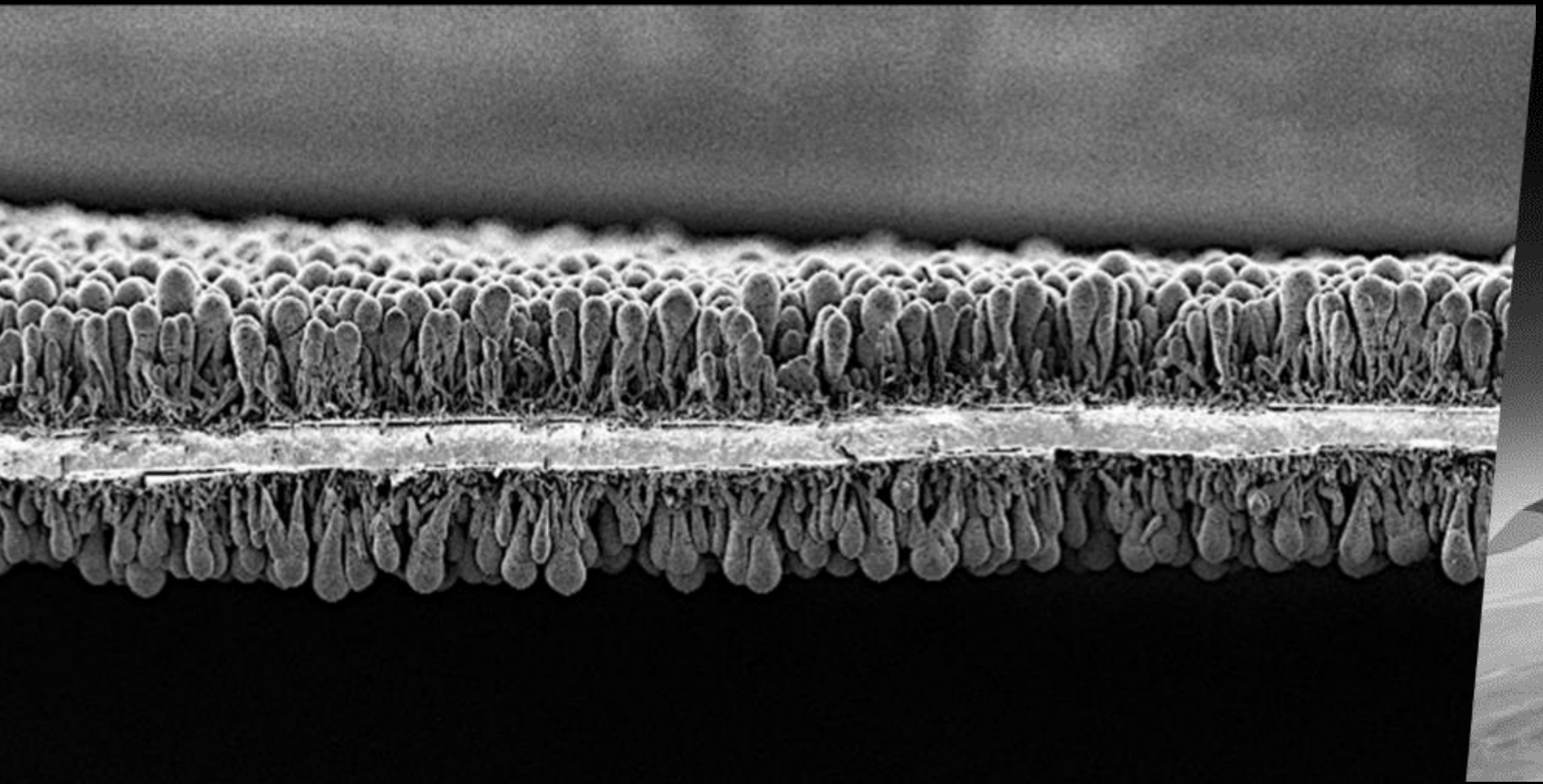
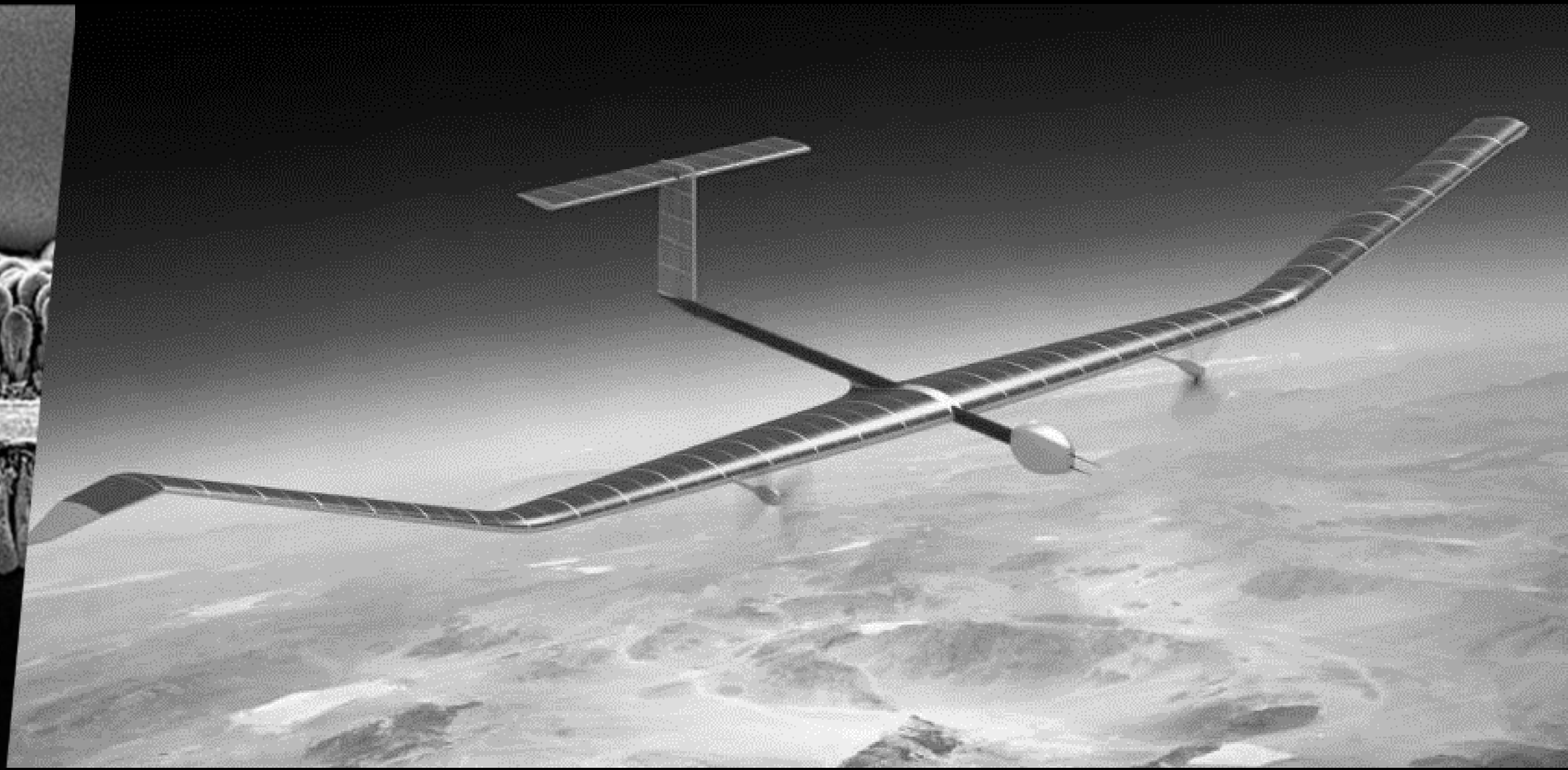
Safe silicon anode cells with high energy density





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2022 NASA Aerospace Battery Workshop

November 2022

We Enable the Future of Electric Mobility Today

Innovation

100% silicon anode battery[1]

Superior Battery Performance

- **High Energy Density**
  Up to 450 Wh/kg[2] and 1,150 Wh/L[2][3]
- **High Power Density**
  Up to 10C
- **Fast Charge Rate Capability**
  80% charge in <6 minutes
- **Wide Operating Temperature**
  -30°C to 55°C

