



Soteria Battery Innovation Group

Using Novel Separator and Current Collector Technology to
Prevent Thermal Runaway in Lithium-Ion Batteries

November 19, 2019

Dirk L. Van Hying, Ph.D.

The Soteria Mission: Eliminate Costly and Deadly Lithium-Ion Battery Fires



Tesla Adds Titanium Underbody Shield and Aluminum Deflector Plates to Model S
Elon Musk, Chairman, Product Architect & CEO • March 28, 2014

World

FOLLOW MASHABLE

Crashed Tesla explodes into a massive fireball

Forbes / Autos

DEC 12, 2011 @ 01:32 PM 18,295 VIEWS

Chevy Volt Battery Fires Threaten All Electric Vehicle Makers, Not Just GM

BUSINESS NEWS OCTOBER 11, 2016 / 2:04 AM / A YEAR AGO

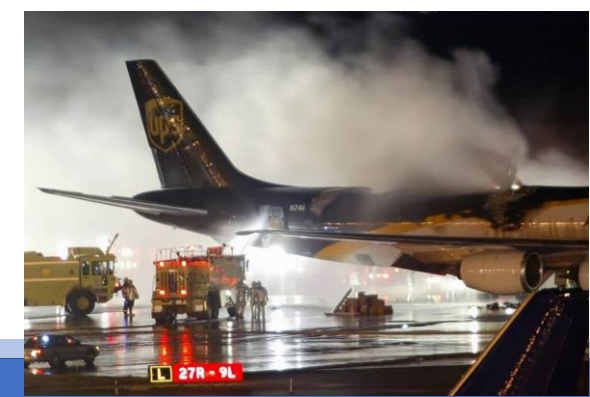
Note 7 fiasco could burn a \$17 billion hole in Samsung accounts

The Dreamliner Debacle Has Already Cost Boeing \$600 Million

REUTERS Tim Hetherington, Alwyn Scott, Reuters
Apr. 18, 2013, 9:37 AM 2,310

Amazon stops selling some hoverboards over safety

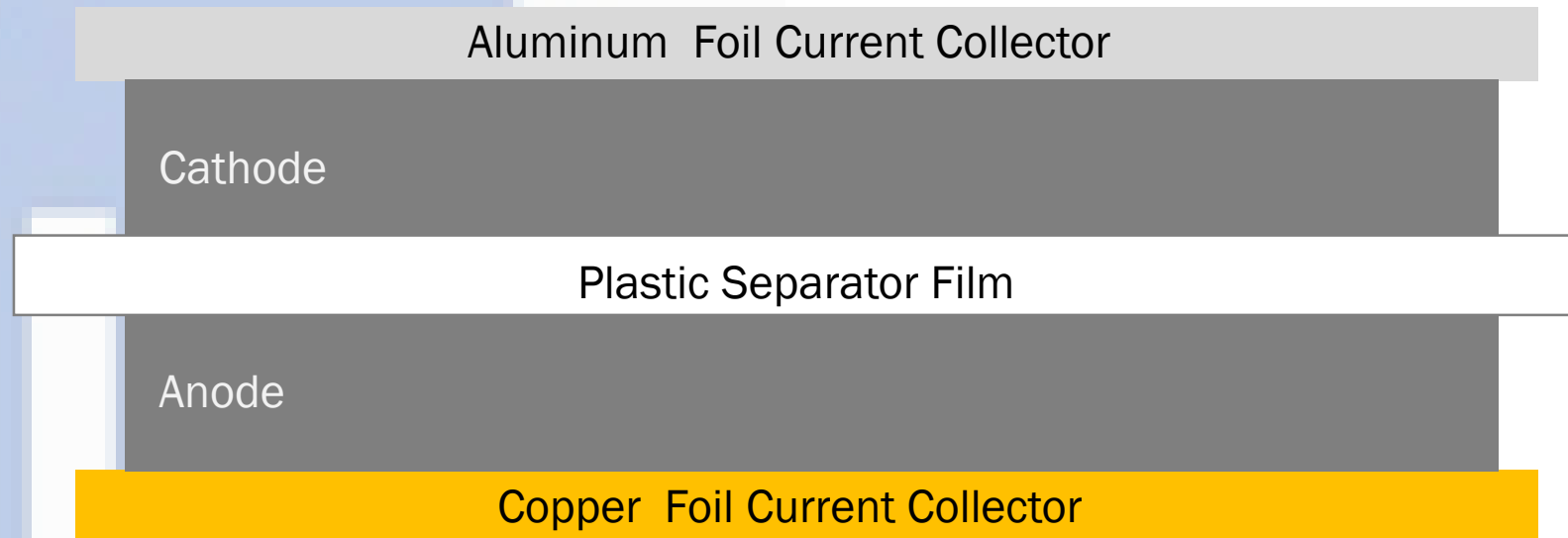
Brett Molina and Elizabeth Weise, USATODAY 6:02 p.m. EST December 14, 2015



