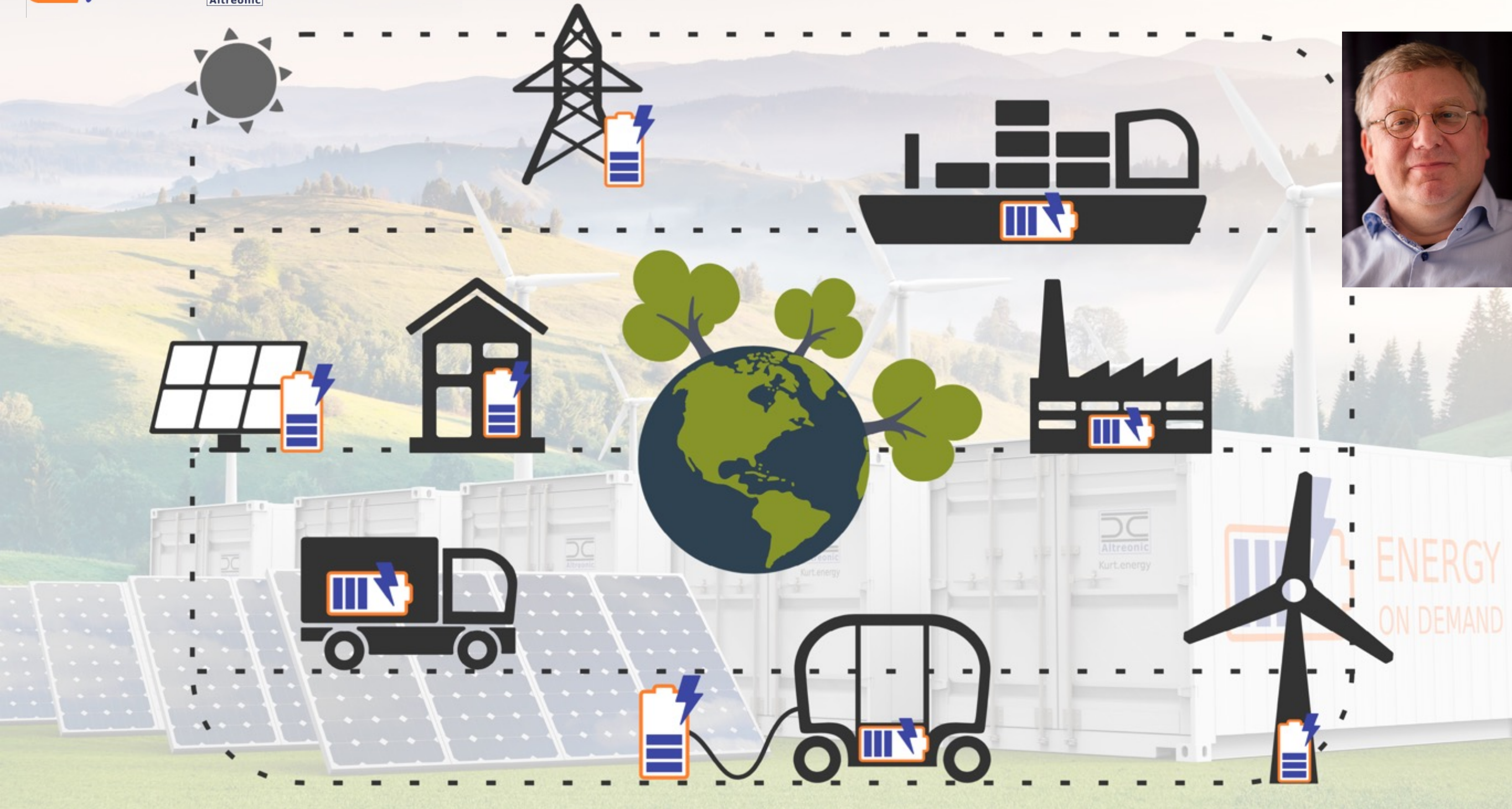


ENERGY FOR LIFE, BLUE CELL POWER



Eric Verhulst, CEO/CTO

**THE SHIFT TO CLEAN ENERGY NEEDS BETTER BATTERIES NOW:
We have them!**

Altreonic NV - previously Eonic Systems NV

- 30 years safety-critical embedded software
 - Trustworthy systems engineering
 - International technology focused SME
 - ESA: Virtuoso RTOS in Rosetta mission
 - 5Gen unique fault tolerant VirtuosoNext RTOS
 - GoedelWorks: Systems Engineering portal for certification
 - KURT.mobi: Light Electric Vehicle for urban use (inactive)

Today: KURT.energy:

**Customer specific batteries based on
Hybrid Supercapacitors and
Sodium-ion cells**



Lithium-ion: Sustainable? Practical? Cost-efficient?