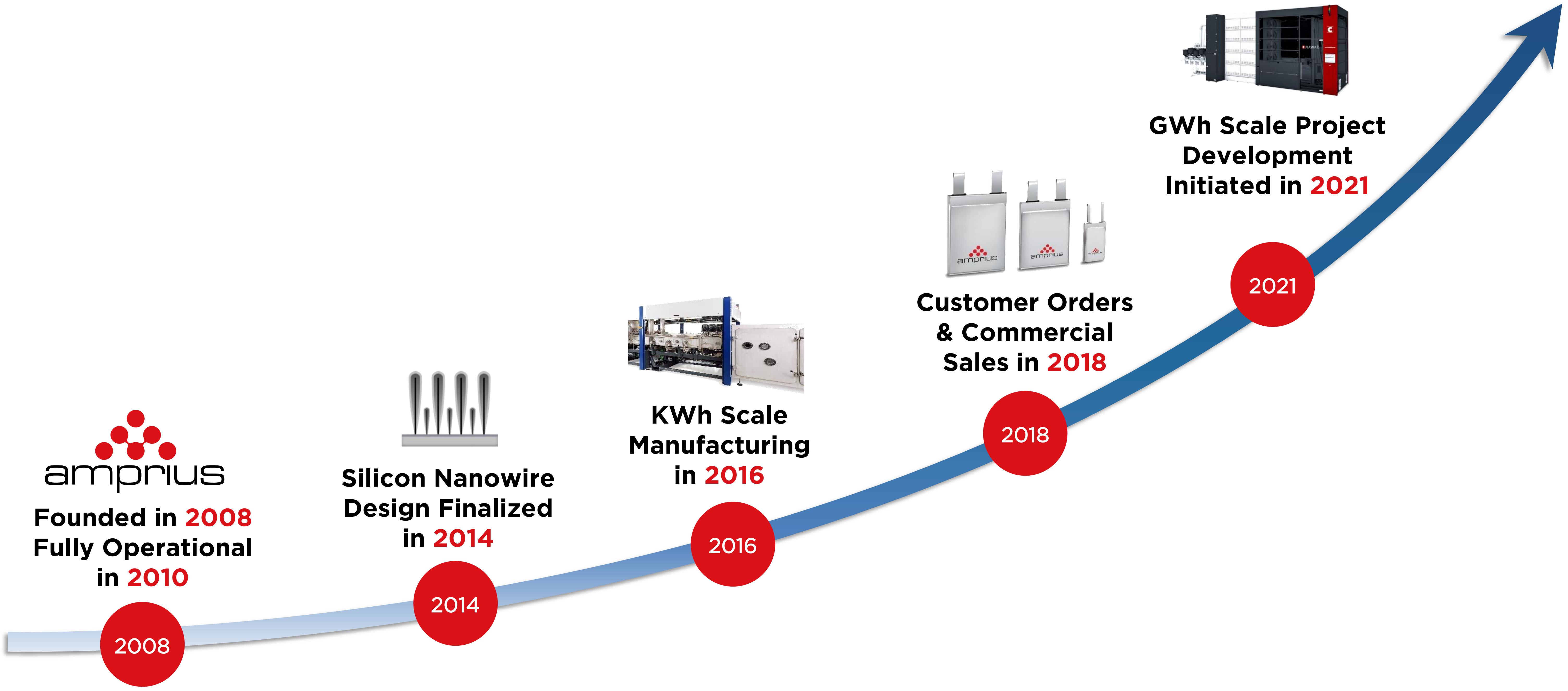
Commercially Proven

Tested and validated by industry leading partners

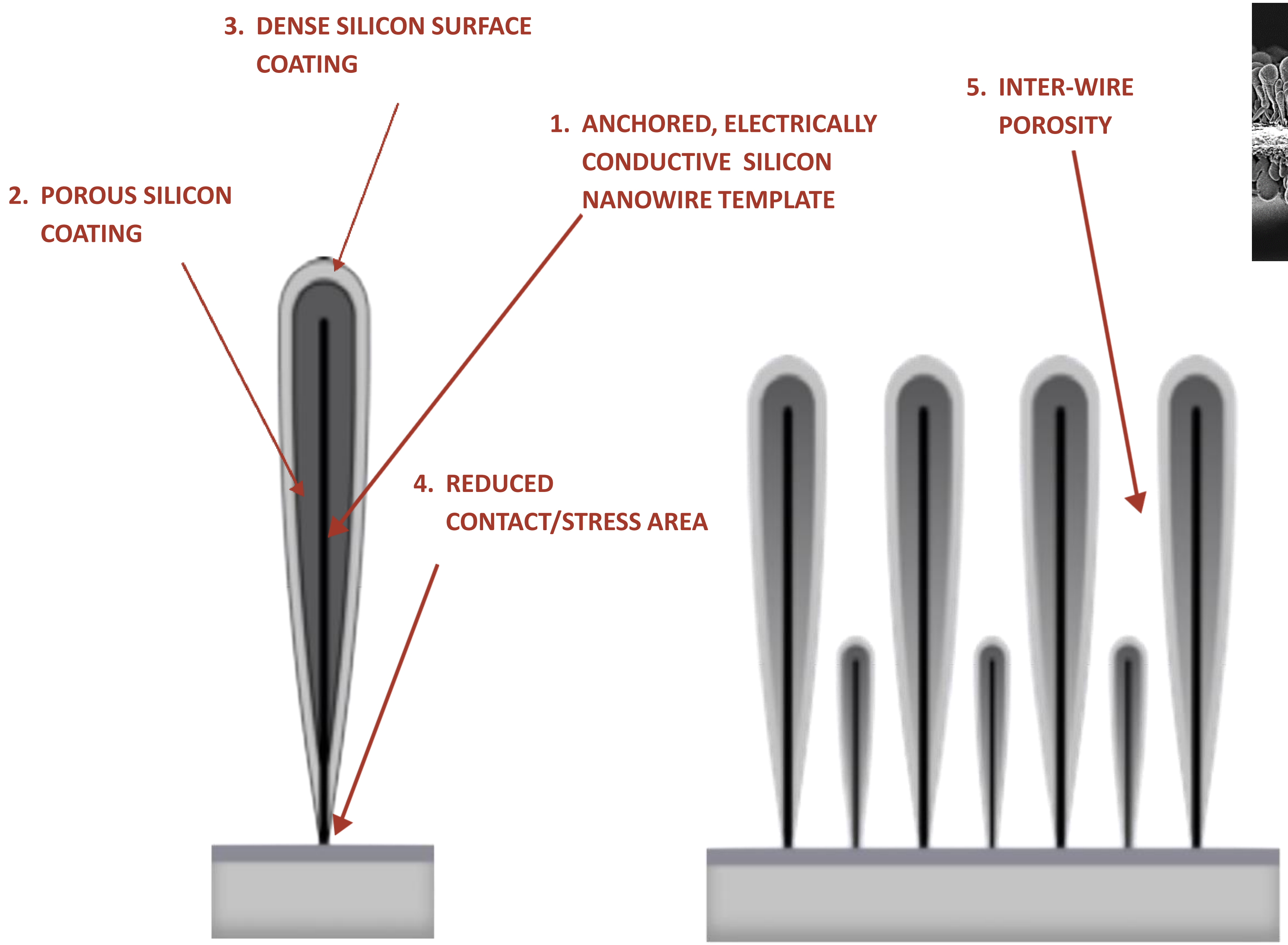
Note: Certain performance metrics are based on specific Amprius products.

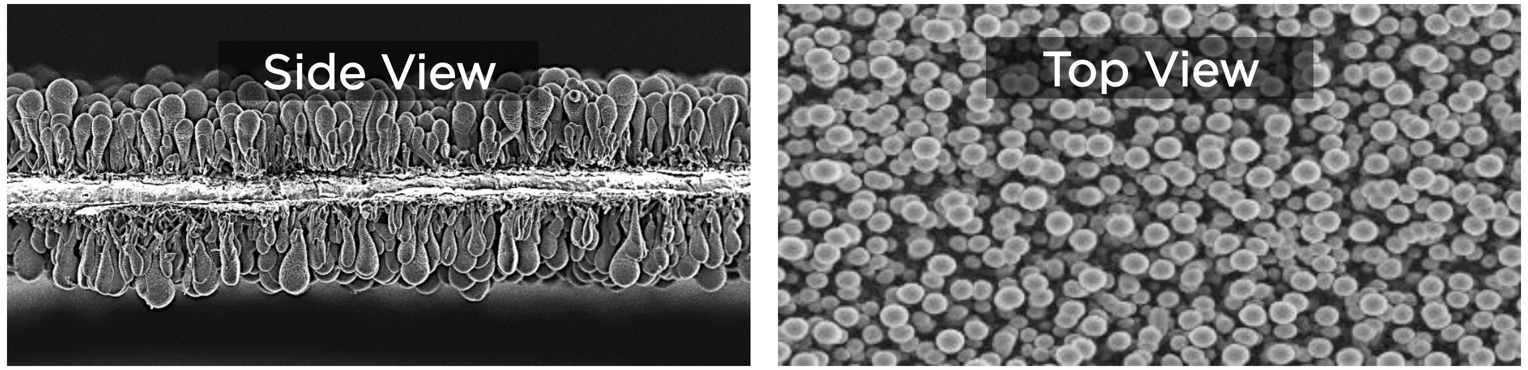
(1) Actual percentage of silicon is 99.5-99.9% which is within the range of acceptable purity levels for materials that are considered 100%.
(2) At C/10 and 23°C.
(3) Volumetric energy density is calculated using body dimensions at 30% state of charge ("SoC").