The Soteria Technologies

Mechanism of Eliminating Thermal Runaway

Conventional Architecture

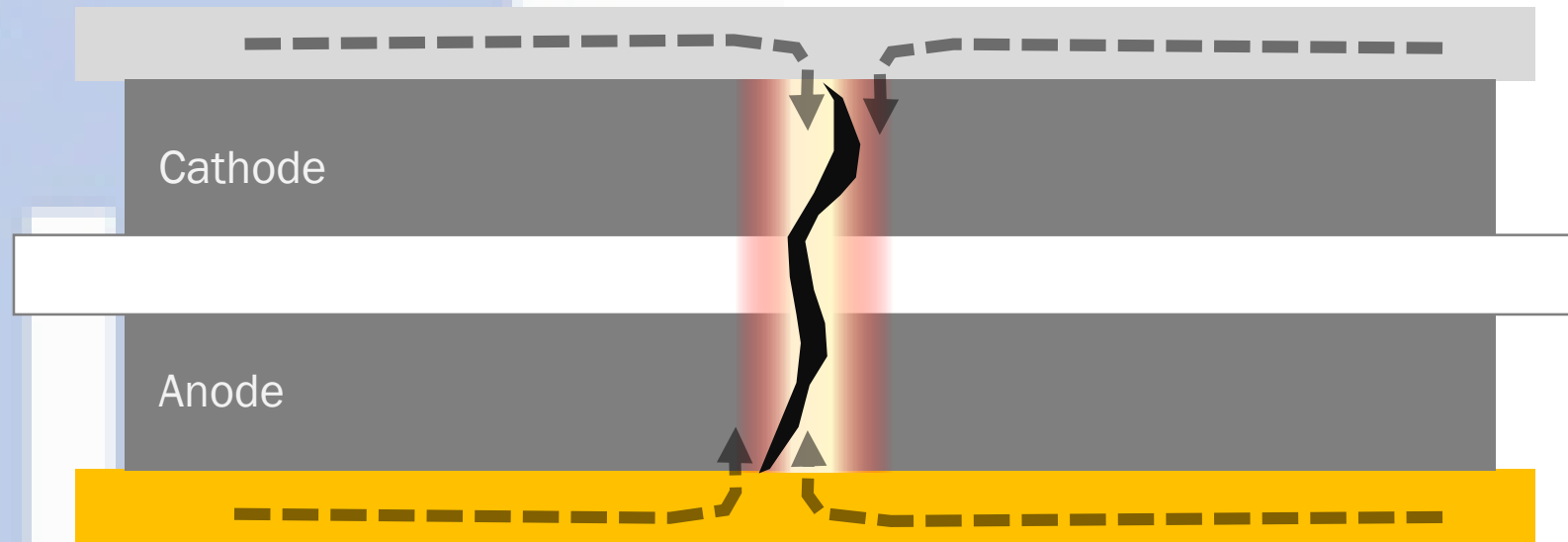


The Soteria Technologies

Mechanism of Eliminating Thermal Runaway

1) A Short Forms

2) Foils Direct Energy Into Short

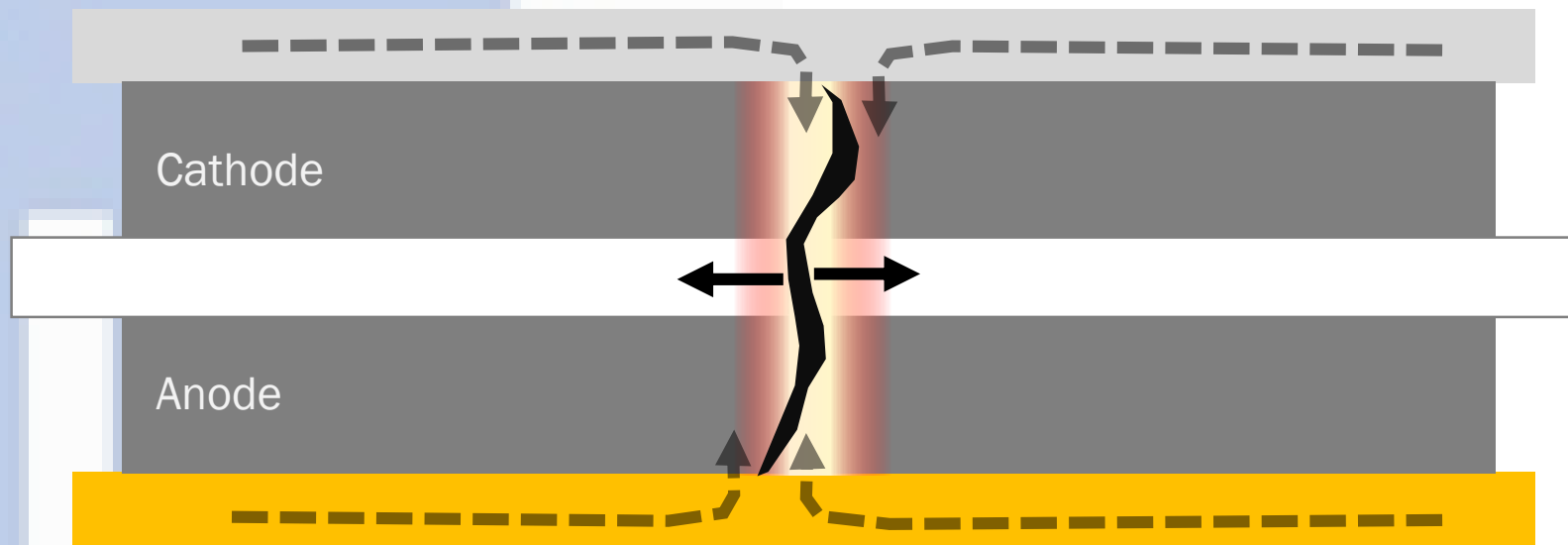


3) High Current Increases Temperature

The Soteria Technologies

Mechanism of Eliminating Thermal Runaway

4) Separator Retreats From Short



5) Current Increases Into Short

6) Thermal Runaway / Fire

The Soteria Technologies

Mechanism of Eliminating Thermal Runaway

Soteria Architecture Part 1: Nonwoven Separator

Aluminum Foil Current Collector

Cathode

Nonwoven Separator

Anode

Copper Foil Current Collector

1) PET

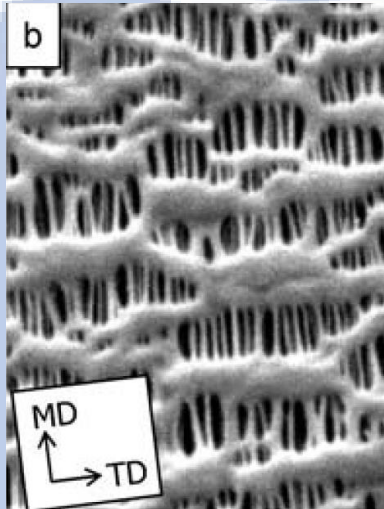
2) Lyocell

3) Aramid

Dreamweaver Separator Material Performance

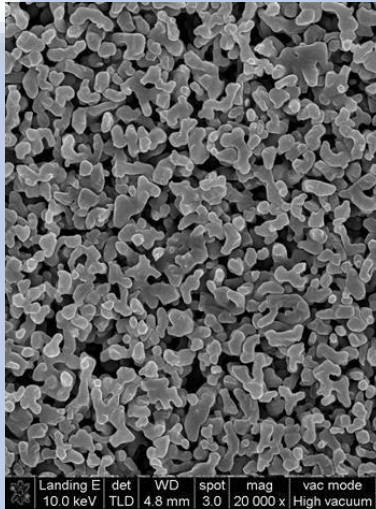
1st, 2nd and 3rd Generation Separators

1st Generation
Biaxially Stretched
Polyolefin



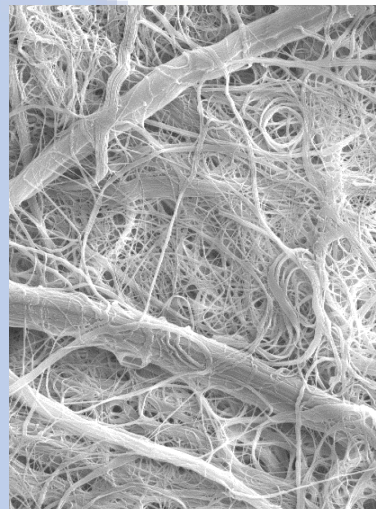
Shrink @ 130C

2nd Generation
Ceramic Coating
Added



Shrink @ 175C

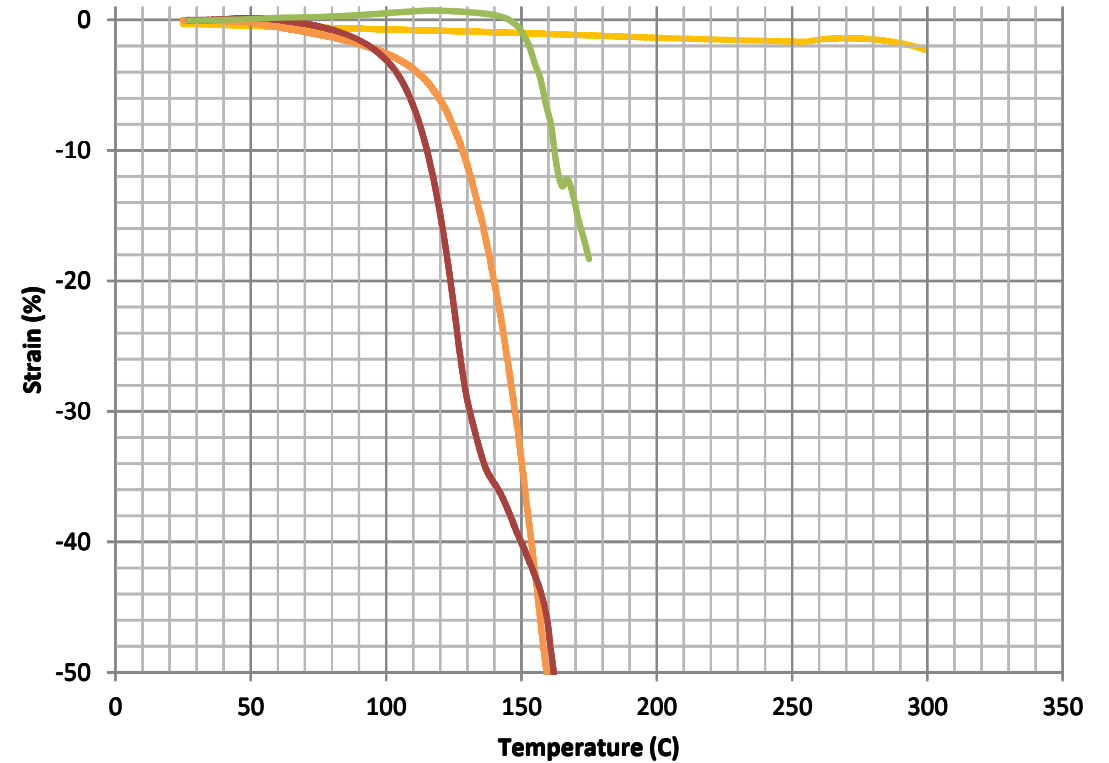
3rd Generation
Dreamweaver
Nonwoven



No Shrink To 300C

- No unstable polymer component
- High temperature materials incorporated in homogenous composite
- Often stable to 500 C