GM asks Chevy Bolt EV owners not to charge overnight or park inside after 2 more fires

Sean Graham - Jul. 14th 2021 1:59 pm PT



SAFETY FIRST

Batteries are full of very inflammable products)



Recall will cost 2 billion US\$



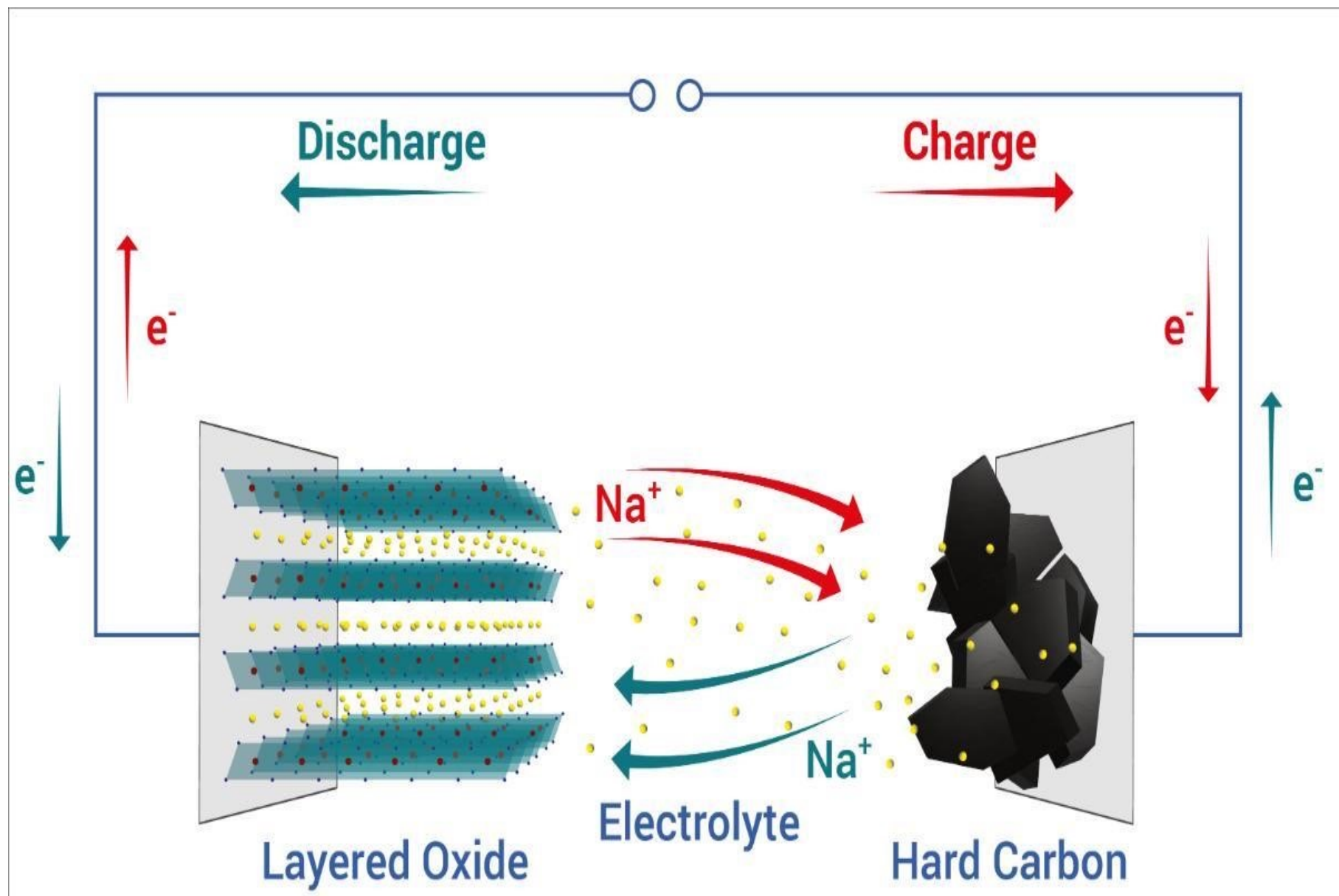
Toxic smoke 10 km away

From smartphones to warehouses

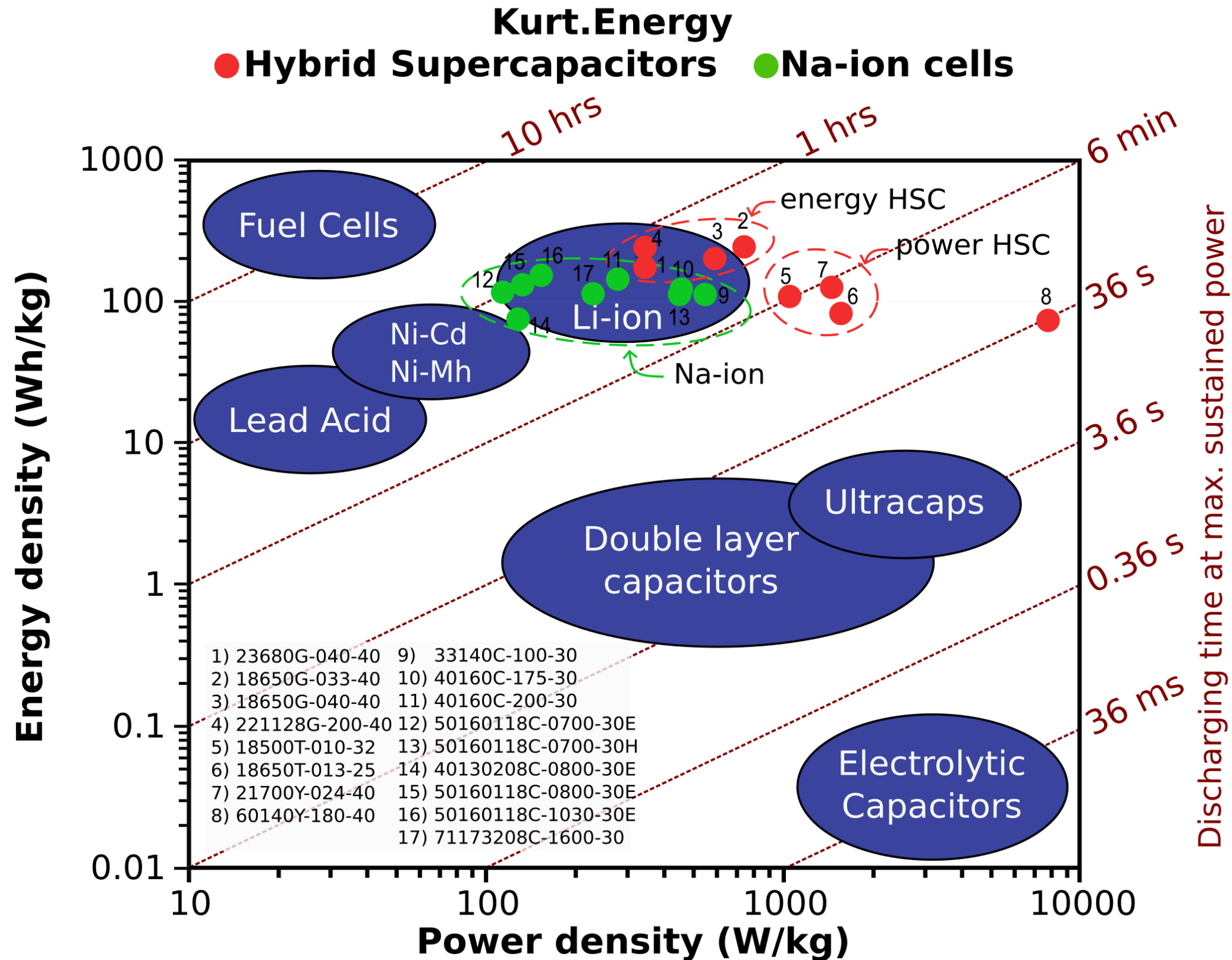
Our Selected Hybrid Supercapacitors and Sodium-ion cells are safe, and more...

