24M SemiSolid™ Manufacturing Platform

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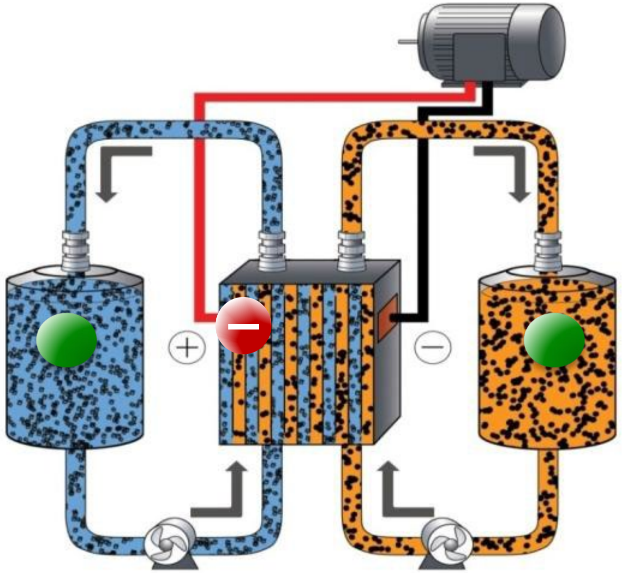
Dr. Junzheng Chen

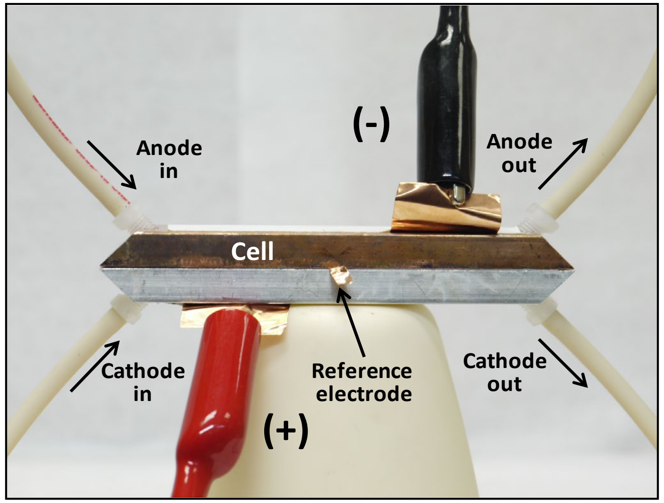
The Original Idea Behind 24M: Combine the High Energy Density of Li-Ion with the Flexible Architecture of Flow Batteries

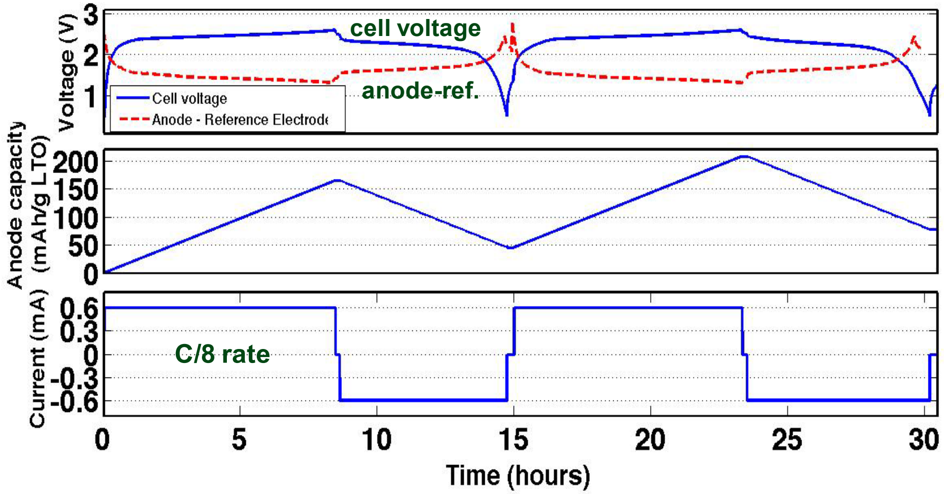
Semi-Solid Flow Cells (SSFCs):

- Highly concentrated yet flowable semi-solid suspensions
- Electronically and ionically conductive fluid
- Rechargeable, renewable, storable, electrochemical fuel