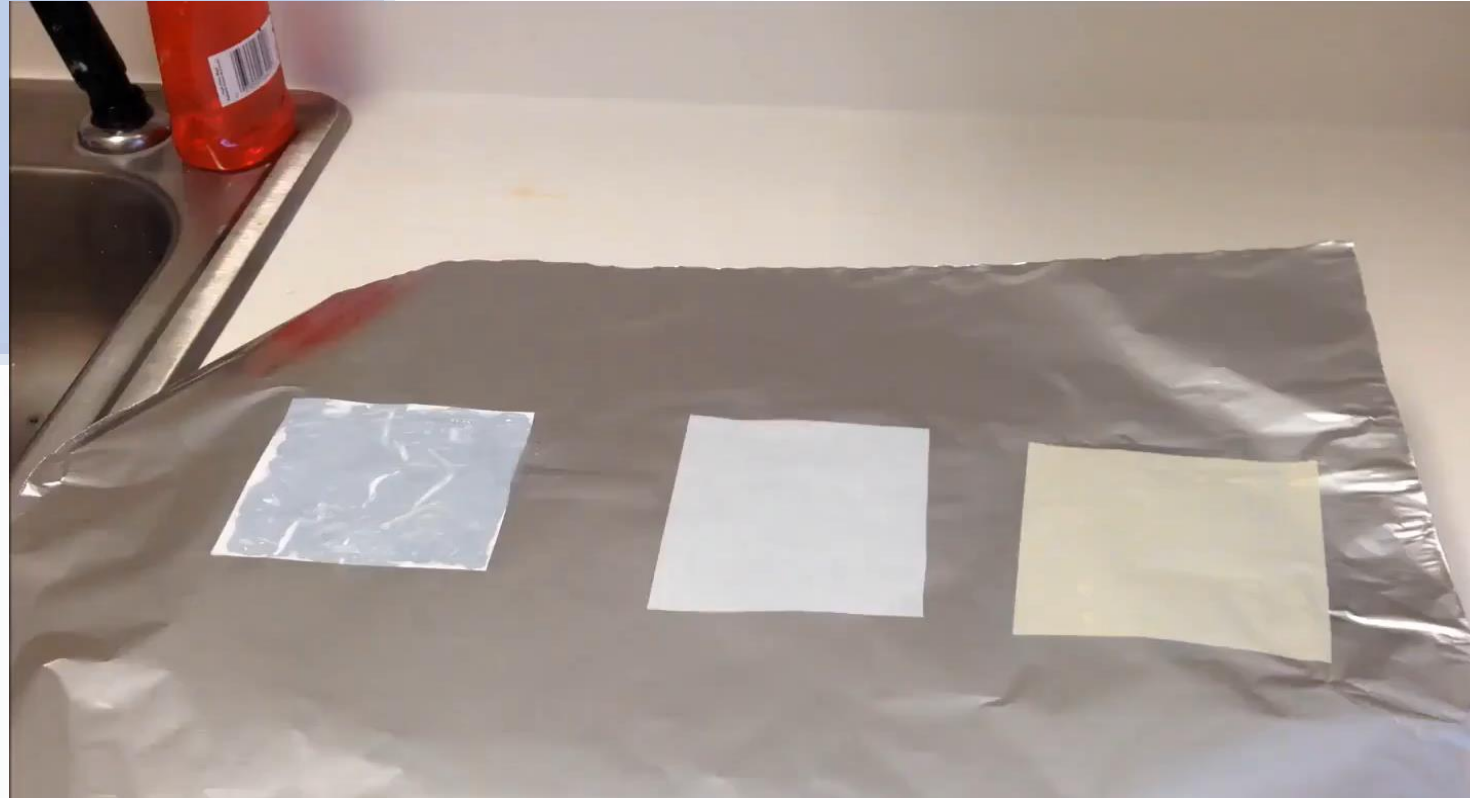
Thermo Mechanical Analysis*



*Measurement of shrinkage as a function of temperature

Dreamweaver Separator Material Performance

Flammability With Electrolyte



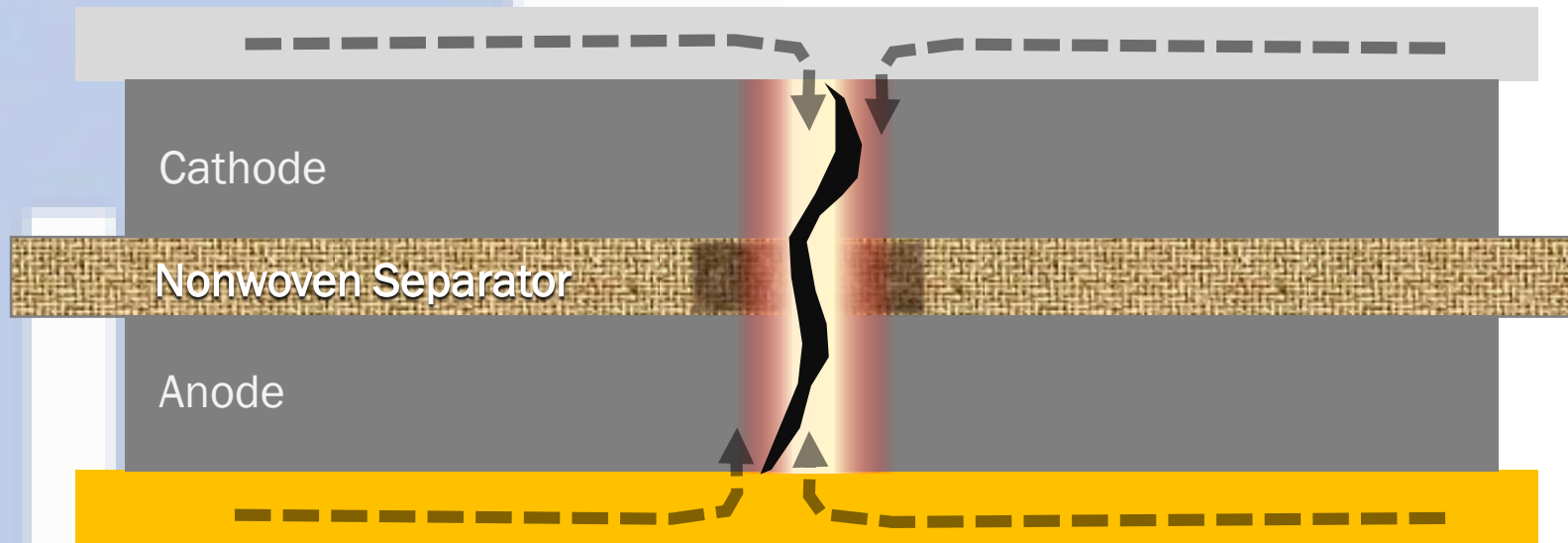
WATCH THE VIDEO

<https://youtu.be/j9XWJgTIT1w>

The Soteria Technologies

Mechanism of Eliminating Thermal Runaway

Soteria Architecture Part 1: Nonwoven Separator

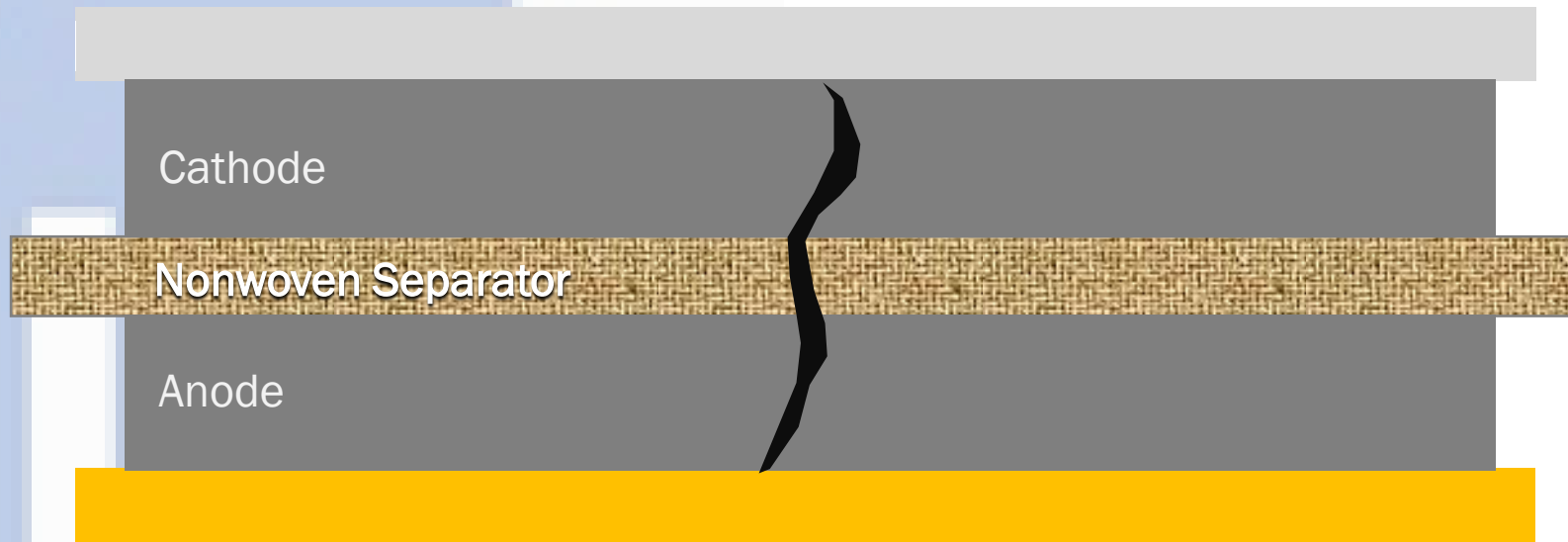


Dreamweaver Separator will char but not retreat from a short.

The Soteria Technologies

Mechanism of Eliminating Thermal Runaway

Soteria Architecture Part 2: Metallized Film Current Collector

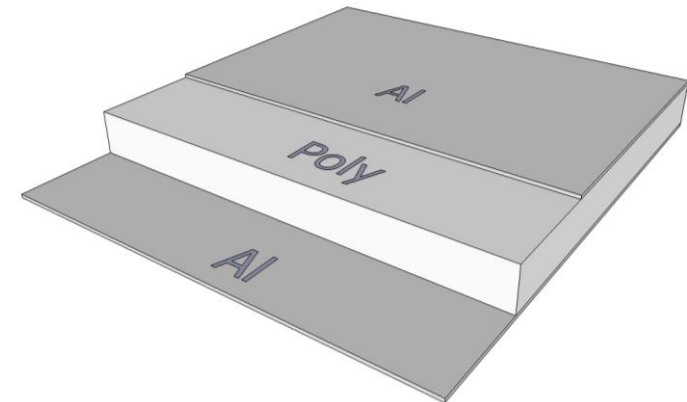


Soteria Metallized Current Collector

Prototype Properties

	Copper Foil	Soteria Copper Film	Aluminum Foil	Soteria Aluminum Film
Thickness	10um	11um	15um	11um
Metal Thickness	10um	500nm per side	15um	500nm per side
Weight	90 g/m ²	21.5 g/m ²	43 g/m ²	16.4 g/m ²
Tensile	400 N/mm ²	120N/mm ²	150 N/mm ²	126 N/mm ²

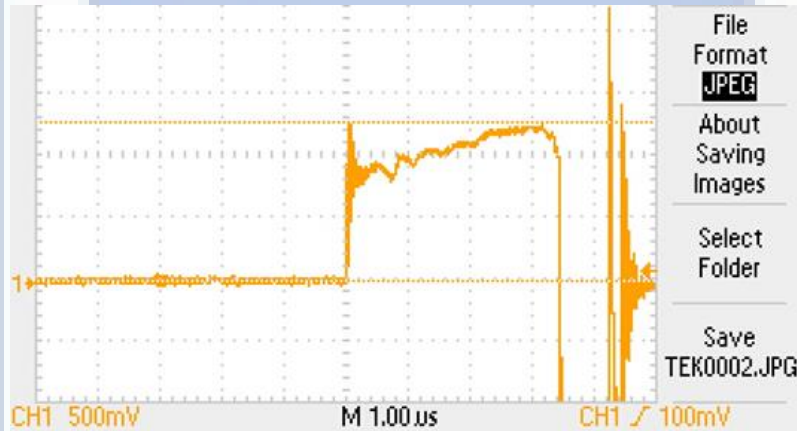
- Initial base film: 10 um, 13.7 g/m², PET
- Developing metallized films down to 4.5um
- Substrate and metallization thickness engineerable



