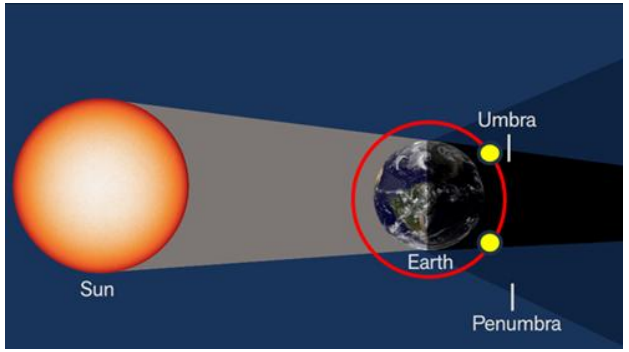
GEO TEST (12.5Ah Cell)



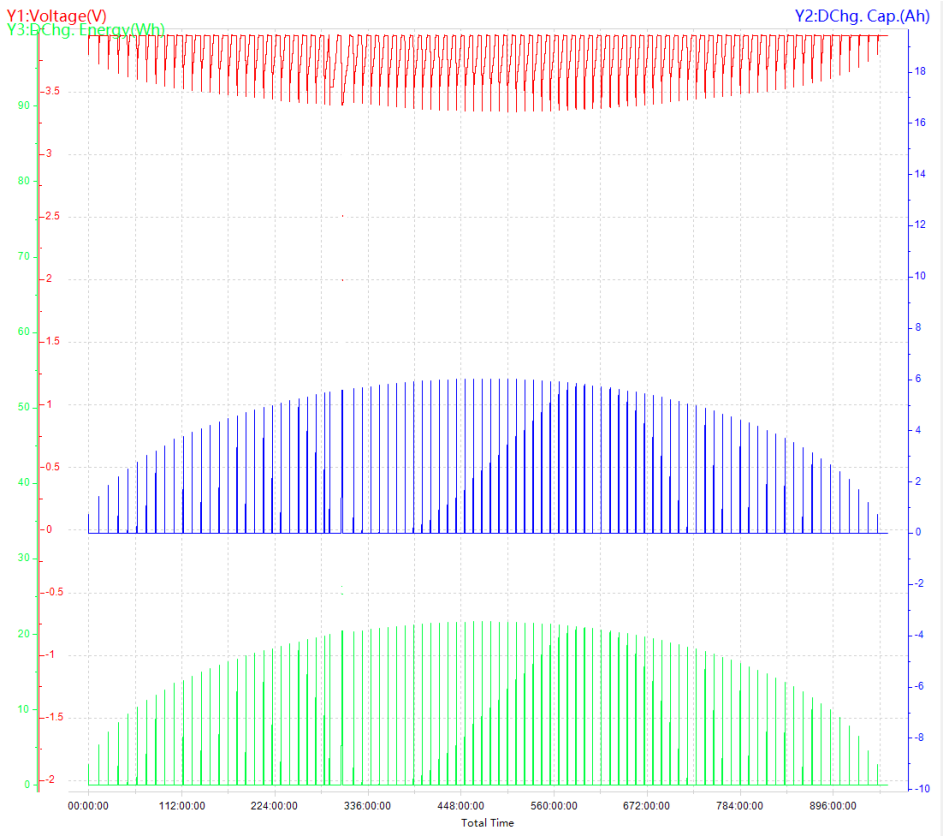
- Test Procedure:
- Charge Current 1.0416A: (6A/8)*(100/72) to 4.1V cut off 0.1A
- Discharge Power: 22.75W: (131W/8)*(100/72)
- 44 days Test (44 cycles)
- Discharge time= Umbra+2 Penumbra*

GEO test pass the first eclipse season (2 season/year)

Cycle number	1	2	3	...	22	...	44
End voltage (V)	4.1	4.1	4.1		4.1		4.1
Time (Discharge) minutes	20.9	29.2	35.3	....	70.0	...	20.9



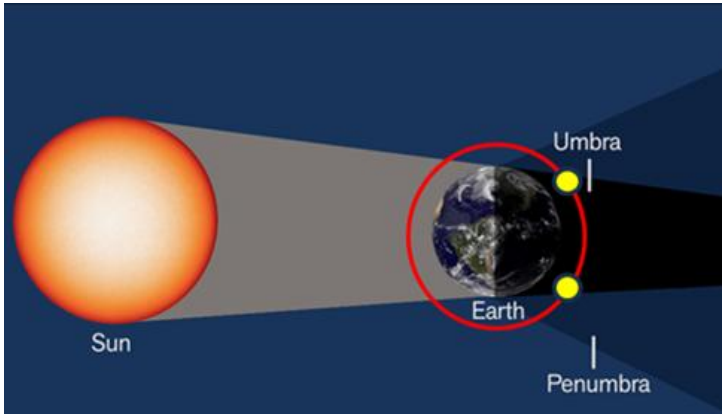
MEO TEST (12.5Ah Cell)