The step beyond Lithium-ion batteries

- First Sodium-ion battery cells in 2023, no Lithium, no Nickel, no Cobalt
- Sodium-ion cells are safe and sustainable
- Customer and volume production ramping up
- From 100 Wh/kg to 155 Wh/kg upto 6000 cycles



Hybrid supercaps and Sodium-ion technology map



Sodium-ion chemistries involved

Anode:

Na-oxide: (Na_xMO₂)

Polyanion: (NaMPO₄)

Prussian White/Blue (Na_xPR(CN)₆)

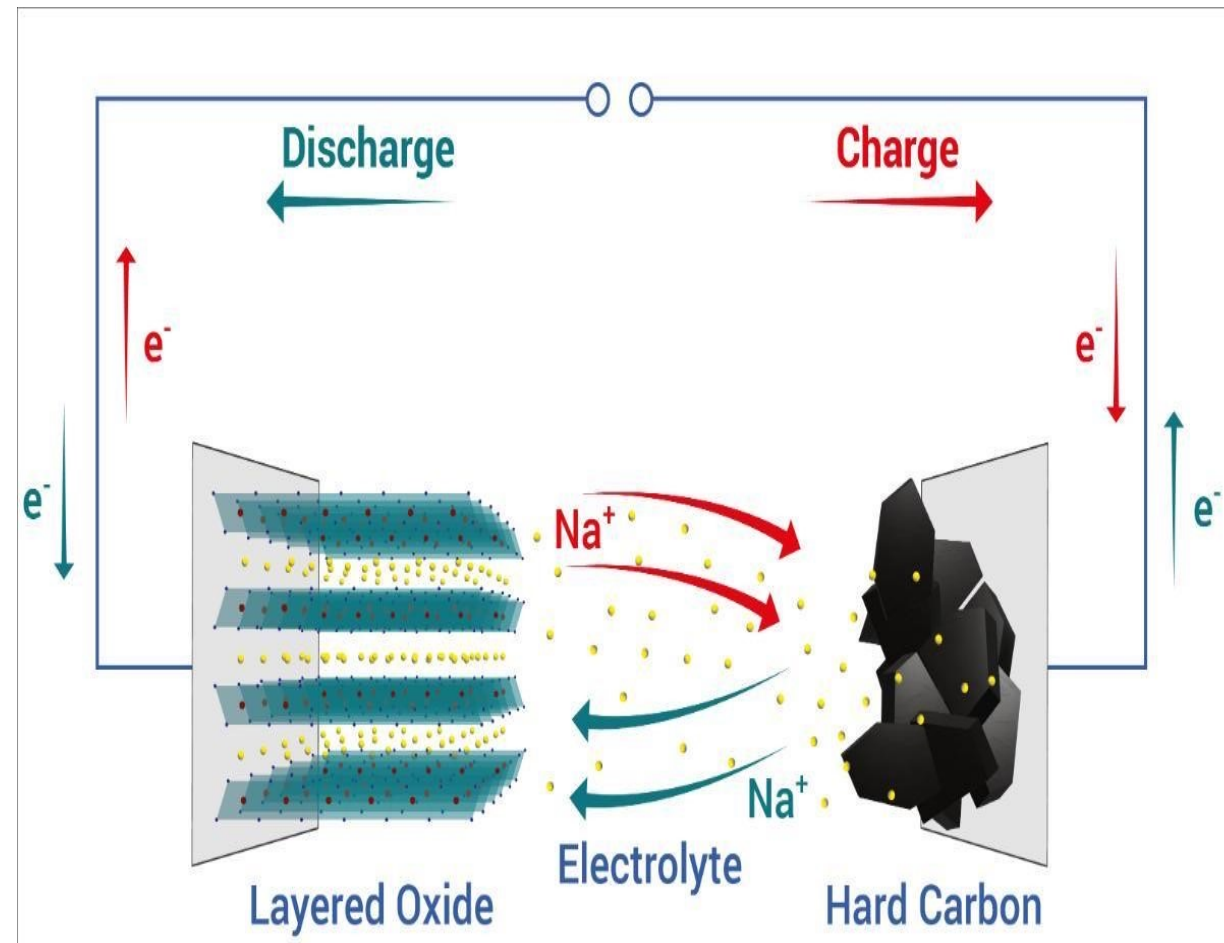
Cathode:

Hard carbon / 300-400 mAh/g



Capacity/cell:

From 1.3 Ah to 160 Ah



Electrolyte:

Typically Sodium hexafluorophosphate

Current collector: Aluminum

Cylindrical or prismatic



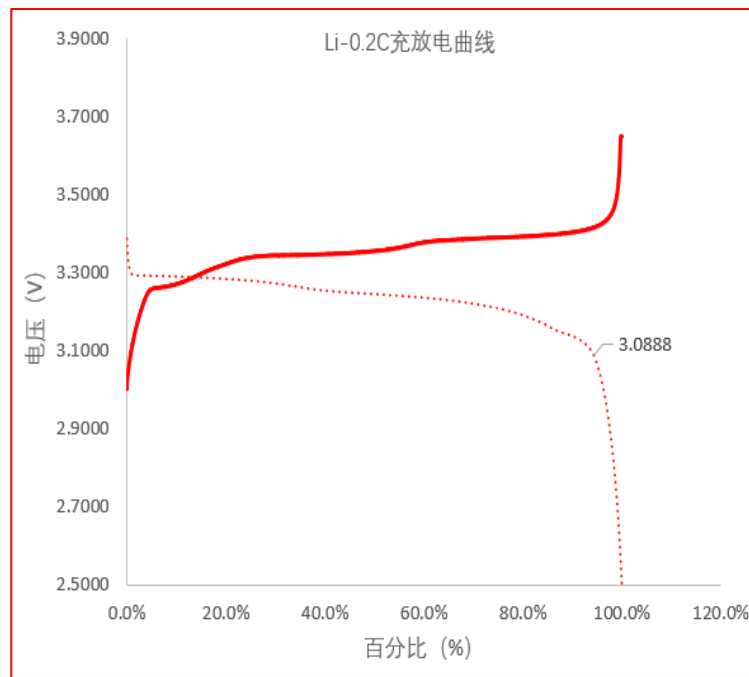
Sodium-ion vs. Lithium-ion (LFP): overview

	LFP	Sodium-ion (layered oxide)	Sodium-ion (polyanion prismatic)
Energy density (Wh/kg)	150-180	120-150	100-110
Cycle life (times)	3000-10000	3500-4000	8000~10000
Voltage range	2.5~3.65	1.5~4.0	(2.0) 1.5~3.8 (3.6)
Capacity retention -40°C	n.a.	> 80%	> 70%
Average operating voltage	3.2V	3.0V	3.0V
safety	Good	Very good	Very good
Resistance to discharge	medium	good	good
High temperature cycle	good	good	good
Power capability	medium	good	medium
System SOC estimation	approximate	accurate	acurate
-40°C discharging	n.a.	yes	yes

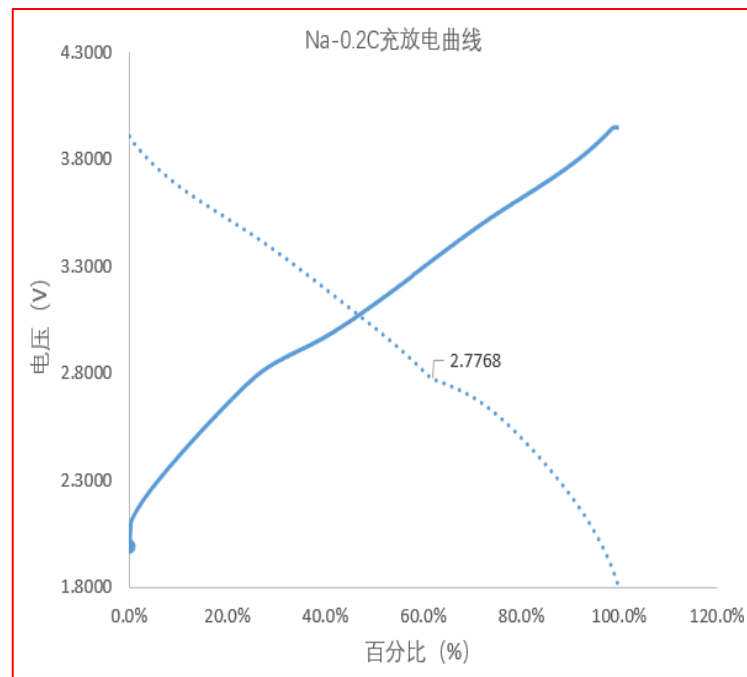
Temperature range charging / discharging: tbd