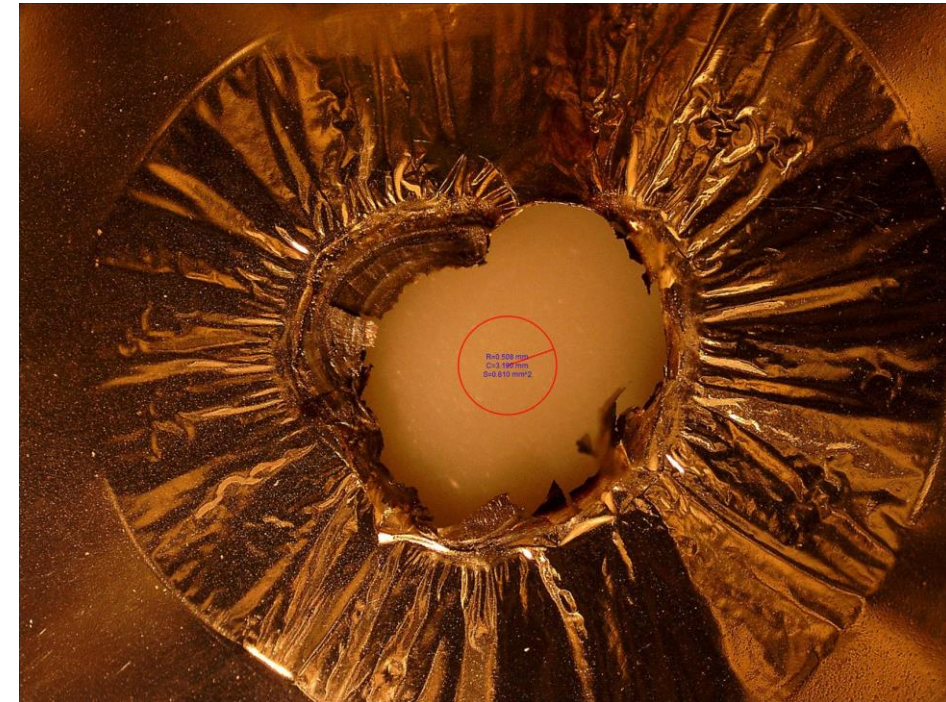
Soteria Current Collector Material Performance

Response Dynamics During a Short

Property	Aluminum	Copper
Time before broken	5 μ s	28 μ s
Joules generated	4×10^{-6} J	4×10^{-5} J



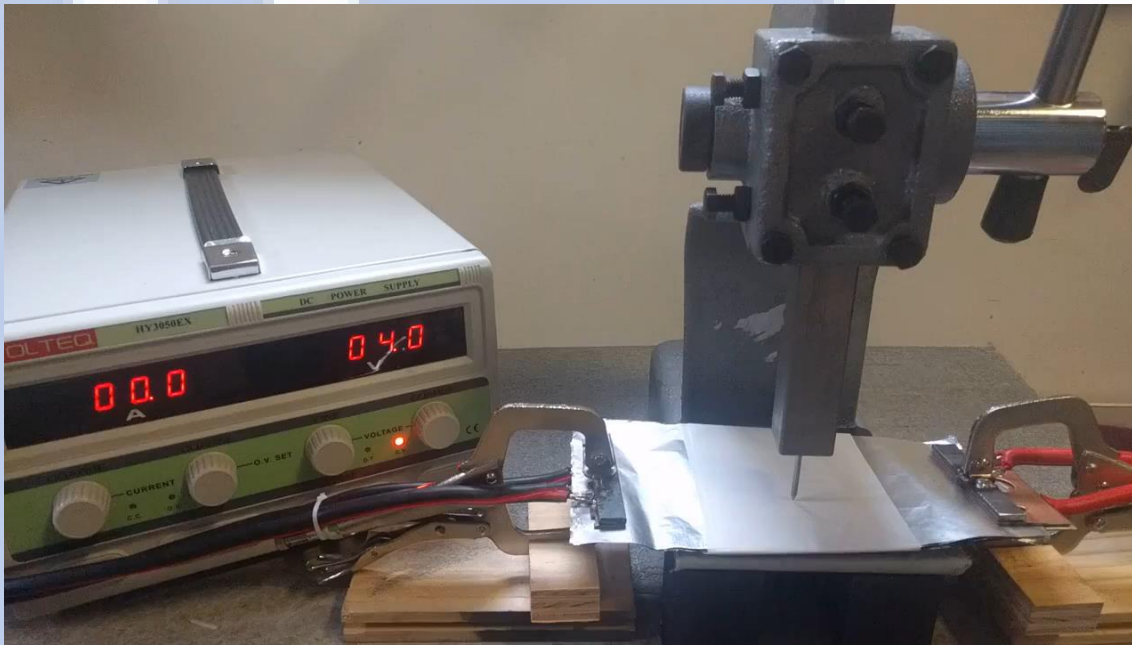
Once a short is created, the time before it is broken is so short that almost no energy is generated.



Soteria Current Collector Material Performance

Dry Stack Nail Penetration – Voltage and Current

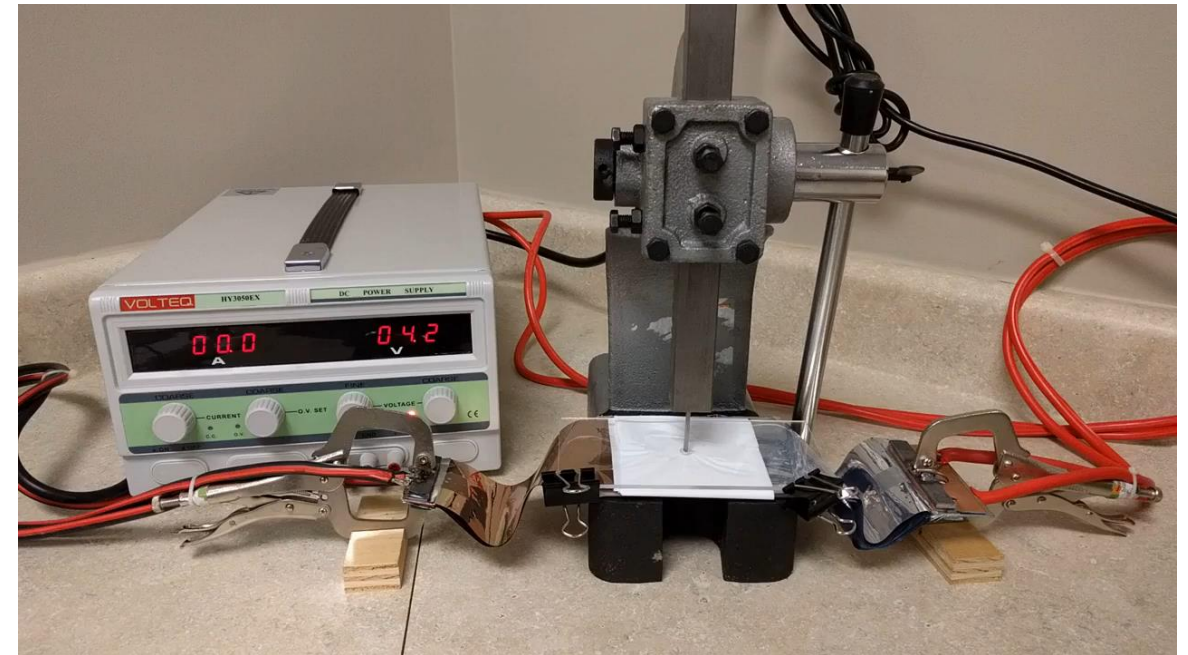
Conventional Material



Nail allows current to flow between layers

$$V = 0.5 \text{ V}, I = 50 \text{ A}$$

Soteria Architecture



Metallized current collector **does not allow current to flow** between layers

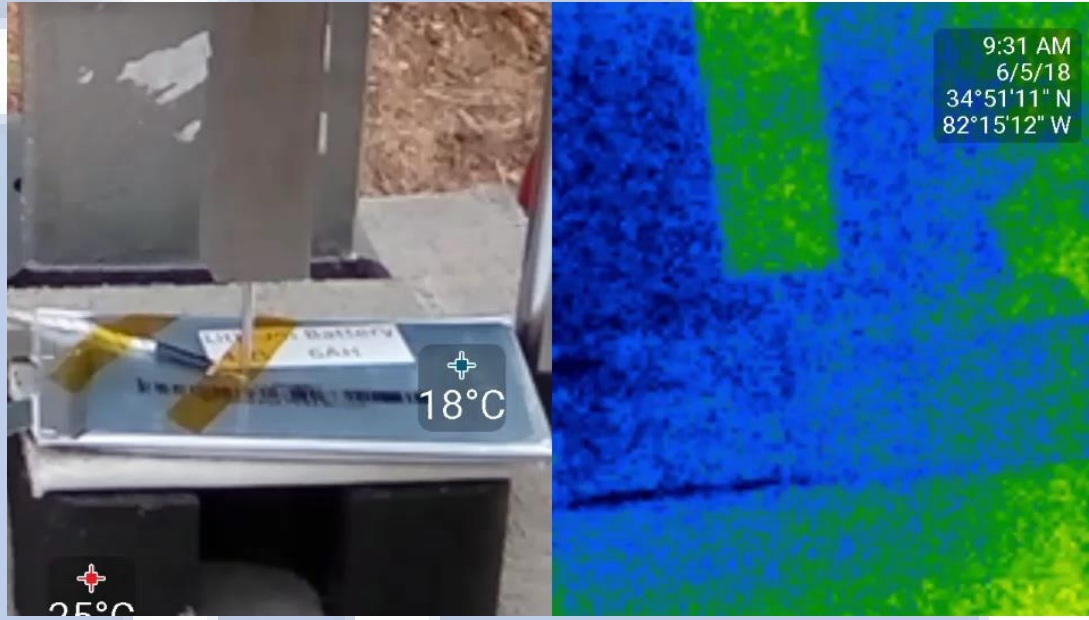
$$V = 4.0 \text{ V}, I = 0 \text{ A}$$

Watch Video: <https://youtu.be/4uKyOb0PxaE>

Watch Video: <https://youtu.be/Bdt2MsWdlEtE>

Soteria Cell-Level Performance #1 (3 Ah Pouch)