Turning a Transformational Technology Into a Commercial Reality



Five Key Material and Structural Features





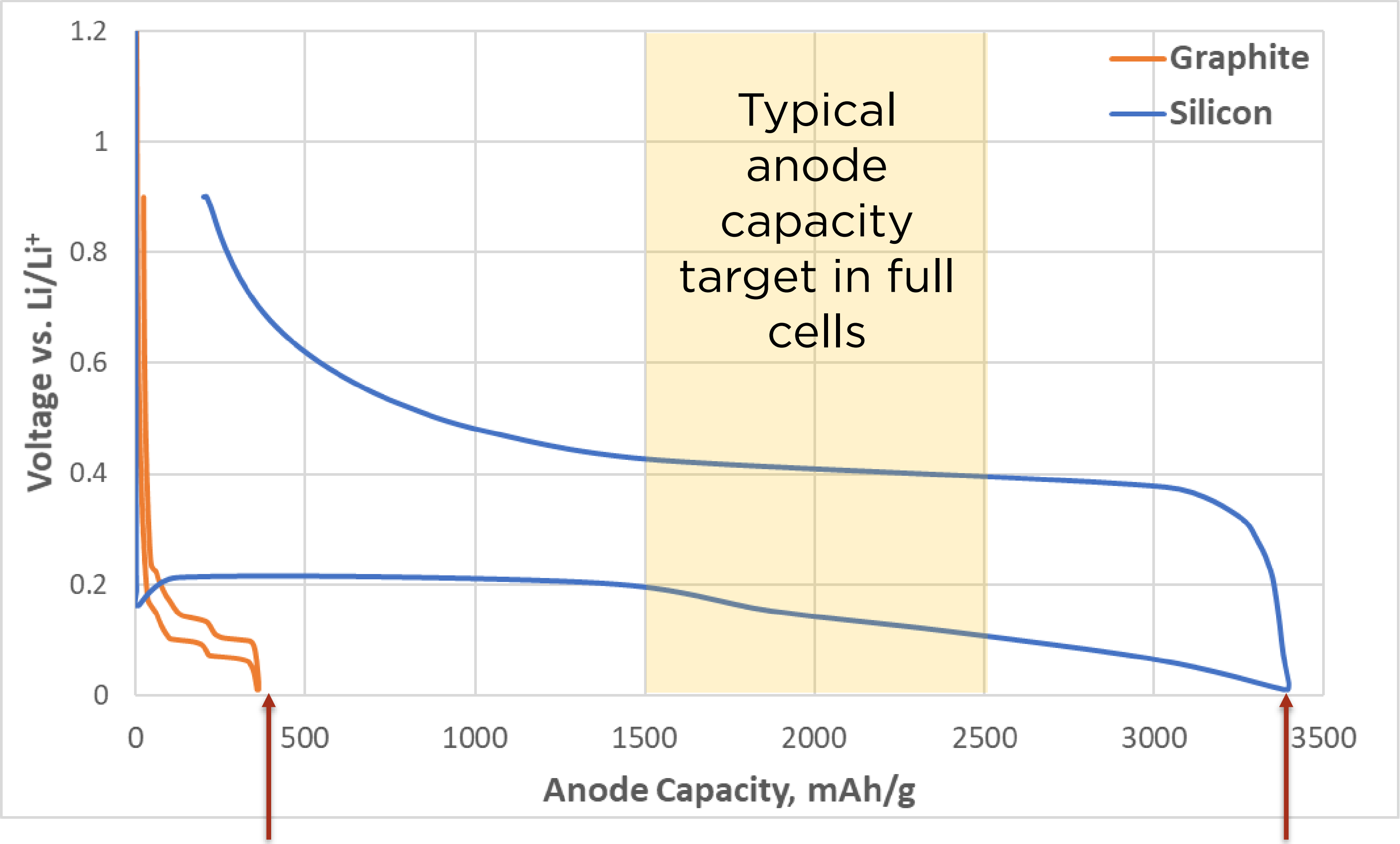
Nanowire rooted – "metallurgical" anchoring; *mechanically and electrically connected to substrate.*

Micro & macro porosity *– prevents silicon cracking and interference between nanowires.*

*Spacing between nanowires **avoids impact of silicon volume expansion**.*

High electrical and ionic conductivity, low tortuosity – **enables fast charging**.

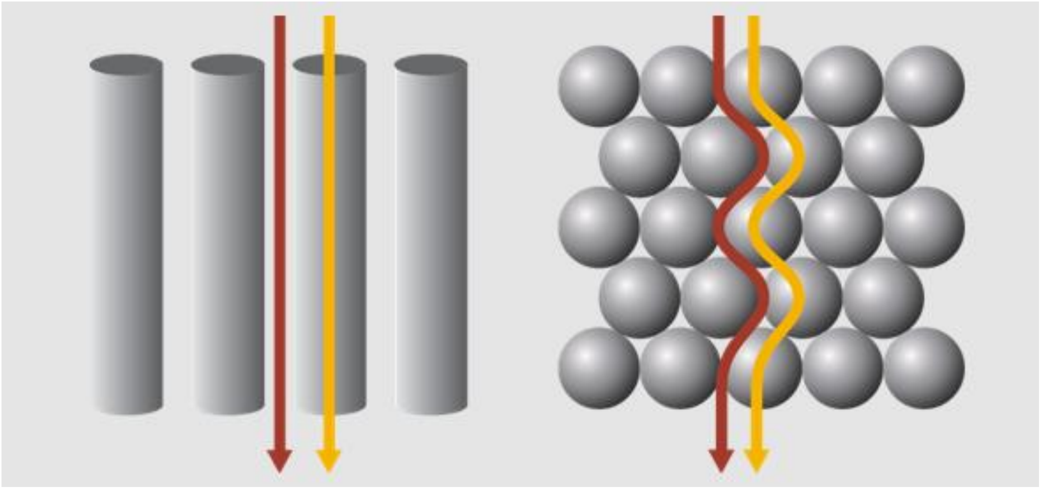
Near-theoretical capacity for a silicon anode



372 (theoretical Graphite)

3400 (Si Nanowire)
3569 (theoretical Si)

- High first cycle efficiency due to low surface area (typically 94%)
- Mechanically stable electrode structure – no particle-particle interactions
- Good electrical and ionic conductivity, low tortuosity – ***high power capability, fast charge***



Amprius Utilizes Existing Commercial Manufacturing Processes

Cathode and Assembly Processes are Unchanged; the Only Change is to the Anode Manufacturing Line