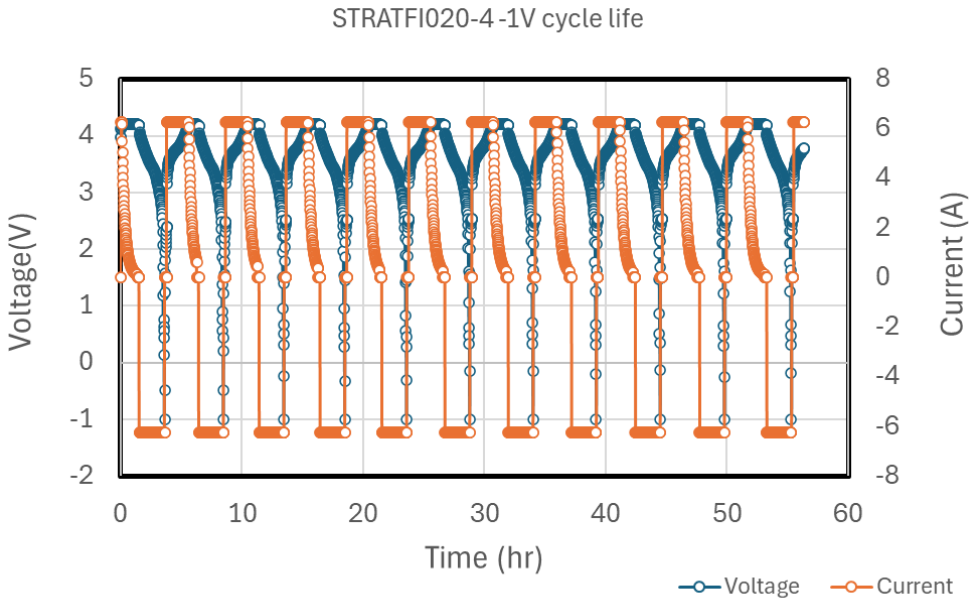
- Test Procedure:
- Charge Current 1.0416A: (6A/8)*(100/72) to 3.95V cut off 0.1A
- Discharge Power: 22.75W: (131W/8)*(100/72)
- 45 days Test (90 cycles)
- Discharge time= Umbra+2 Penumbra*

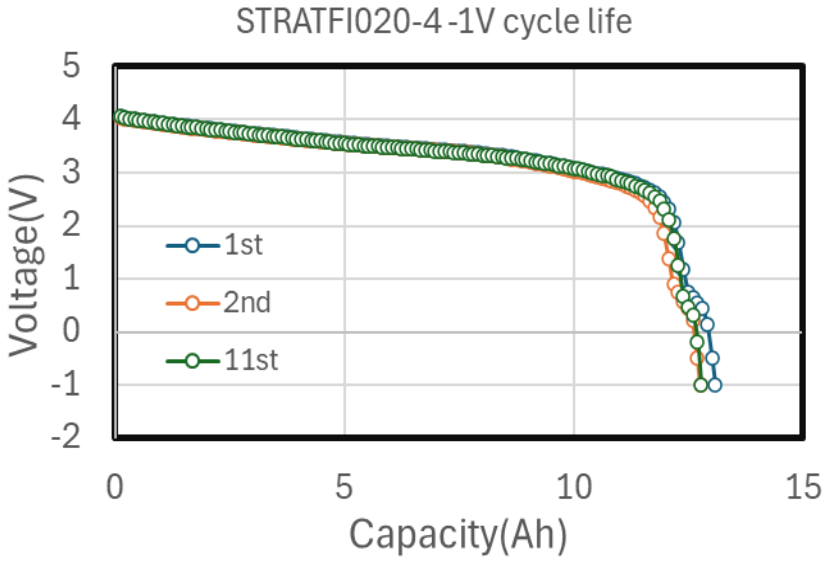
MEO test pass the first eclipse season (2 season/year)

Cycle number	1	2	3	...	45	...	90
End voltage (V)	3.95	3.95	3.95	...	3.95	...	3.95
Time (Discharge) minutes	7.1	14.1	18.4	....	57.0	...	7.1