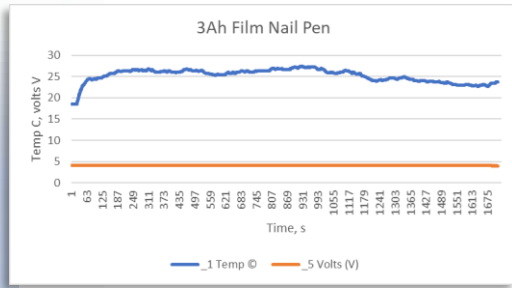
Nail Penetration Response



Conventional Materials



Soteria Materials

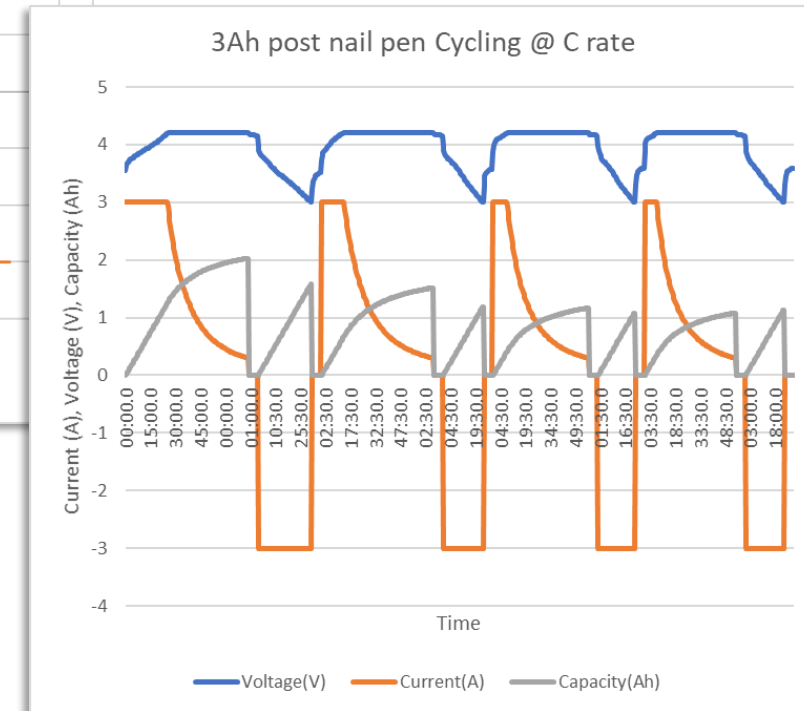
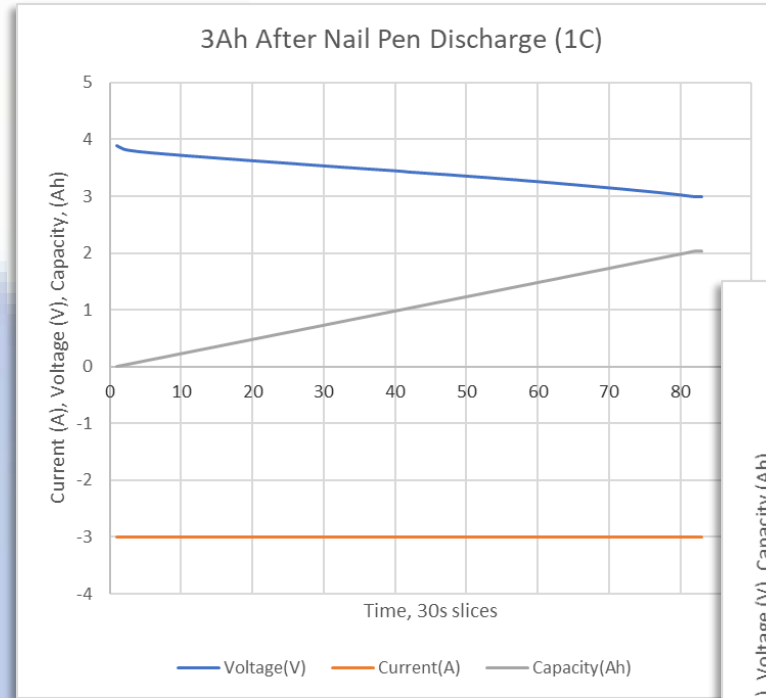


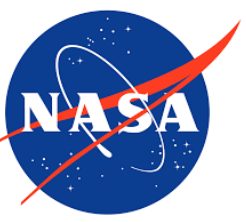
- Maximum surface temp near penetration point = 26C
- No detected voltage perturbation

Soteria Cell-Level Performance #1 (3 Ah Pouch)

Post-Nail Penetration Cell Cycling

- Nail removed, cell discharged at C rate (3A)
- Total capacity remaining: 2025mAh
- Achieved 2Ah/3Ah - ~66% remaining capacity at 1C.
- After capacity check discharge, cell cycled at C rate (3A)
- Capacity decreased on each subsequent charge/discharge from 2028mAh to 1125mAh





Soteria Cell-Level Performance #2(18650)

NASA Full-Scale Safety Validation



2.1 Ah Cell – 100 % SOC (4.2 V)
Standard materials
Without ISC device



2.1 Ah Cell – 100 % SOC (4.2 V)
Al coated polymer current collector
Without ISC device

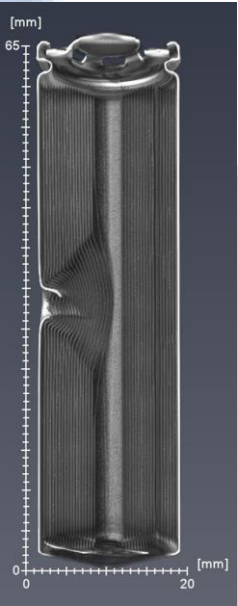
Watch Video: <https://youtu.be/LhlaHTKIgqc>

Watch Video: <https://youtu.be/uIAPoho44tM>

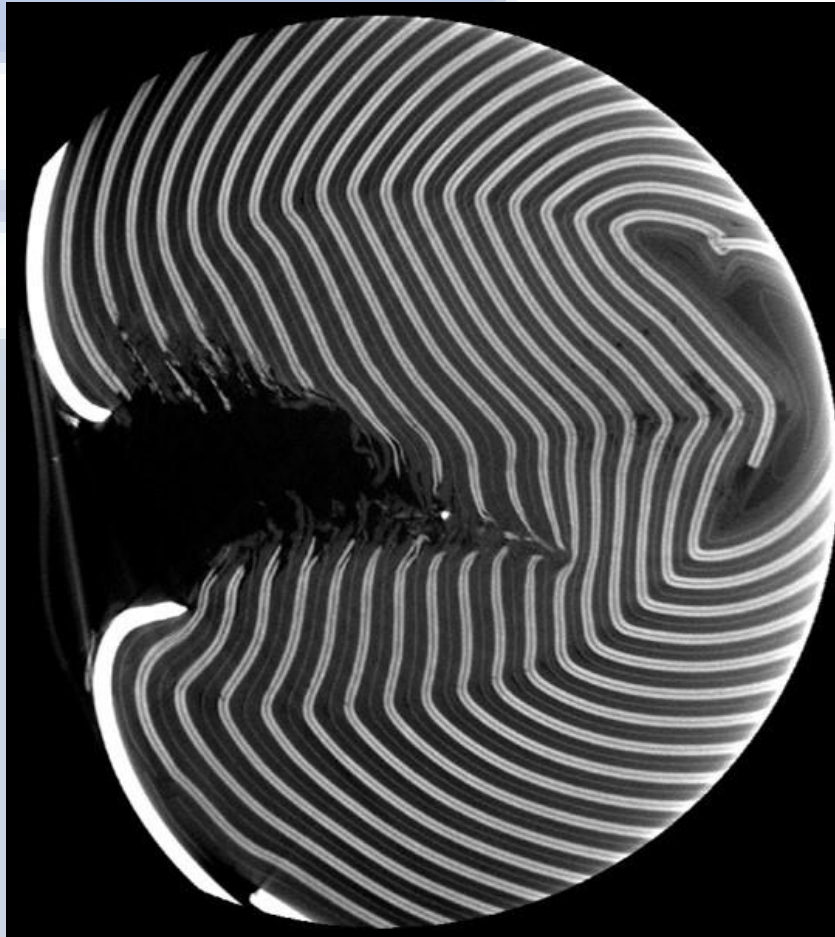


Soteria Cell-Level Performance #2 (18650)