"Cambridge Crude"





M. Duduta *et al., Adv. Energy Mater.* 1[4] 511-516 (2011); Y.-M. Chiang, W.C. Carter, M. Duduta and P. Limthongkul, *High energy density redox flow device,* US Patents 8,722,226 and 8,722,227, May 13, 2014;

ENERGY

Liquid Fuel for Electric Cars

A new type of battery could replace fossil fuels with nanotech crude

BETTER BATTERIES are the key to electric cars that can drive for hundreds of miles between rechargings, but progress on existing technology is annoyingly incremental, and breakthroughs are a distant prospect. A new way of organizing the guts of modern batteries, however, has the potential to double the amount of energy such batteries can store.

The idea came to Massachusetts Institute of Technology professor Yet-Ming Chiang while he was on sabbatical at A123 Systems, the battery company he co-founded in 2001. What if there was a way to combine the best characteristics of so-called flow batteries, which push fluid electrolytes through the cell, with the energy density of today's best lithium-ion batteries, the kind already in our consumer electronics?

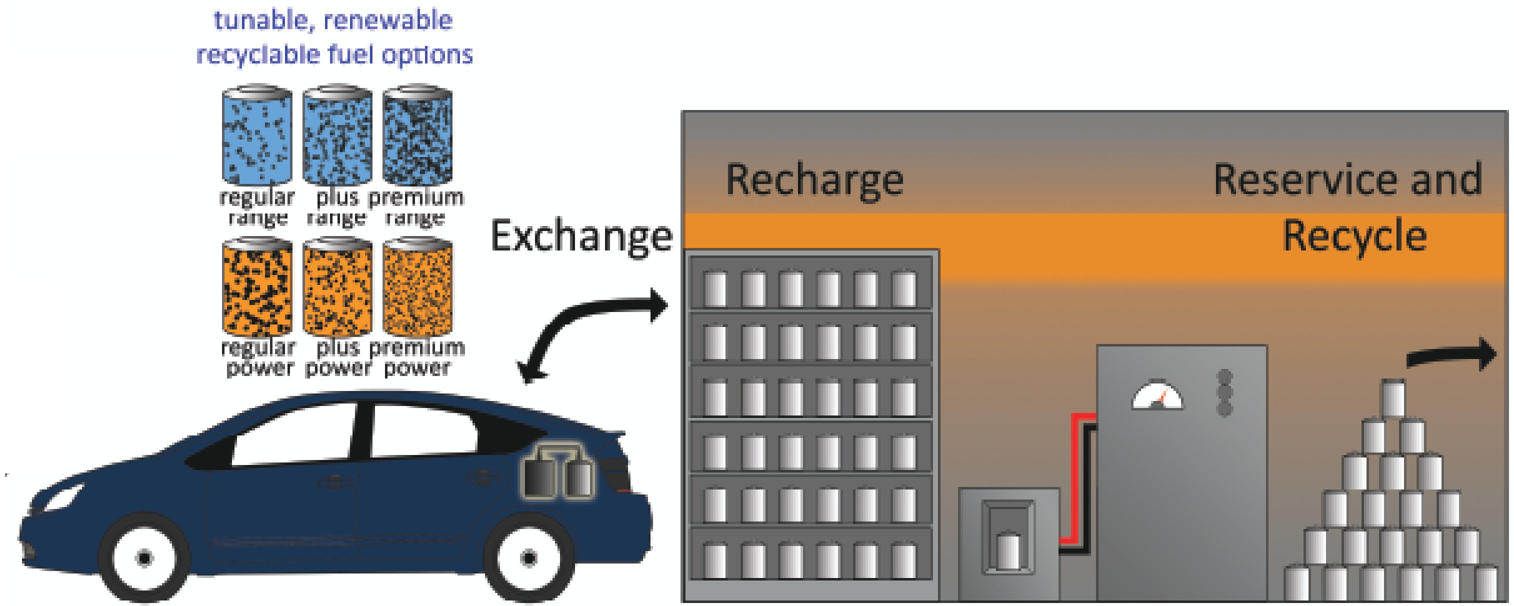
Flow batteries, which store power in tanks of liquid electrolyte, have poor energy density, which is a measure of how much energy they can store. Their one advantage is that scaling them up is simple: you just build a bigger tank of energy-storing material.