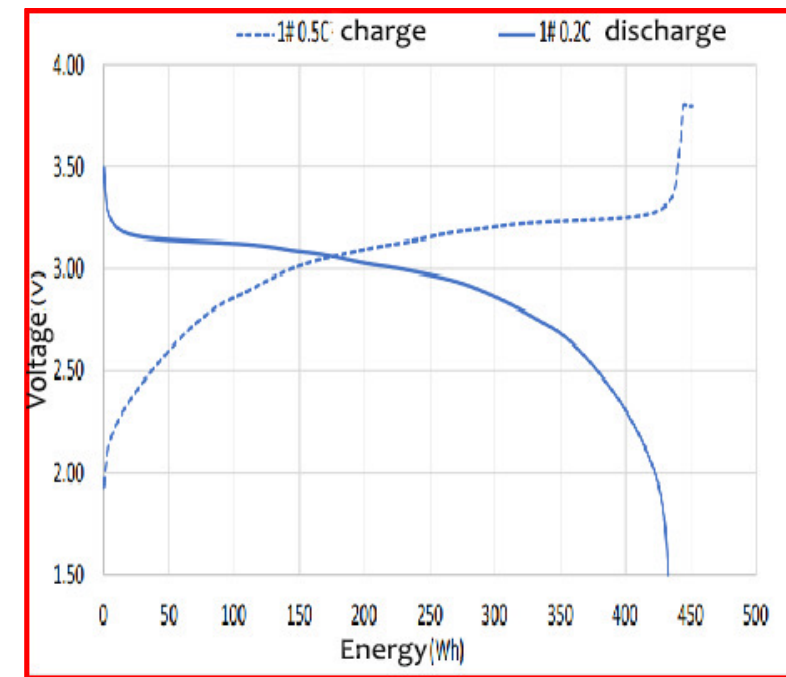
Sodium-ion vs. Lithium-ion (LFP): Charge / discharge curves



LFP



Na-ion (layered oxide)



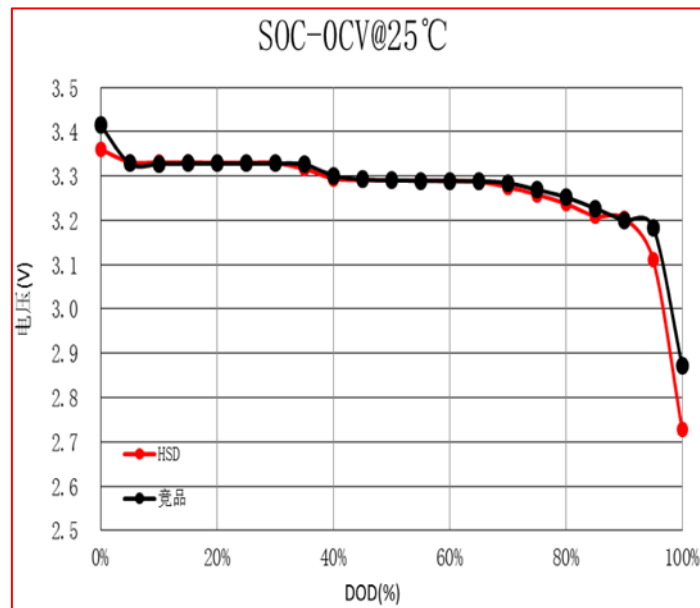
Na-ion (polyanion)

Sodium-ion (layered oxide) more linear: easy to estimate SoC

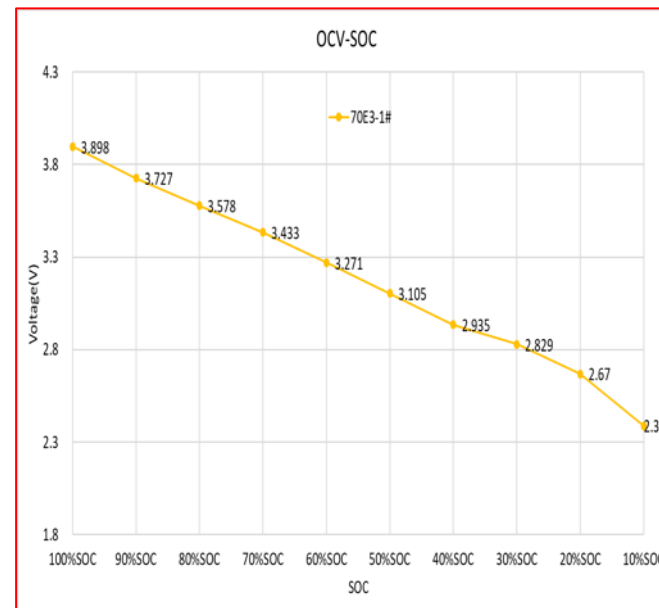
Sodium-ion (polyanion) more like LFP



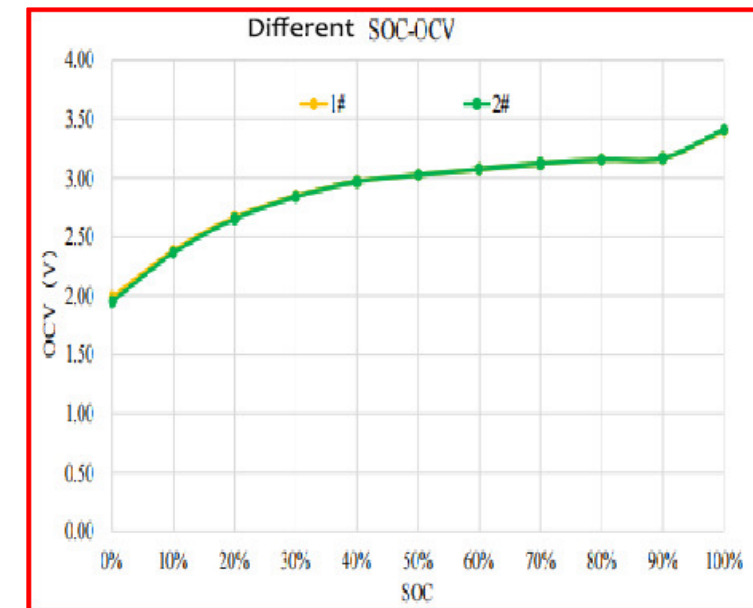
Sodium-ion vs. Lithium-ion (LFP): SoC / OCV