SILICON NANOWIRE ANODE

BATTERY CATHODE

Mixing

Coating

Calendaring

SILICON NANOWIRE ANODE BATTERY ASSEMBLY

Slitting

Stacking

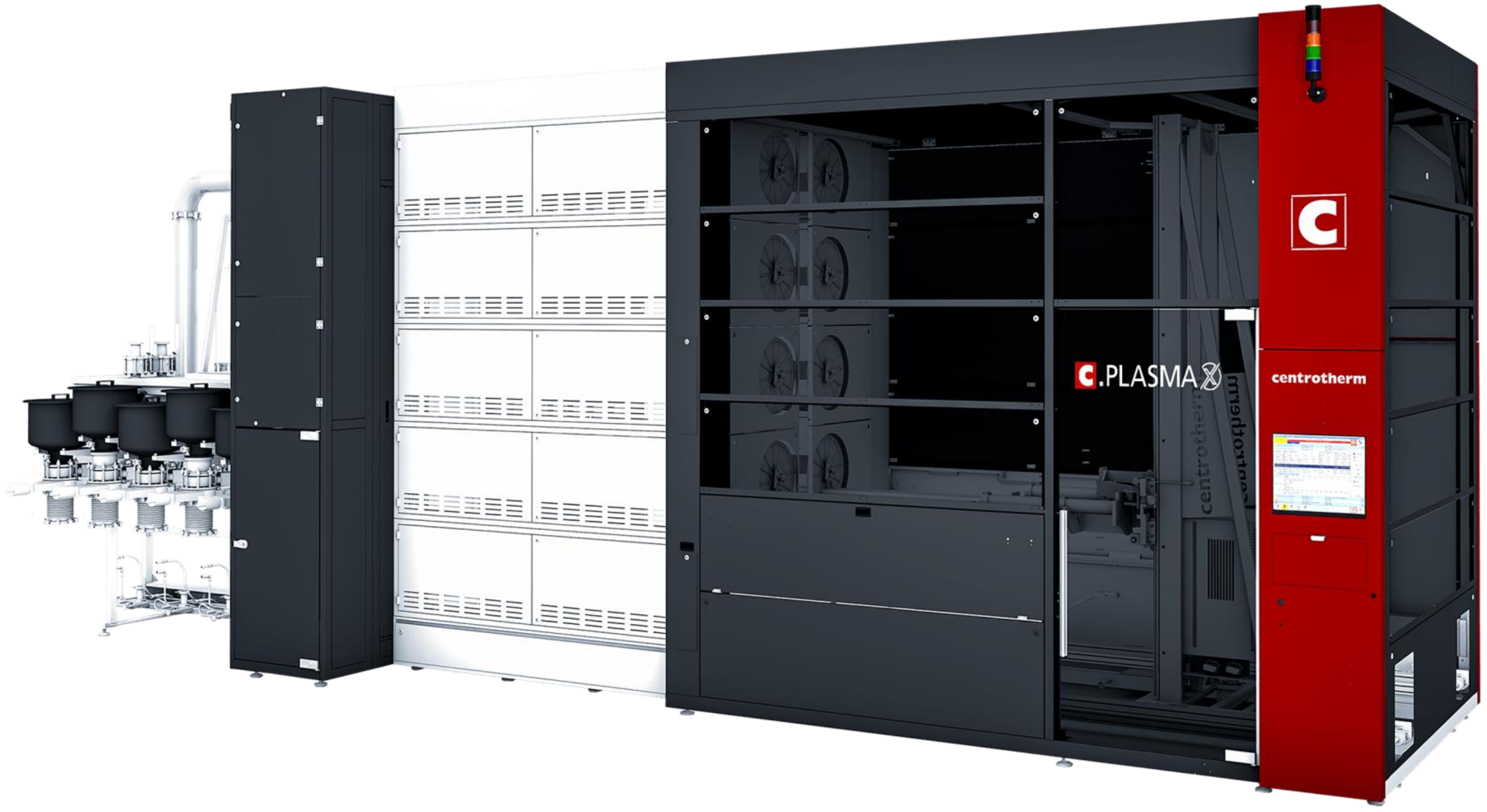
Formation

SILICON NANOWIRE ANODE MANUFACTURING LINE

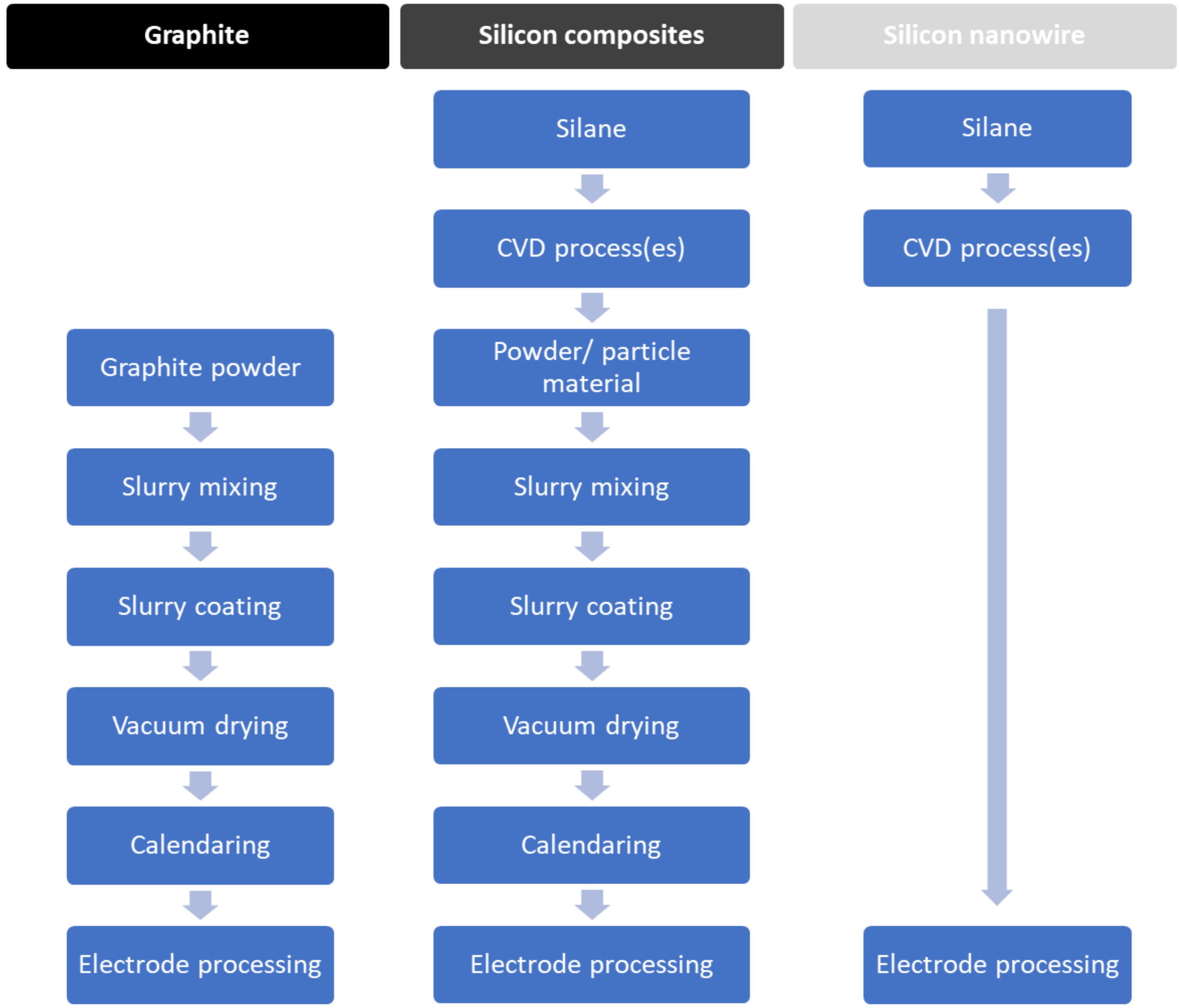
TRADITIONAL BATTERY MANUFACTURING LINE

Equipment Designed for GWh-Scale Production

Foil + Gases = Finished Anode



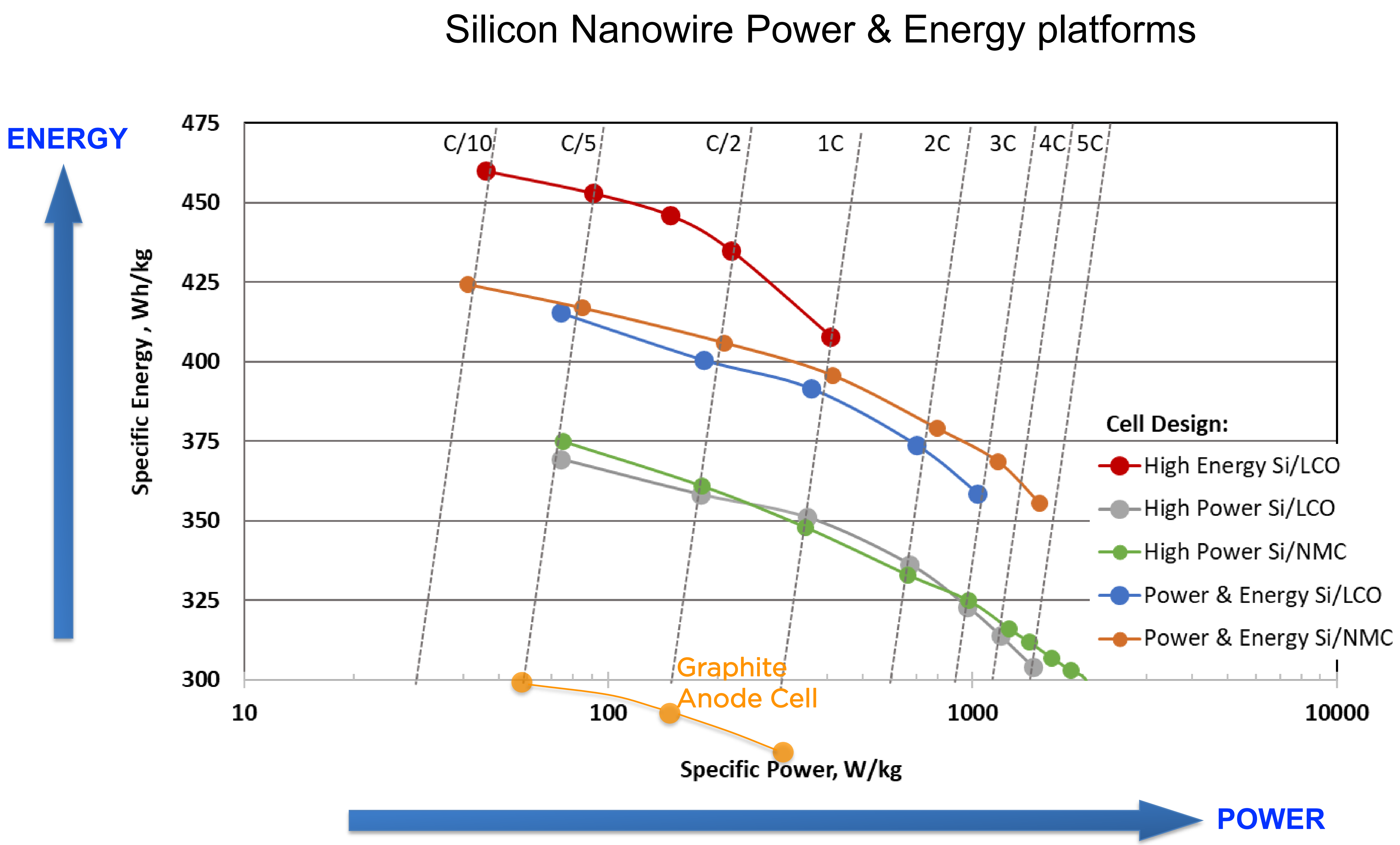
Centrotherm equipment, well-established equipment provider