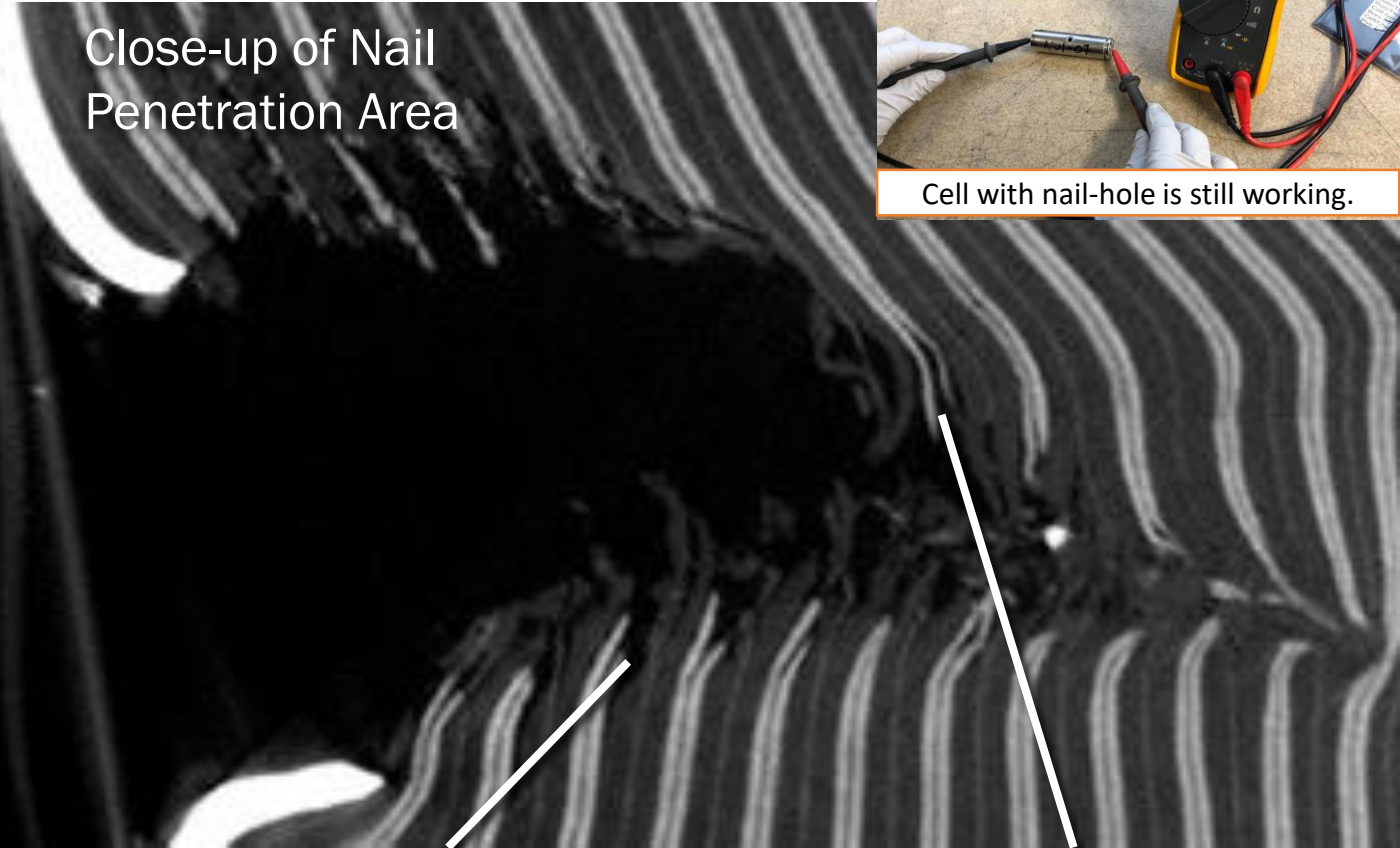
NASA Full-Scale Safety Validation



18650 cell with nail entry hole



High resolution CT scan of nail entry area. Light grey is cathode with Al Soteria films; dark grey is anode with Cu Soteria films.



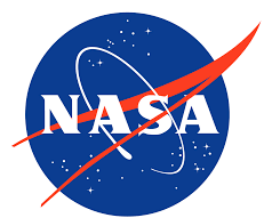
Close-up of Nail Penetration Area

Light cathode layers have retreated below grey anode, preventing short through nail.



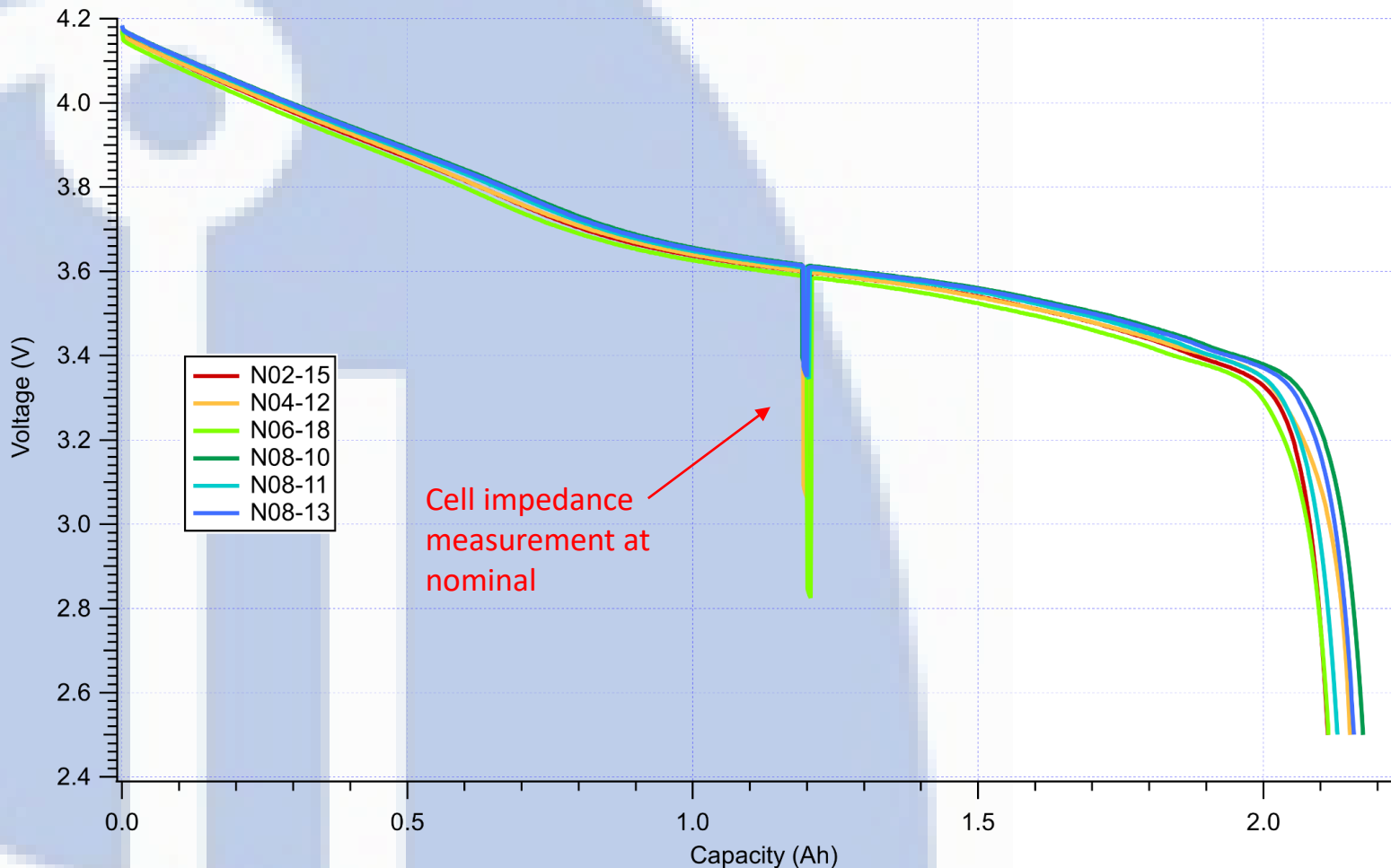
Cell with nail-hole is still working.

Open "alligator jaws" show residual electrode after collector retreated.



Soteria Cell-Level Performance #2(18650)

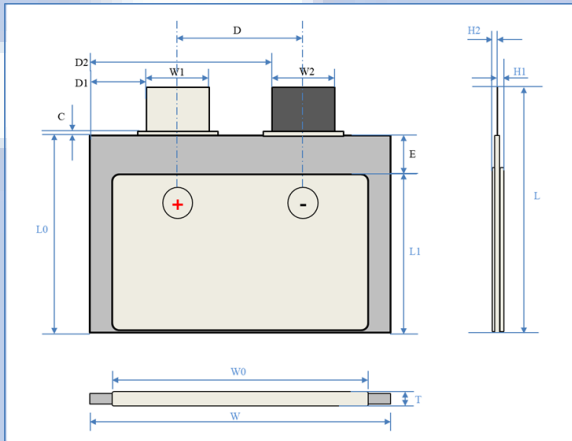
Cell Discharge Curves



- Data is combination of cells with:
 - conventional foils
 - copper Soteria films only
 - aluminum Soteria foils only
 - Soteria copper and aluminum foils
- Negligible difference in discharge curves
- Data is at low C discharge rates
- Higher C rates may require manipulating:
 - Metal thickness
 - Electrode layer thickness
 - # of layers

Soteria Cell-Level Performance #3 (5 Ah Pouch)

Svolt Producing NMC 811/Graphite (~250Wh/kg) cells for distribution



Cell Specifications

Model 6.0*120*76 (mm)