LFP



Na-ion (layered oxide)



Na-ion (polyanion)

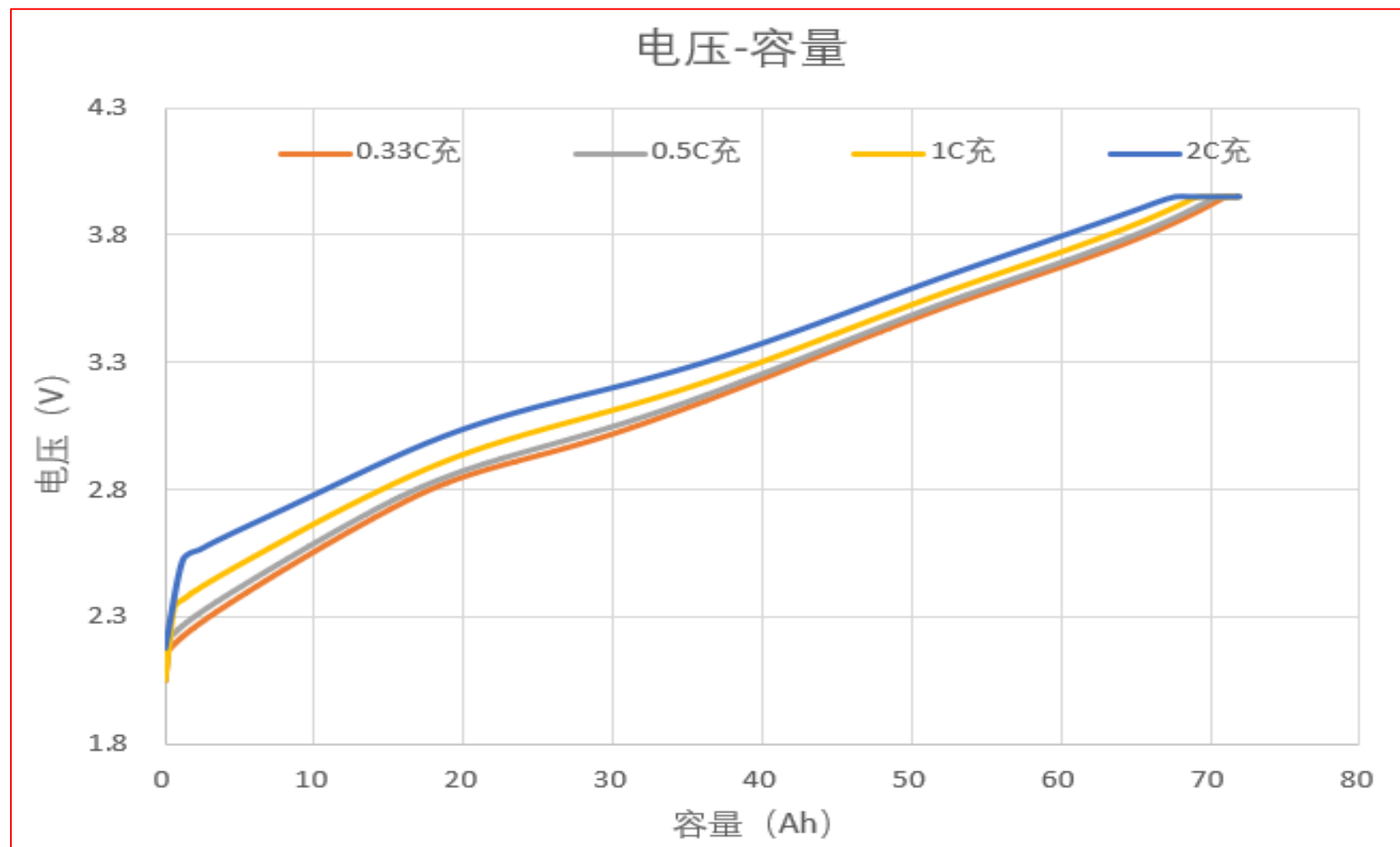
Sodium-ion (layered oxide) more linear: easier to estimate SoC

Sodium-ion (polyanion) more like LFP



Charging capability Sodium-ion (layered oxide)

- Constant current – Constant Voltage charging profile
- Hard carbon cathode has higher energy density
- Temperature range: 5 – 60°C for fast charging, -10 to +0°C for 0.1C
- Max. rates are cell dependent (upto 20C)