Simple process steps with high precursor utilization

Products and Applications

Minimal trade off between specific energy and specific



amprius

High Power capability with high energy density and specific energy

Applications	HAPS, portable power, CE	Long Endurance Drones, eVTOL, UAM	High power drones	EV, Electric Flight	High power drones, eVTOL
Dimensions (T x W x H) mm	Si/LCO Platforms			Si/NMC Platforms	
	High Energy 0.5C max rate	Power-Energy 3C max rate	High Power 5C max rate	Power-Energy 4C max rate	High Power 6C max rate
4.5 x 50 x 55	420 Wh/kg 1125 Wh/L	415 Wh/kg 1040 Wh/L	370 Wh/kg 920 Wh/L	410 Wh/kg 950 Wh/L	370 Wh/kg 820 Wh/L
5.4 x 54 x 65	450 Wh/kg 1150 Wh/L	420 Wh/kg 1050 Wh/L		420 Wh/kg 970 Wh/L	
4.5 x 50 x 105	430 Wh/kg 1240 Wh/L				

Operating temperature range: -30°C to 55°C. Cycle life 200-1200 cycles, depending on operating conditions

Electric Flight Applications Enabled by Amprius' Batteries

	Unmanned Aerial Systems (Drones)	High Altitude Pseudo Satellites	Air Transportation
Product			
Application	Recon Drone	Stratospheric Satellite	eVTOL[(1)]
Amprius Product	*Balanced Energy/Power*	*High Energy*	*High Power*
Performance Specification	*1.4 Ah, 390 Wh/kg at C/5*	*5.8 Ah, 450 Wh/kg at C/10*	*15+ Ah, 380+ Wh/kg at C/5 with 6C long pulse*
End User Benefit	**Very long endurance** *and* **increased capacity** *with* **no increase in weight or volume**	*Ultra long sustained flight* **at high altitude with max payload**	*eVTOL with* **extreme-fast charge** *and* **greatly extended service radius**

(1) Actively sampling with OEMs and continuing to pursue joint development agreements.

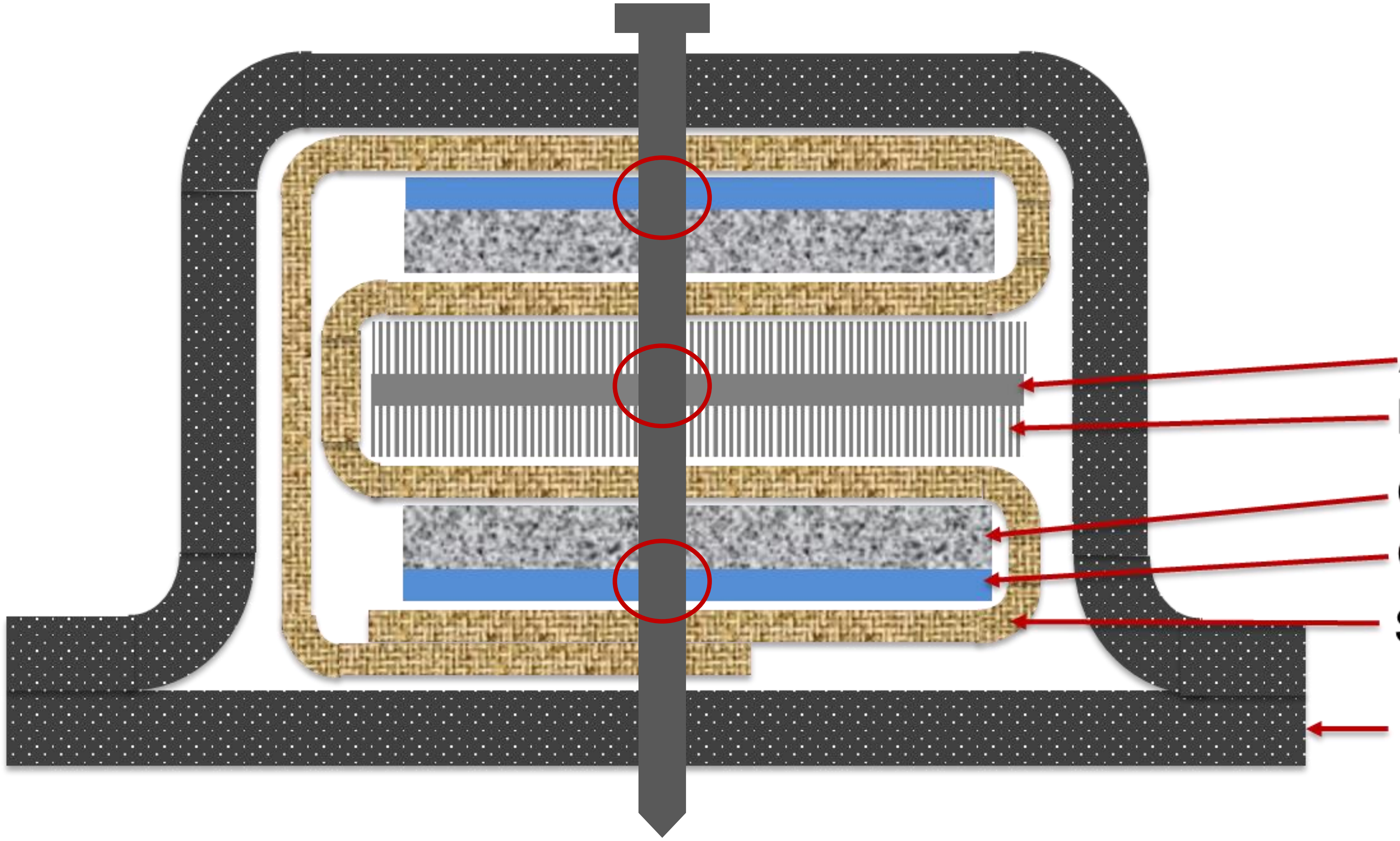
Conformal-Wearable Battery – Full day operation

2X Energy Content

Specification	CWB-150 (Fielded Model)	Amprius
“Flexible” battery		 HAS TO BE SAFE TO NAIL PENETRATION
Energy (Pack)	148 Wh	320 Wh
Weight	2.6 lb	2.6 lb
Dimensions	8.7” x 7.65” x 0.7”	8.7” x 7.65” x 0.7”
Cells specific energy	201 Wh/kg	395 Wh/ kg

UN38.3 certified in 2020, confirmed performance in field test

What can go wrong during nail penetration?



Solutions

- Mitigate thermal runaway effects by reducing temperature and flame generation of the process – Battery integration; adds mass
- Delay or increase the onset thermal run-away temperature – [More] stable chemistries (e.g. LFP, less Ni, less Co); lower energy density
- Break/stop short circuit immediately after penetration – Active cell components (layers, foils, contacts) that interrupt the current flow (e.g. Soteria foils); effective if faster than thermal runaway onset
- Prevent short from occurring or replace it with a high resistance discharge – Gel/polymer electrolyte; effective if the number of layers/electrodes is relatively low

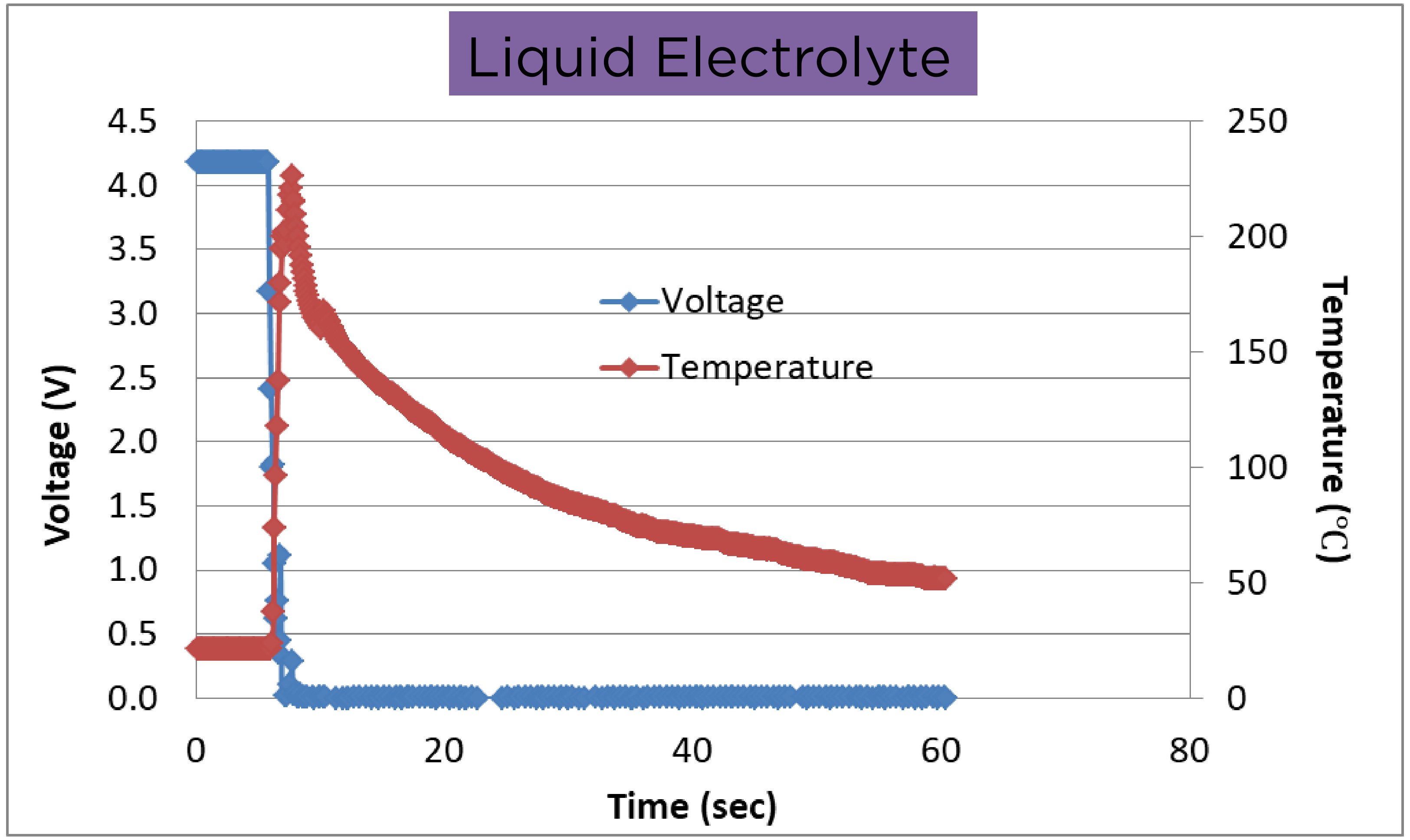
Nail Penetration Test (MIL-PRF-3288A)