Chiang and his colleagues constructed a working prototype of a battery that is as energy dense as a traditional lithium-ion battery but whose storage medium is essentially fluid, like a flow battery. Chiang calls it "Cambridge crude"—a black slurry of nanoscale particles and grains of energy-storing metals.

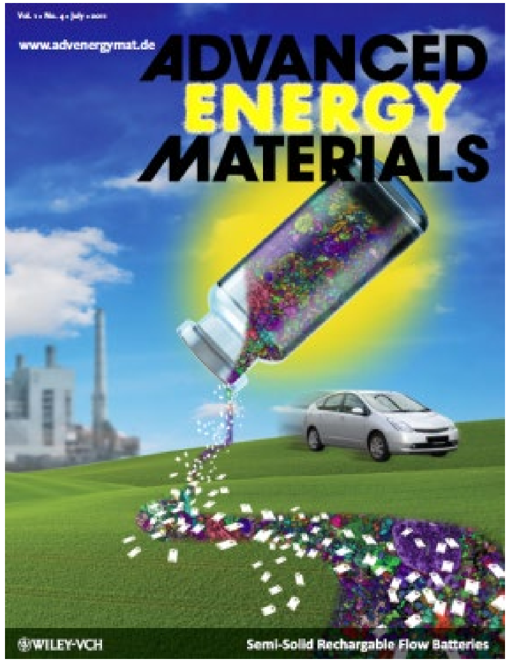
If you could visualize Cambridge crude under an electron microscope, you would see dust-size particles made of the same materials that make up the negative and positive electrodes in many lithium-ion batteries, such as lithium cobalt oxide (for the positive electrode) and graphite (for the negative one).

In between those relatively large particles, suspended in a liquid, would be the nanoscale particles made of carbon that are the secret sauce of this innovation. Clumping together into a spongelike network, they form "liquid wires" that connect the larger grains of the battery, where ions and electrons are stored. The result is a liquid that flows, even as its nanoscale components

50 Scientific American, December 2011



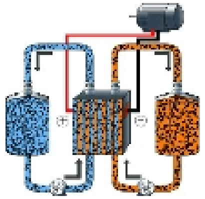
Y.-M. Chiang and R. Bazzarella, *Fuel System Using Redox Flow Battery*, US Patent No. 8,778,552, issued July 15, 2014.



Electrolyte smoothie produces more juice: New electrolyte for lithium batteries

by **Martin Ottmar** published: 2011-05-27

The scientific paper behind this article is now free to access until the 27th of June!



In batteries, both the energy storage materials themselves and the system around them such as casing, electrodes, electrolytes or membranes play important roles for the resulting performance. Naturally, one would want to pair those materials with the highest possible energy density with minimum technical ballast.

M. Duduta *et al., Adv. Energy Mater.* **1[4]** 511-516 (2011)

The Semisolid Electrode

- Higher Li-ion area capacity (6-12mAh/cm^2)
- Lowest tortuosity = thickest electrodes
- Lowest materials cost per stored energy
- Solvent-free manufacturing
- Soft design - extreme abuse tolerance
- **Easiest lithium-ion cell to recycle/reuse**