Negative Voltage Cycle life



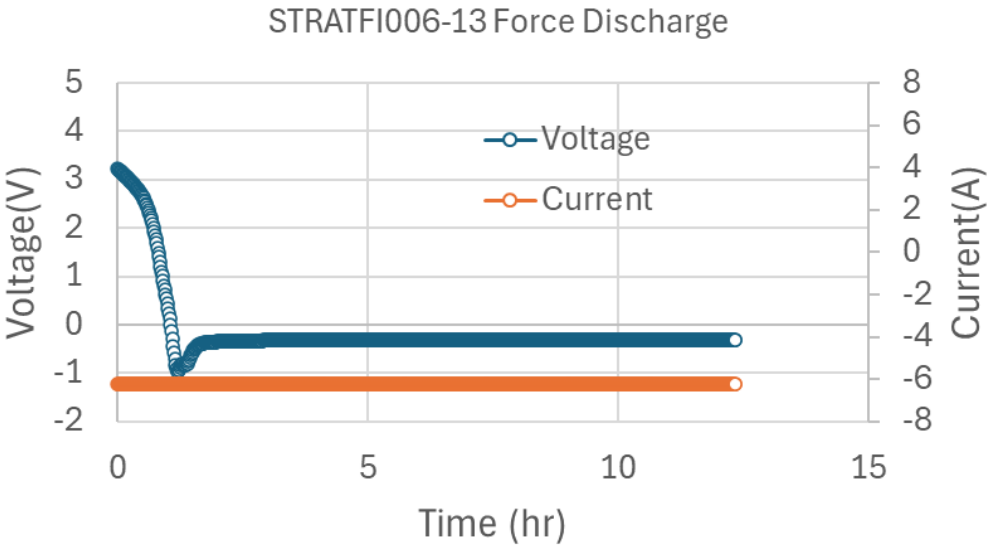


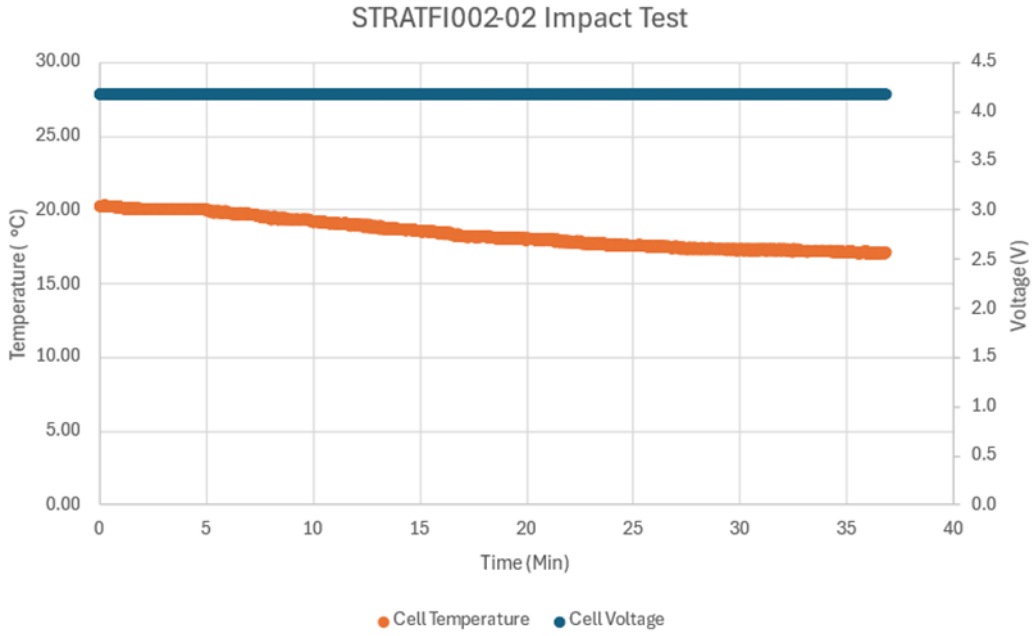
Cycle condition	1st	2nd	11st
Capacity (Ah)	13.09	12.77	12.78
Charge Voltage (V)	4.2	4.2	4.2
Discharge Voltage (V)	-1	-1	-1
Impedance (mohm) 1kHZ	2.52 (before cycle)/3.1 (after 11 cycles)		

Test: C/2 discharge to -1V, C/2 charge to 4.2V

- 1st discharge (larger capacity); 2nd discharge (less capacity)
- 11st discharge (stable capacity)
- Li+ loss from SEI layer broken and reconstruction
- (similar impact from the first charge/discharge during formation)
- No Capacity loss 4.2-2.5V
- *Meet the requirement*

Abuse Test





C/2 (6.25A) discharge for 1 hr to -1V
Continue C/2(6.25A) discharge for 11 hr (discharge capacity 5.5C)
No fire, No explosion (Pass)

100%SoC Impact: No fire, No explosion (Pass)

Summary

- ALE First Generation ZTV:
  - Excellent ZV stability at 0V 14 days, only ~1.5% loss
  - LEO: 20DOD cycle life close to 20,000, ~0.6% loss from 1500 to 18750 cycles, project cycle life > 75,000 cycles (15 years) after ZVE 0V 14days

- ALE Second Generation ZVT:
  - LEO: 20DOD cycle life test ~2,700 cycles, projected cycle life > 75,000 cycles.
  - GEO: 50DOD cycle life ~2,900 cycles, pass the requirement > 1500 cycles
  - GEO: pass the first eclipse season at 4.1V 44 cycles
  - MEO: 40DOD cycle life ~2,500 cycles, projected cycle life >> 3000 cycles
  - MEO: pass the first eclipse season at 3.95V 90 cycles
  - ZV cycle life: Done 11 cycles to -1V at C/2, no capacity loss in 4.2-2.5V.
  - Abuse test: Discharge 11hr at C/2 after -1V, no fire, no explosion

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