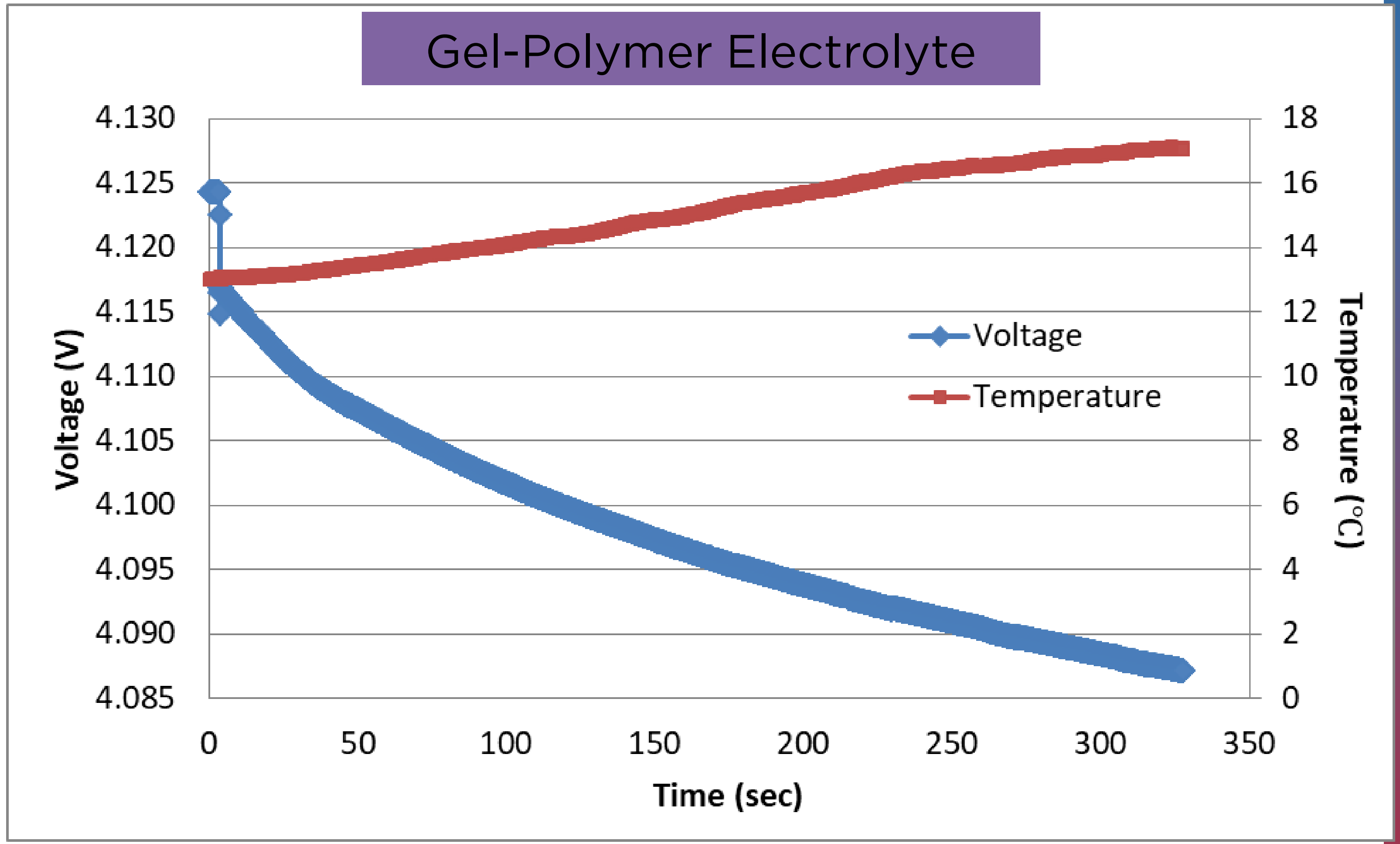
- NMC 2.6 Ah cells (4.25 V, SOC 100%); 390 Wh/kg
  - 0 Days

  - 3 Days

Nail Penetration Test (MIL-PRF-3288A)

- NMC 2.6 Ah cells (4.25 V, SOC 100%); 390 Wh/kg





- Hard short with complete voltage drop in seconds
- Maximum temperature (recorded) ~225°C

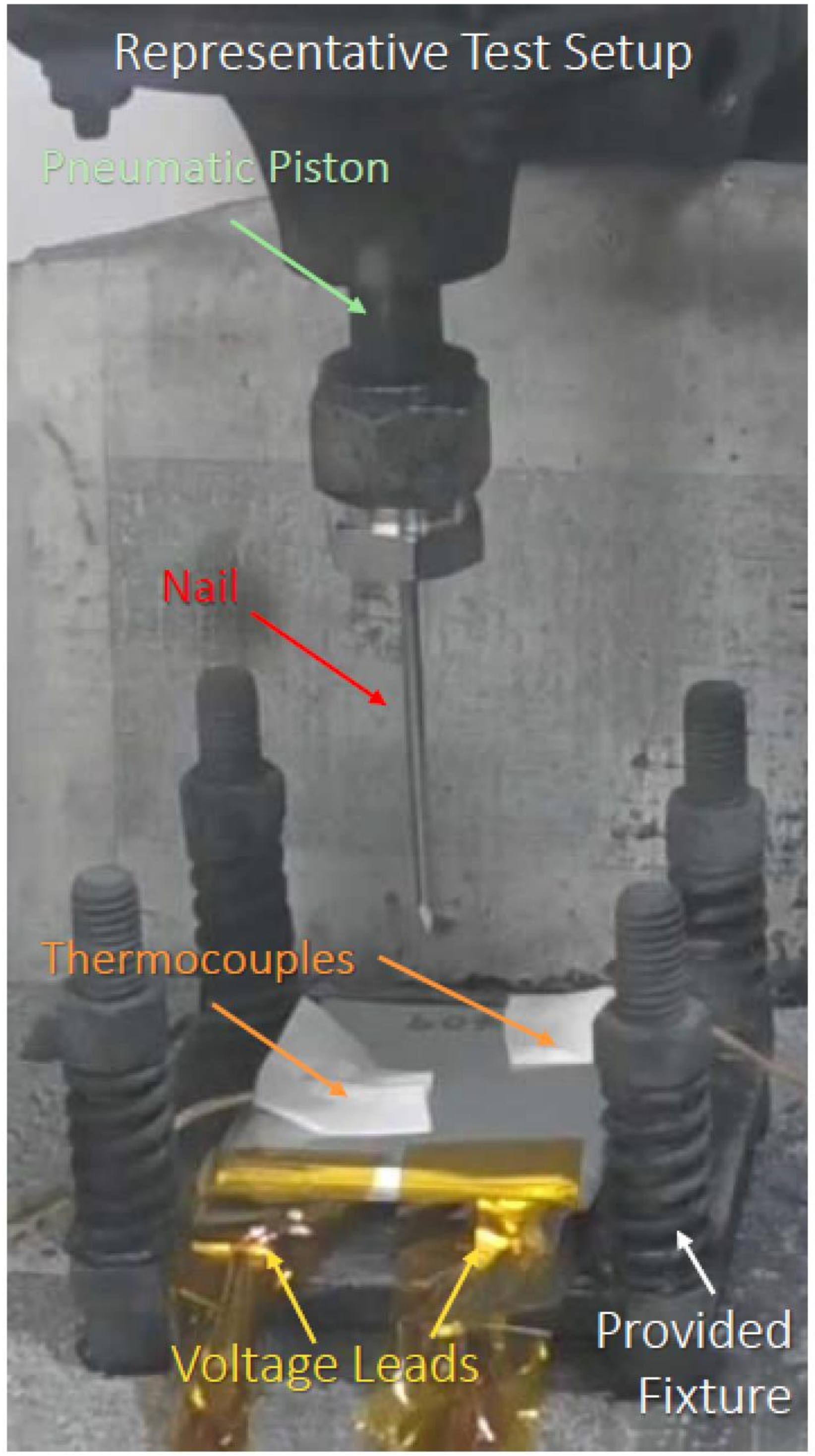
- Weak short results in ~10mV drop and slow discharge
- Minimum temperature increase