Rated Capacity 5.0 Ah

Minimal Capacity 5.0Ah @25°C, 0.33C, 2.8~4.2V

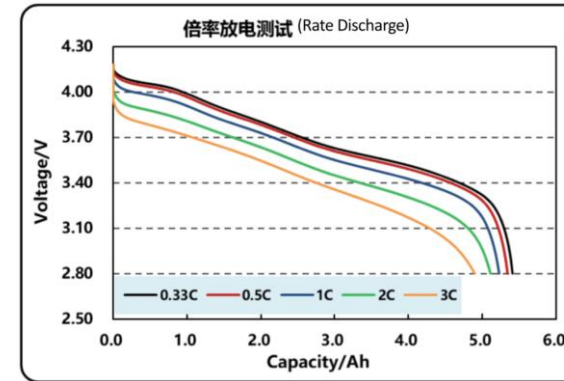
Rated Voltage 3.65V @0.33C

Cathode NMC811

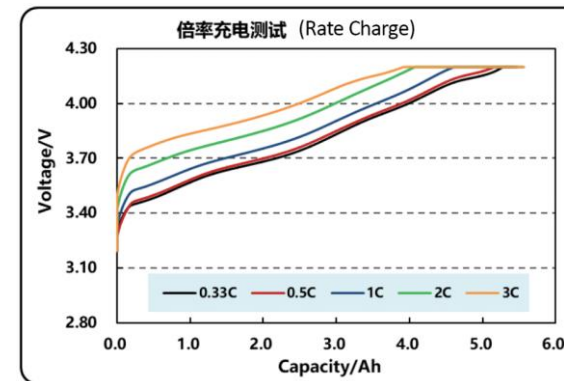
Anode Graphite

Weight 86g

A) Cell Discharge Data

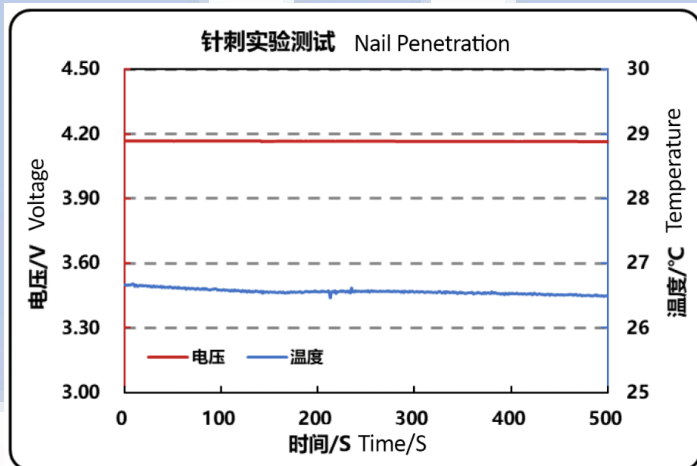


B) Cell Charge Data



*Charge and discharge performance within 2% of control cells – data available

C) Nail Penetration Performance



- Nail penetration test resulted in no smoke, no flame, weight loss <5g
- EUCAR Safety Level 1 (nail penetration)

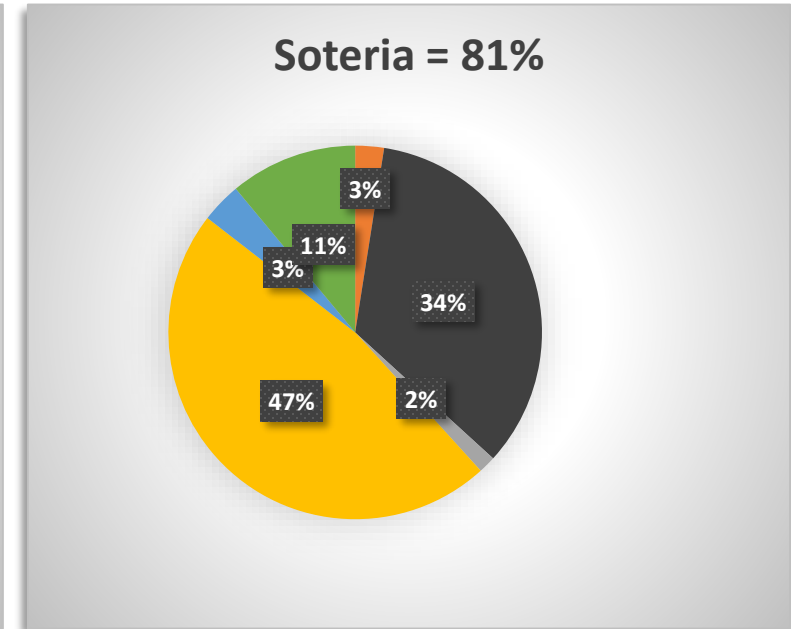
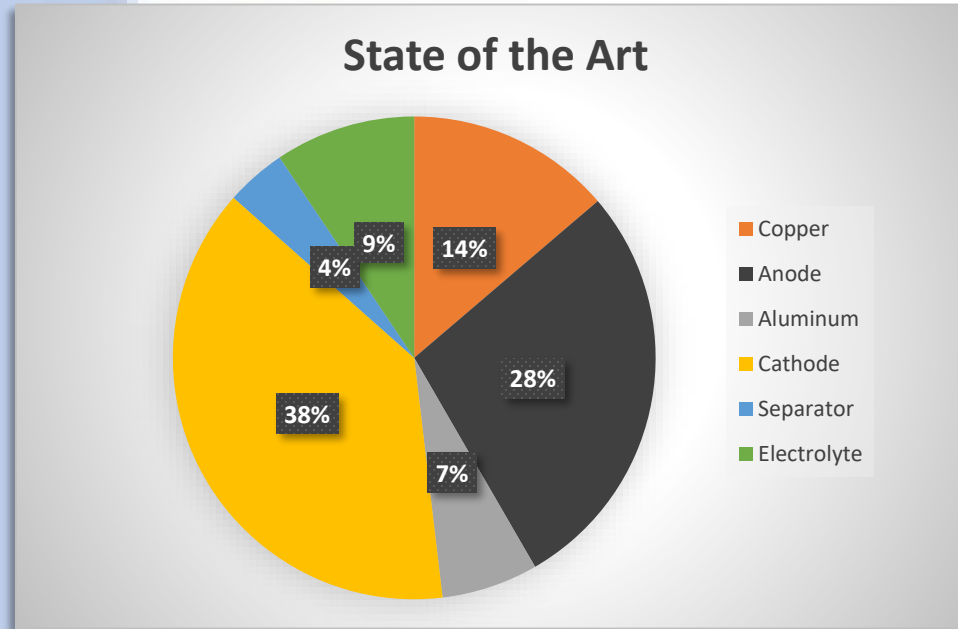
Current / In-Process / Planned Cell Builds

Pushing the safe boundaries of energy density – capacity – charge/discharge

	Application	Form Factor	Cathode	Anode	Energy Density	Safety Components
High Energy Density	Distribution / Validation	5Ah Pouch	NMC 811	Graphite	240 Wh/kg	Aluminum CC
High Capacity	Distribution / Validation	25Ah Pouch	NMC 523	Graphite	150 Wh/kg	Nonwoven Separator
High Discharge Pulse	Military Vehicle Battery	46 Ah 6T	NMC 622	LFP/LTO	135 Wh/kg	Aluminum and Copper CC
Ultra-High Energy Density	Military Wearable Battery	3Ah pouch or 18650	NMC 811	Silicon	300+ Wh/kg	Aluminum and Copper CC, Separator, Others?
High Energy Density Cylindrical	Distribution / Validation	18650	NMC 622 / NMC 811	Graphite	240+ Wh/kg	Aluminum and Copper CC

Effect of Soteria Materials on Weight

Samsung Galaxy Note 7 Comparison



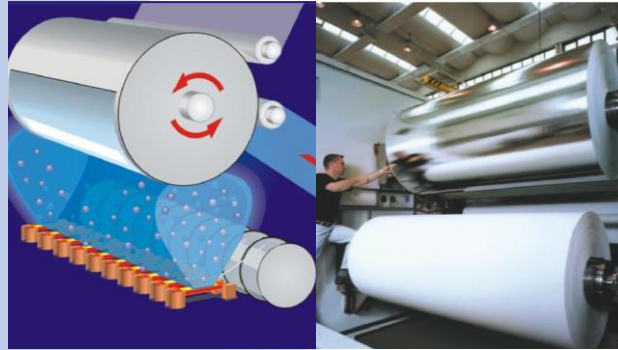
Soteria materials can reduce copper/aluminum/separator from 25% of the weight to 8%.

Effect of Soteria Materials on Process

Minimal Change in Equipment or Process

Material Production

- Current Collector
- Vacuum deposition
- Similar to food pkg
- Separator



Refining



Papermaking



Calendering

Both materials made on existing robust manufacturing processes adopted from other industries.

Battery Production

- Coating
- Stacking and Winding



Automatic Stacking Equipment



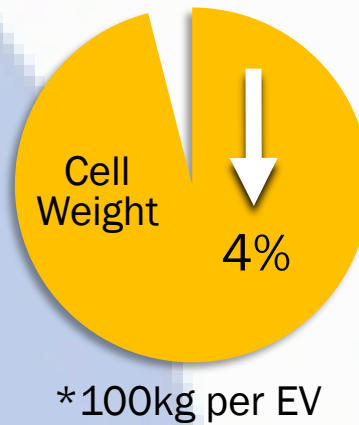
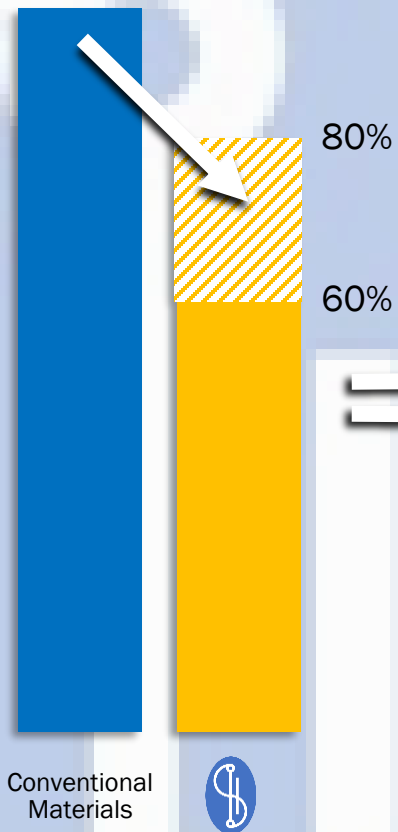
Winding Equipment

Both materials are drop in replacements to existing materials in normal lithium ion battery production.