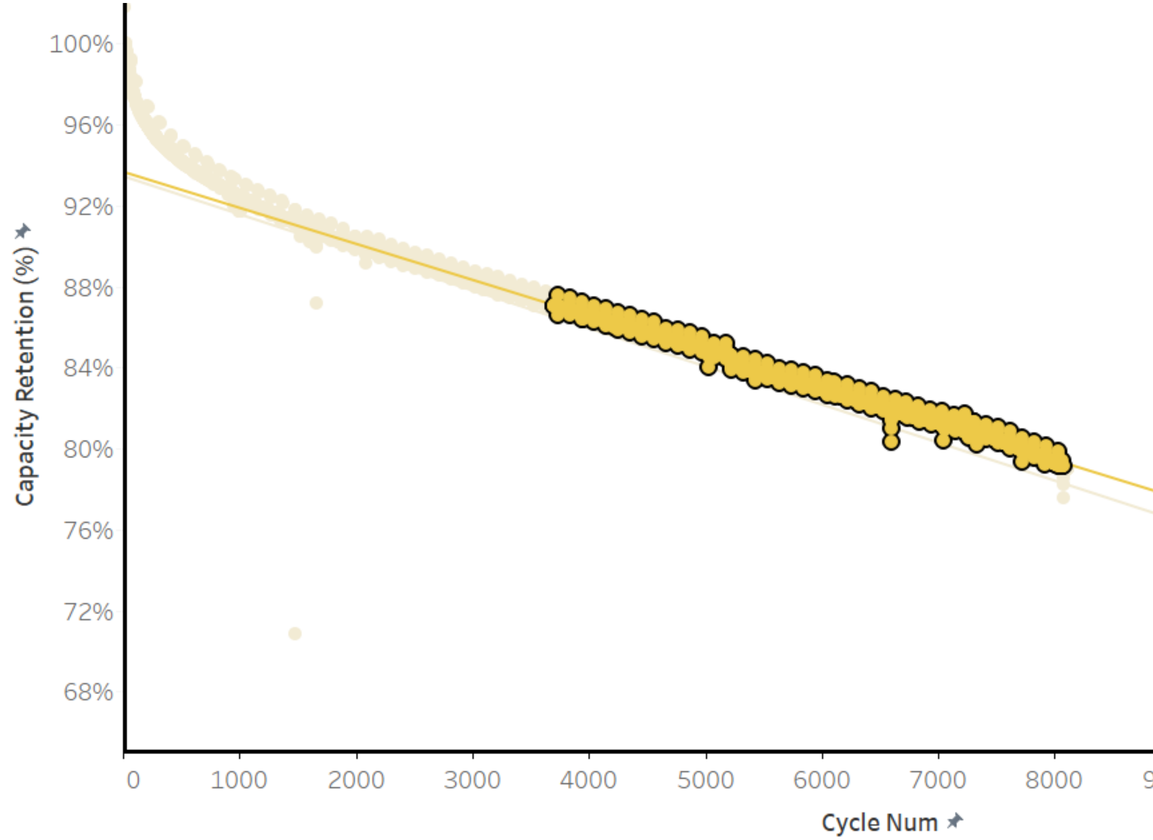
24m

http://24m.com/

- LFP cells for Grid and Automotive Applications

  - LFP for Grid
  - LFP for Automotive

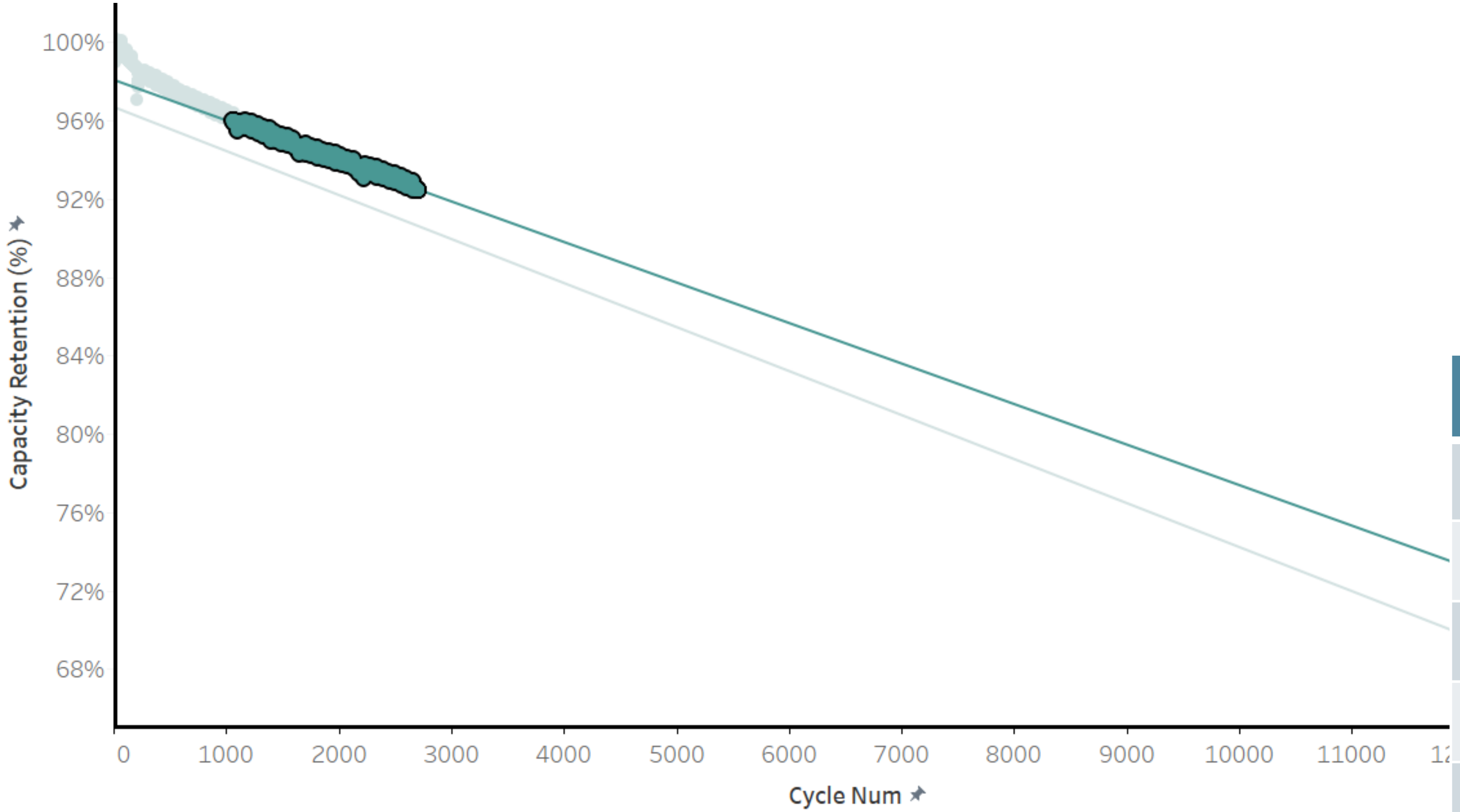
ESS first 5.5 Ah pouch LFP/Gr cell cycling – built in 2014



Demonstration	24M 5.5Ah LFP/Gr
Cell Capacity	5.5Ah
Cathode	LFP, 9 mAh/cm^2
Anode	Gr
Charge-discharge rate	C/4 CCCV – C/4
Voltage Window	2.0-3.6V
Cycle Life (Prediction)	10,000+ @75%
Temperature	25C

- More than **7 years of cycling data** collected, projecting to **> 10000 cycles retention** with minimum ASI growth
- 1C cycling for 7000 cycles will be about 2 years of data, which is much milder than 7 years test.

Production intent LFP/Gr prismatic product , 110Ah cell cycling, built in 2018



Demonstration	24M 110Ah LFP/G
Cell Capacity	110Ah
Cathode	LFP, 8 mAh/cm^2
Anode	Gr
Charge-discharge rate	C/4, CCCV-C/4
Voltage Window	2.0-3.6V
Cycle Life (Prediction	>13000 @75%
Temperature	25C