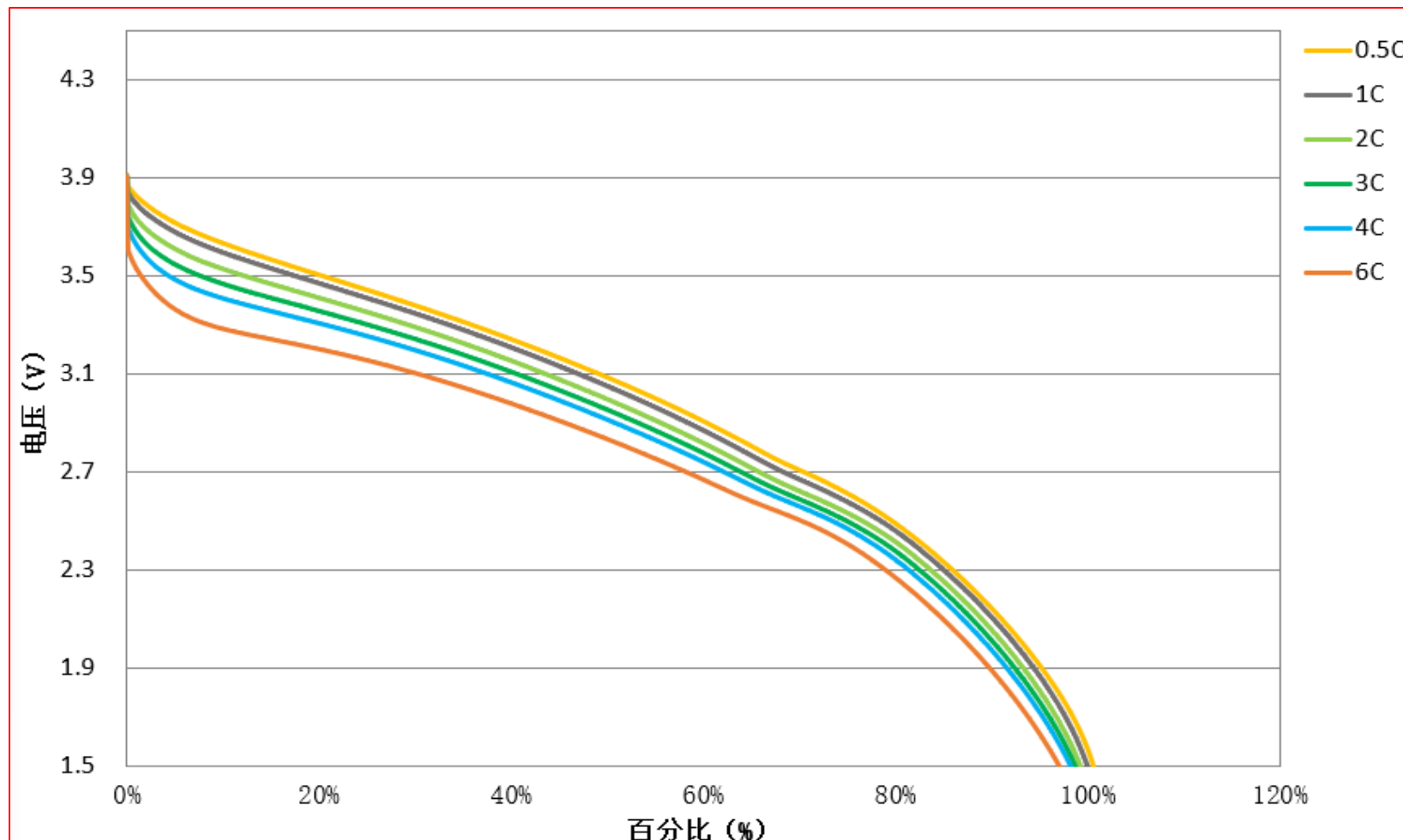
C-rate	CC % SoC
0.33	98.72%
0.5	98.20 %
1.0	97.16%
2.0	96.07%

Test protocol:
Charging 0.5C to 3.95V
10 min. rest
Discharging 0.5 – 6.0 C till 1.8V



Discharging capability Sodium-ion (layered oxide)