Effect of Soteria Materials on Cost

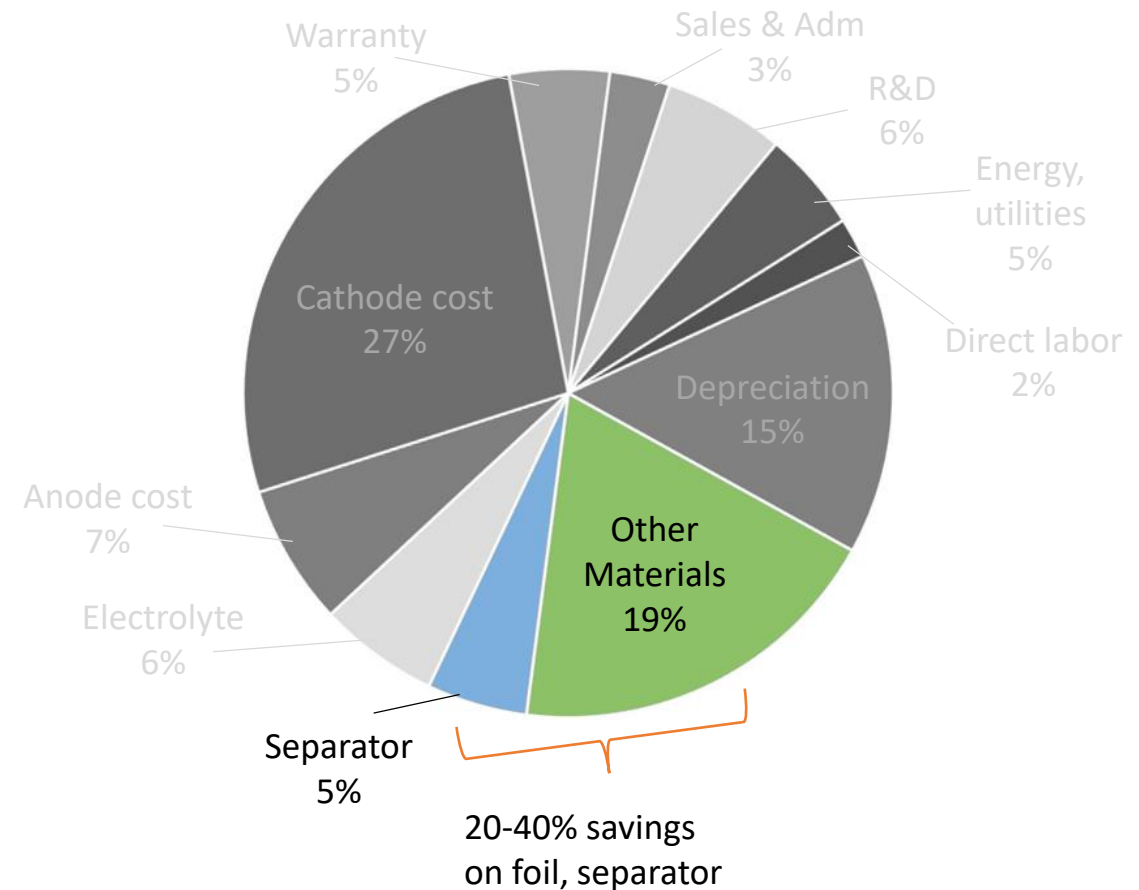
Cost Comparison & Effect on Cell Costs

Material Cost Effect



Potential elimination of auxiliary safety materials

Lithium Ion Cell Cost Structure



The Soteria Business Model

Connecting Technology with Entire Supply Chain



REVISION.



Innovative by nature



K2 ENERGY



engineered for tomorrow



TELEDYNE TECHNOLOGIES INCORPORATED



A Metallized Film and Converting Co.



Solzen Energy



Rolled-Ribbon BATTERY COMPANY



Mercedes-Benz

Research & Development North America, Inc.



enabling energy



ENERGIZING IDEAS



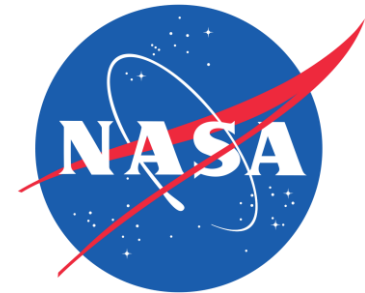
GLATFELTER



CUSTOMCELLS



managing technologies



한국에너지기술연구원 KOREA INSTITUTE OF ENERGY RESEARCH

delfort



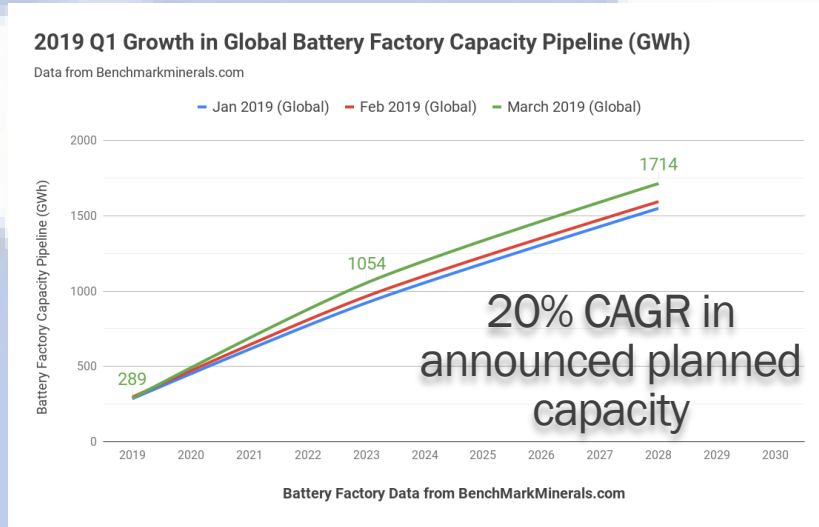
EMERSON



DuPont Teijin Films

UC San Diego

The Soteria Consortium Model: The Motivation to Work Together



Goal: 25% market penetration by 2030

Relevant Benchmarks

NMC (2005-17)	30% share
Celgard (2007-17)	35% share

Resulting Market (per year)



5 Billion Square Meters
of current collectors and separators

approx. \$5 Billion
of existing materials being replaced



Upstream Market Created (per year)



Specialty Fibers

Polyester	\$75M
Lyocell	\$90M
Para-aramid	\$225M



Polymer Film
\$125M



Copper and Aluminum Wire
\$155M (combined)



Paper Machines
\$200M*



Vacuum Metallization Equipment
\$160M*

* after substantial initial investment

The Soteria Value Proposition: Safer, Cheaper, Lighter and Industry Supported

- Currently two licensable technologies

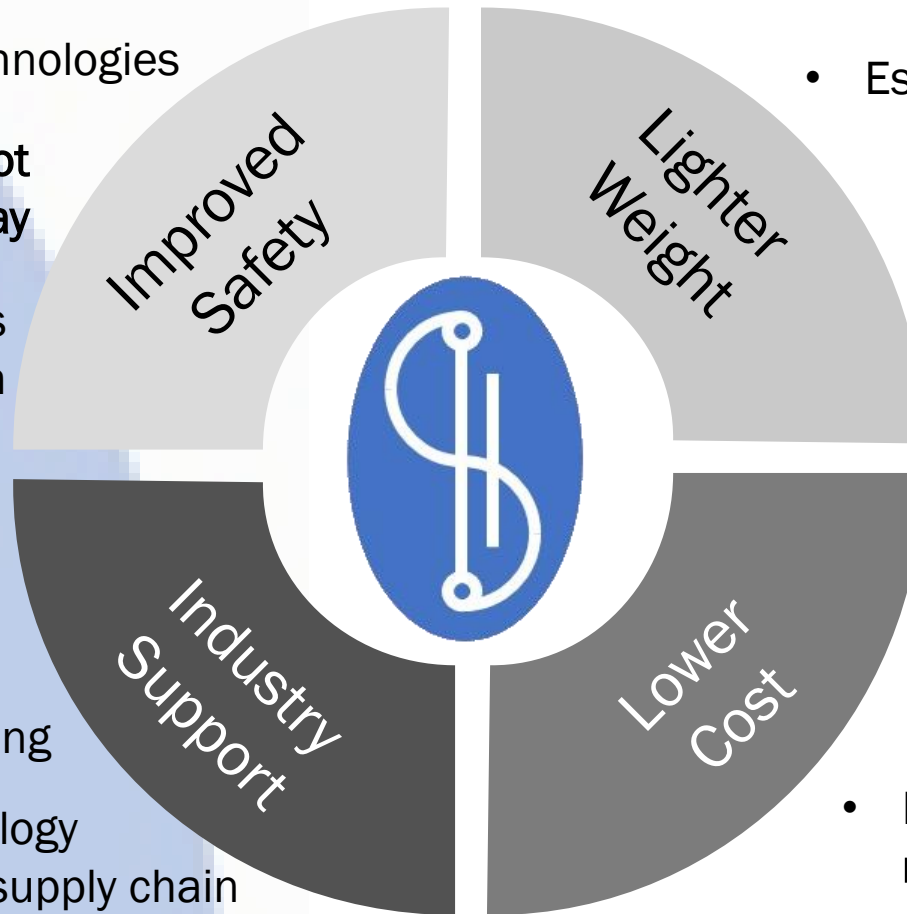
- Technologies address and **eliminate root causes of thermal runaway**

- Technologies enable functioning cells after nail penetration

- Soteria has formed a global consortium of 46 member companies throughout battery supply chain

- Open innovation model with FRAND licensing

- Consortium enables broad technology development support and robust supply chain required by industry



- Estimated **20% reduction in weight** at the cell level

- Potential to remove cost and weight of protective materials & systems

- Replace 90% of current collector metal with commodity film

- **Drop-in replacements** to existing materials

- Estimated **30% reduction in material costs** for separator and current collector



Thank you!