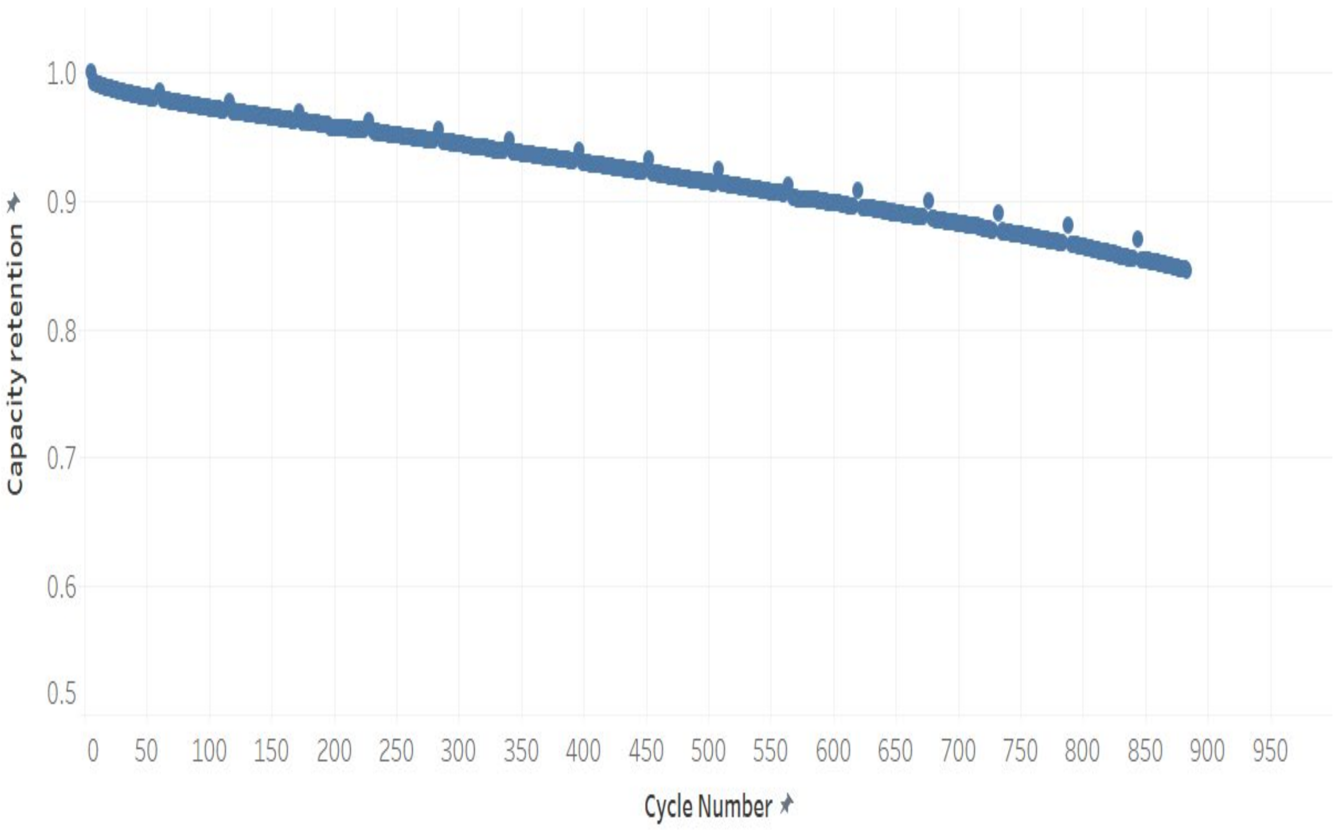
Production scale product , 110Ah, shows a better cycle retention after 2500 cycles.

❑ NMC cells for Automotive Applications

- NMC/Gr Cell

NMC811/Graphite, 50Ah Cell, Cycle Performance, 2020

NMC811/Graphite Cycle Performance



Demonstration	24M 50Ah NMC/Gr
Cell Capacity	50Ah
Cathode	NMC 811, 9.2mAh/cm^2
Anode	Graphite
Charge-discharge rate	C/4, CCCV-C/3 D
Voltage Window	2.8-4.2V
Unit Cell Energy Densi	270 Wh/kg
Cycle Life	>1000
Temperature	30C

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM

NMC-Gr EV design cells achieved more than 1000 cycles stable cycling with minimal ASI growth

24m

NMC EV Cell (50Ah cells) – Electrical Abuse Testing Summary (External Lab / Customer Test)

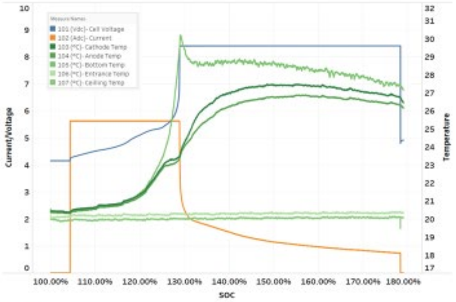
Reference	Test	# of cells tested	Results
Overcharge	1C to 200%SOC or 8.4V@60˚C	6	EUCAR2
External Short circuit	100%SOC (4.2V), 60˚C, 3.5mOhm	6	EUCAR2
Internal Short circuit – Pin penetration	100%SOC, 0.1mm, Voltage drop of ≤ 5mV	4	EUCAR4
Over-discharge	1C to voltage reverse voltage or 1C to 0.7V(20% the nominal voltage)	3	EUCAR2
Crush	100%SOC, 50% deformation or 200kN	2	EUCAR1
Thermal Stability	100%SOC, 5℃/min ramp to 130℃	4	EUCAR2