Power, energy and cycle life are not negatively impacted by the gel polymer electrolyte

Safety decreases with number of layers and cell energy; additional layers of safety required

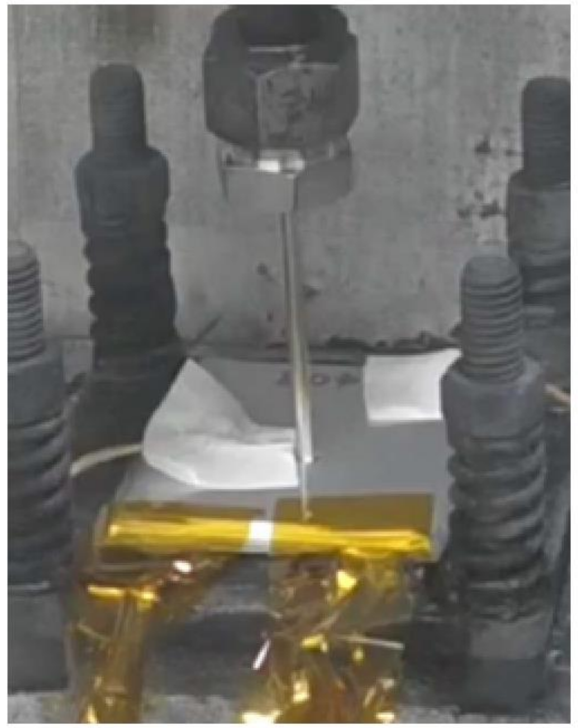
Nail Penetration Test (MIL-PRF-3288A)

- Nail penetration was performed following the guidelines in section 4.7.4.4 of MIL-PRF-32383:
  - A 0.113 inch diameter stainless steel nail was used to penetrate the cell at ±15% of center of the cell. The nail remained within the cell for 24 hours.
  - The nail was driven completely through the cell at a rate of ~1 ft/s using a pneumatic piston.
  - The test was recorded using two video cameras and a thermal camera with greater than 1080p resolution and at least 30 frames per second recording rate. Video recording was performed for a minimum of 10 minutes after the nail penetrated the cell.
- Thermocouples were placed on the top and bottom surfaces of the cell to monitor the cell temperature and in the air above the cell to monitor the ambient temperature.
- The voltage of the cell was monitored during testing.
- The cell was placed on the metal fixture during testing. The fixture elevated the cell from the supporting concrete block and had a hole aligned with the nail enabling the nail to penetrate through the cell without contacting any substrate materials.

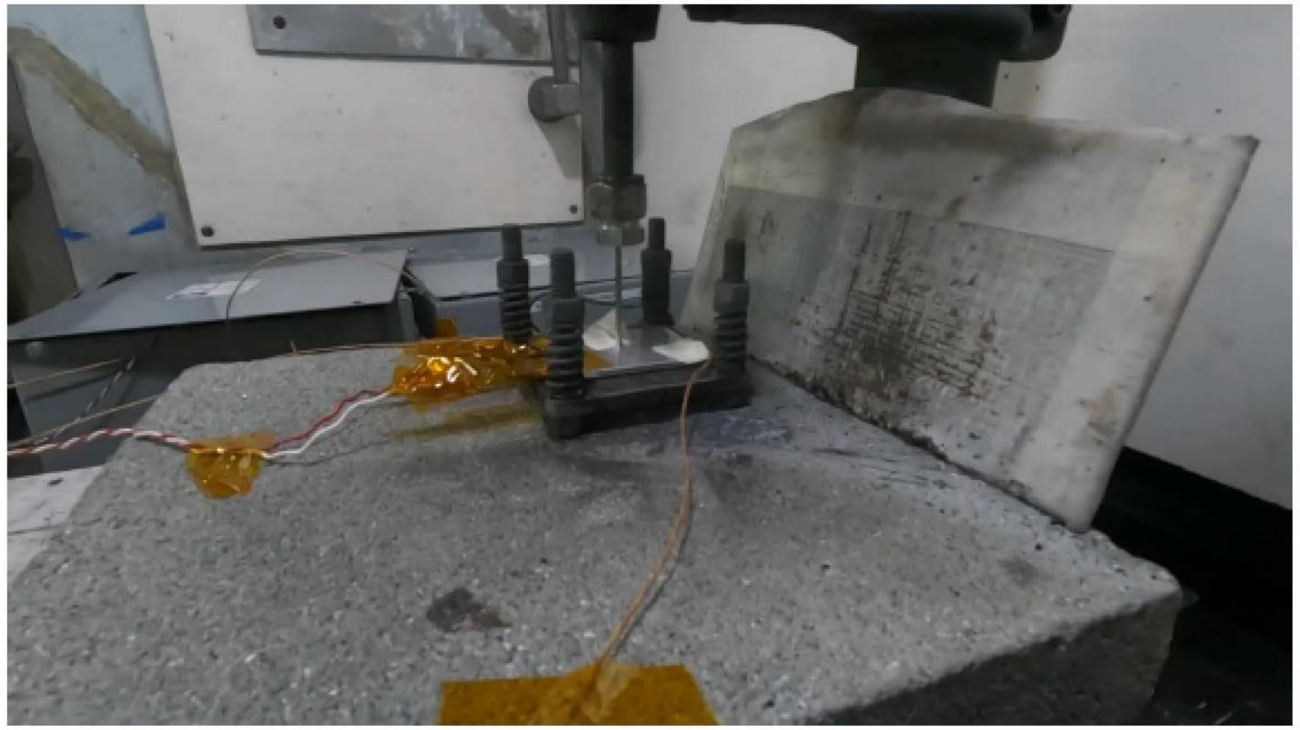


Nail Penetration Test (MIL-PRF-3288A)