- *Semisolid electrode combined with Unit Cell structure enabled to achieve exceptional abuse tolerance with High Energy Material NMC811*

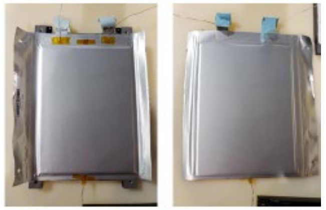
Mechanism of better abuse test result

- Over Charge- Gas Trapped

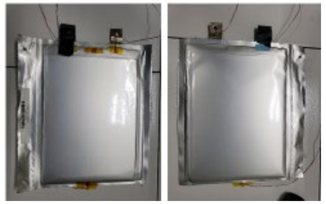
NMC811 EV Cell - Baseline Design, C/2 Overcharge to 200%SOC



Before Overcharge



After Overcharge

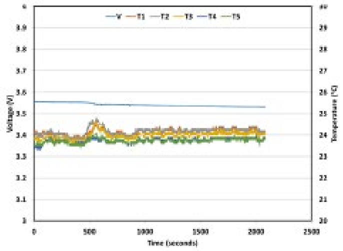


105944A-17 Data	
Max Voltage	8.4V
Max Temperature	30.2°C
Time to max voltage	44min
OCV After Test	4.91V
EUCAR level	2

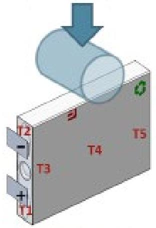
- Crush- Each electrode insulation + Deformable Electrode

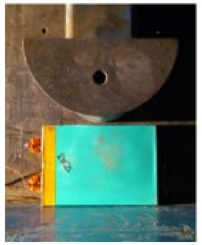
Product Safety : LFP 100Ah+ Cell Crush Test / Unprecedented Level of Safety

	Result
EUCAR rating	EUCAR 1
Venting	No
Max Temp	Ambient



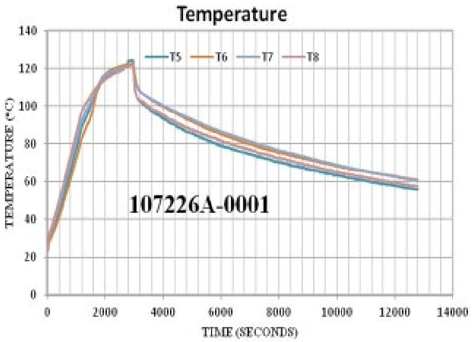
SIDE CRUSH





- Hot Plate Test

NMC811 EV Cell – Thermal Stability: 100%SOC, 5˚C/min ramp to 130˚C



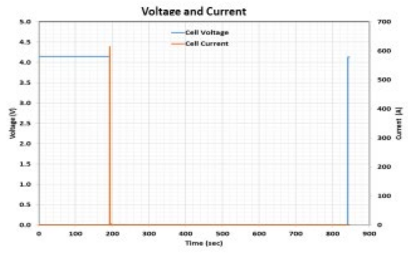
Before Test

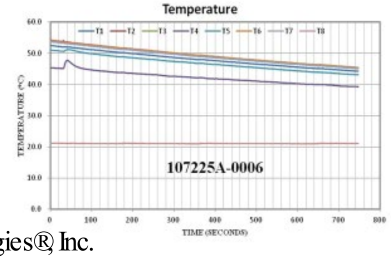
After Test

Cell venting: Did not vent
Venting SOC: Did not vent
Max T at venting: N/A
Max. T: 124ºC
Cell Did Not Vent, No Fire
EUCAR 2

- External Short Circuit Test with Fuse functions

NMC811 EV Cell – Electrical Abuse : 3.5mohm External Short, 100%SOC @ 60˚C – EUCAR 2





Before Test

After Test

Cell venting: Did not vent
Venting SOC: Did not vent
Max T at venting: N/A
Max. T: 63ºC
Cell Did Not Vent, No Fire
EUCAR 2

24m