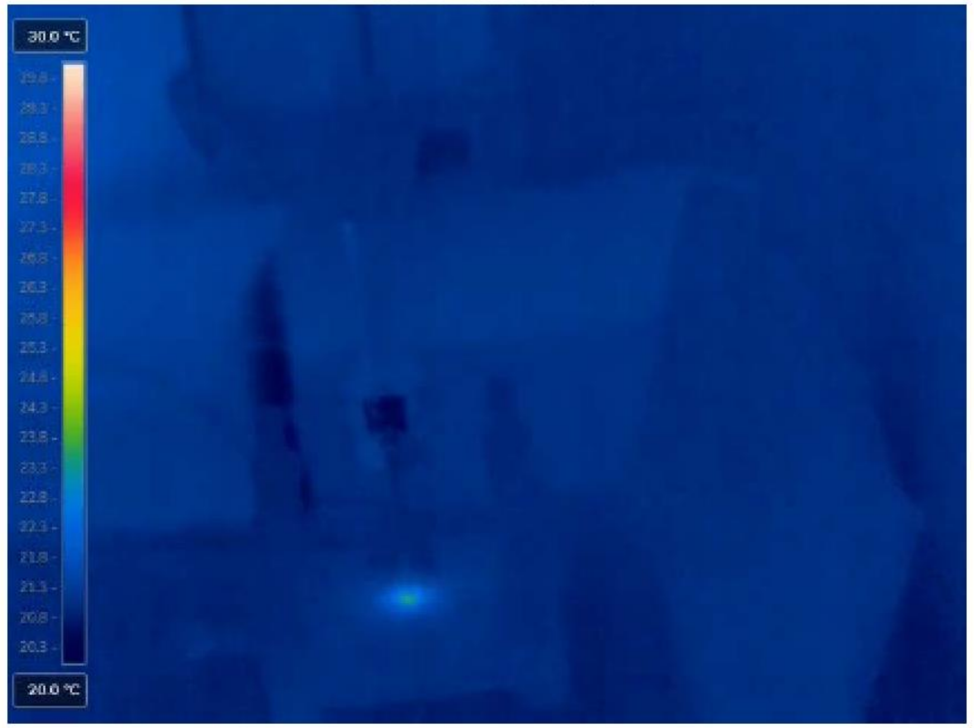
Front View



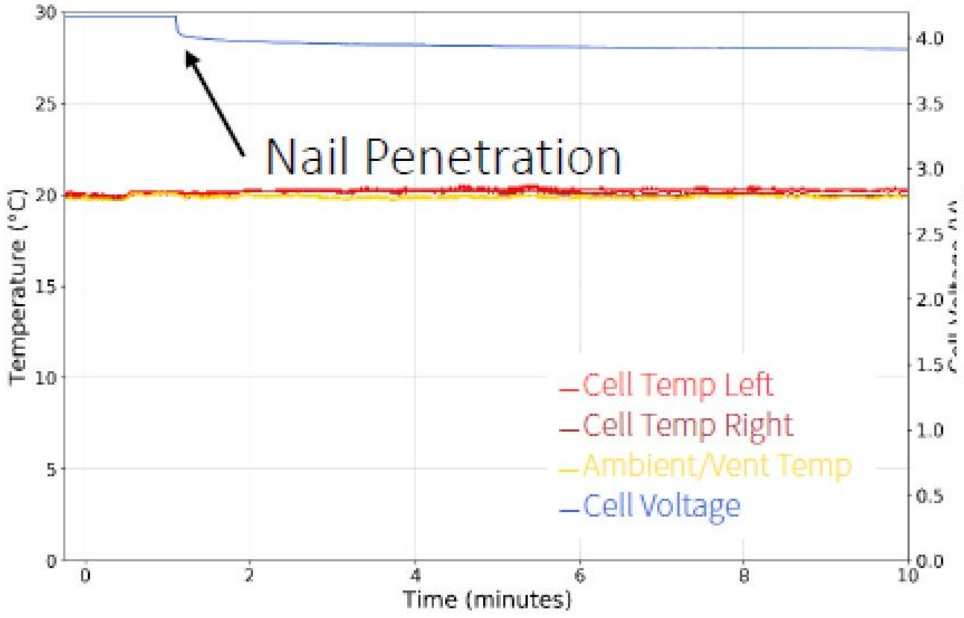
Side View

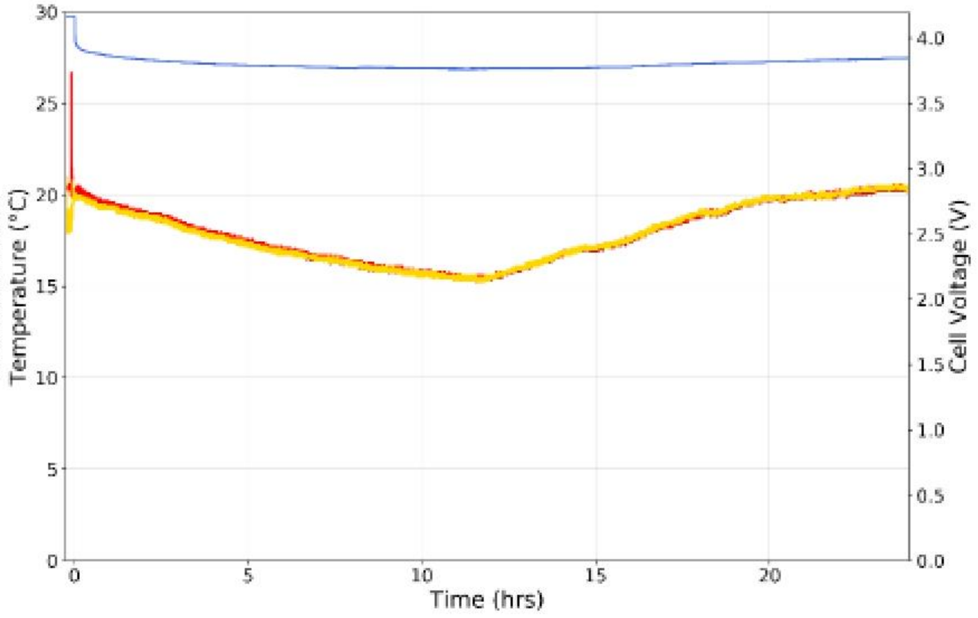


IR Camera



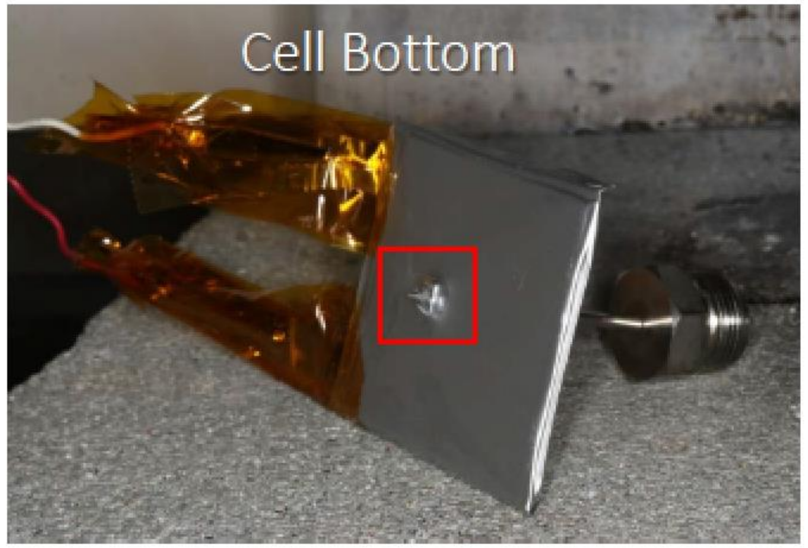
- Cell 33409 did not go into thermal runaway after nail penetration.
- The voltage decreased 266 mV to ~3.900 V upon nail penetration.
- No temperature increase was observed in the 10 minutes immediately after nail penetration.
  - The max temperature recorded over the 24 hour period was 26.7 °C, which occurred when the cell was moved from the test apparatus.





Nail Penetration Test (MIL-PRF-3288A)

Post-Test Cell Remains

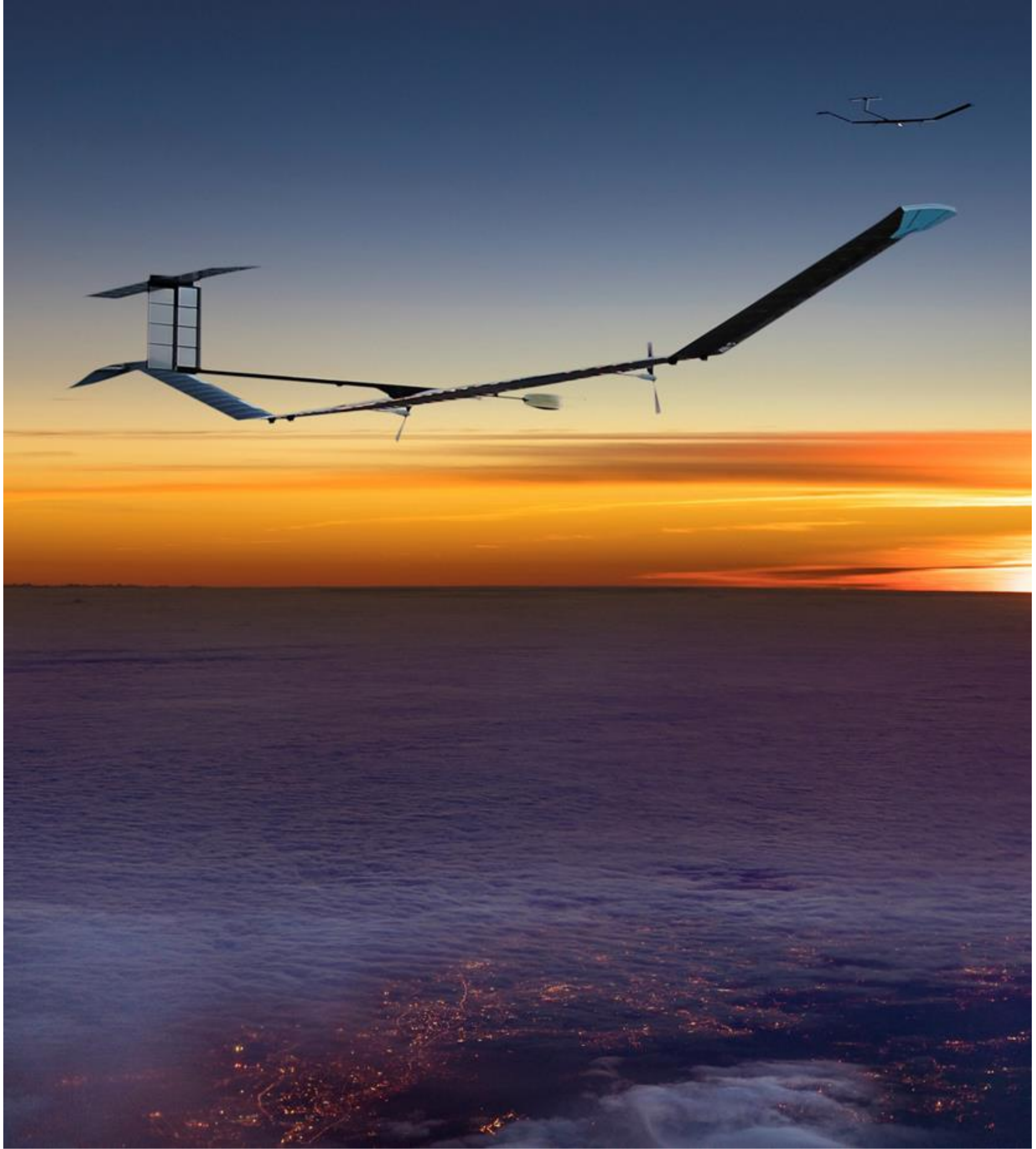


- The nail fully penetrated Cell 33409 and the nail tip can be seen from the bottom of the cell (red arrow).
- No clear signs of thermal damage nor substantial swelling of the cell were observed after nail penetration

SUMMARY/CONCLUSIONS

Silicon solutions to energy problems

- Silicon anodes enable high power capability for charge and discharge
- Energy density levels compatible with electric flight are available today
- New materials and cell design solutions can solve safety concerns for sensitive applications



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