- Discharging possible till 0V, practically limited to 1.8V



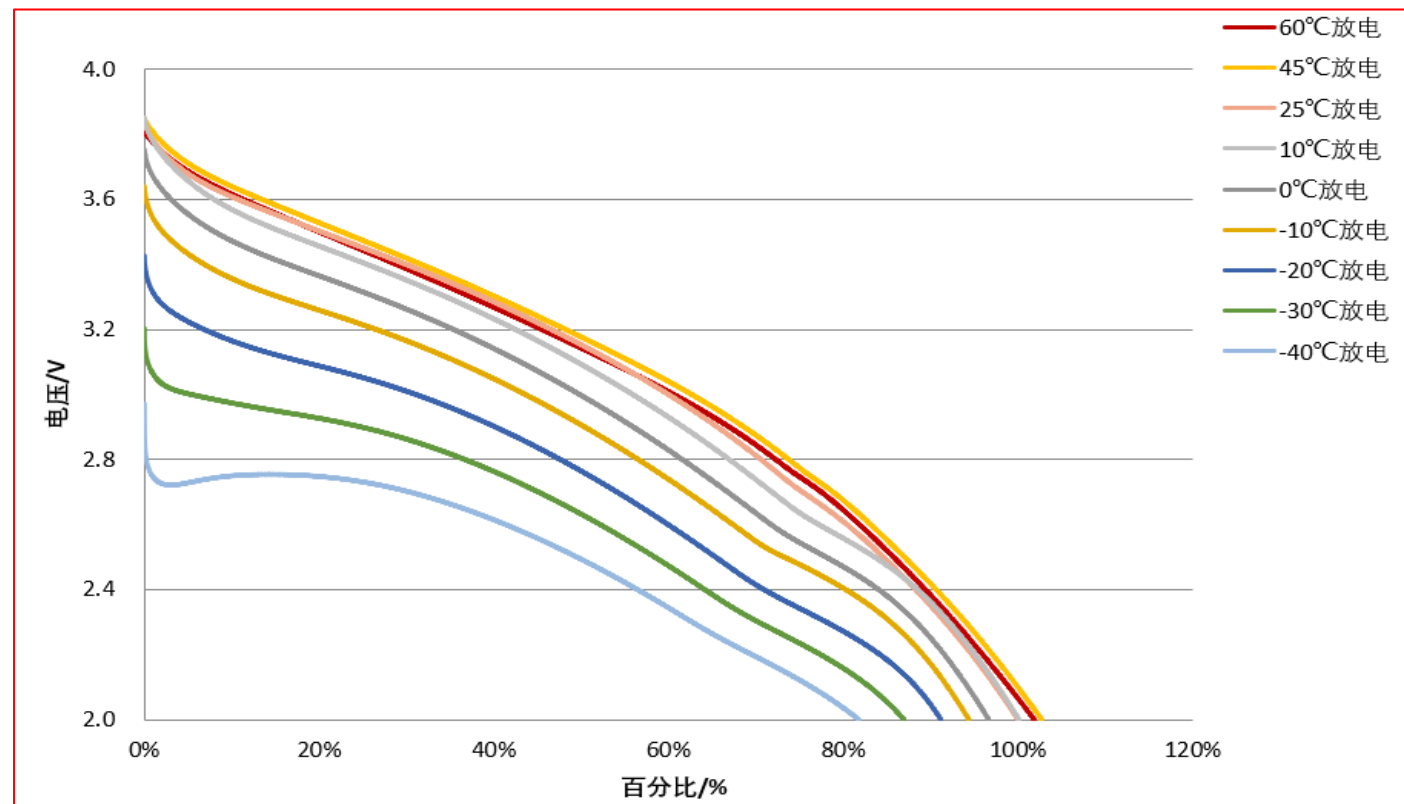
Discharge C-rate	Capacity	% vs. 0.5C
0.5 C	74.37	100.0
1.0 C	74.26	99.85
2.0 C	73.72	99.13
3.0 C	73.33	98.60
4.0 C	72.98	98.14
6.0 C	72.09	96.93

Test protocol:
Charging 0.5C to 3.95V
10 min. rest
Discharging 0.5 – 6.0 C till 1.8V



Discharging capability Sodium-ion (layered oxide)

- Can discharge from -40 to +60°C
- Still > 80 % capacity at -40°C (0.5C, 1.0C)

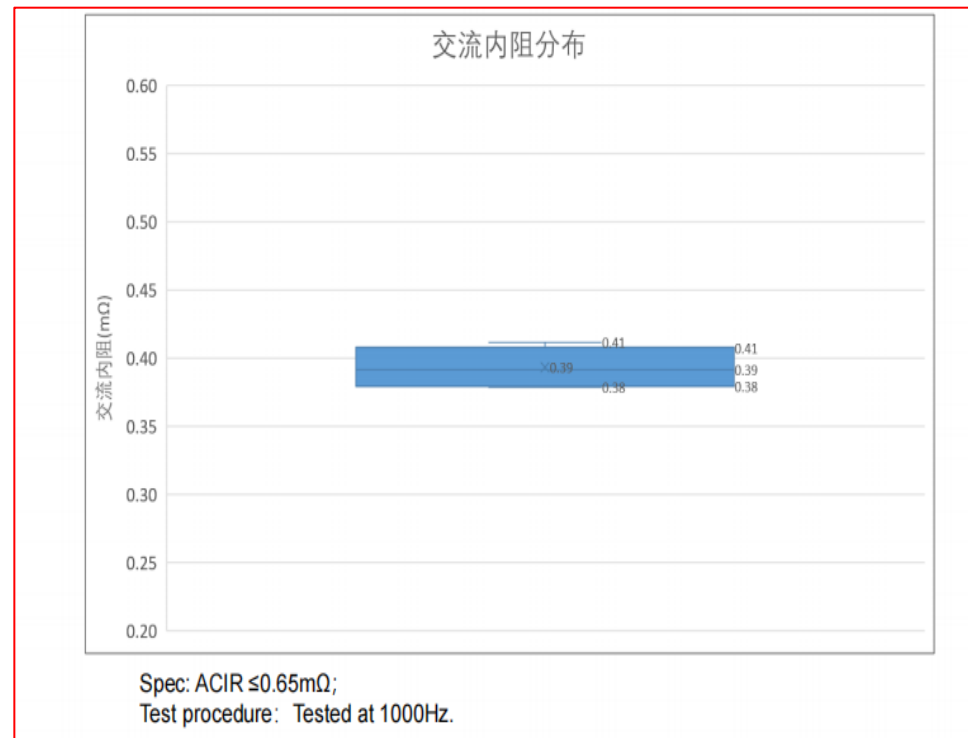


Temperature °C	Capacity % Na-ion	Capacity % LFP
60 °C	101.87	102.15
45°C	102.72	103.15
25 °C	100.0	100.0
15 °C	100.12	93.49
0°C	96.66	89.11
-10°C	94.39	85.02
-20°C	91.20	81.20
-30°C	86.96	n.a.
-40°C	81.77	n.a.

Test protocol:
 Charging 0.5C to 3.95V
 10 min. rest
 Discharging 0.5 – 6.0 C till 1.8V

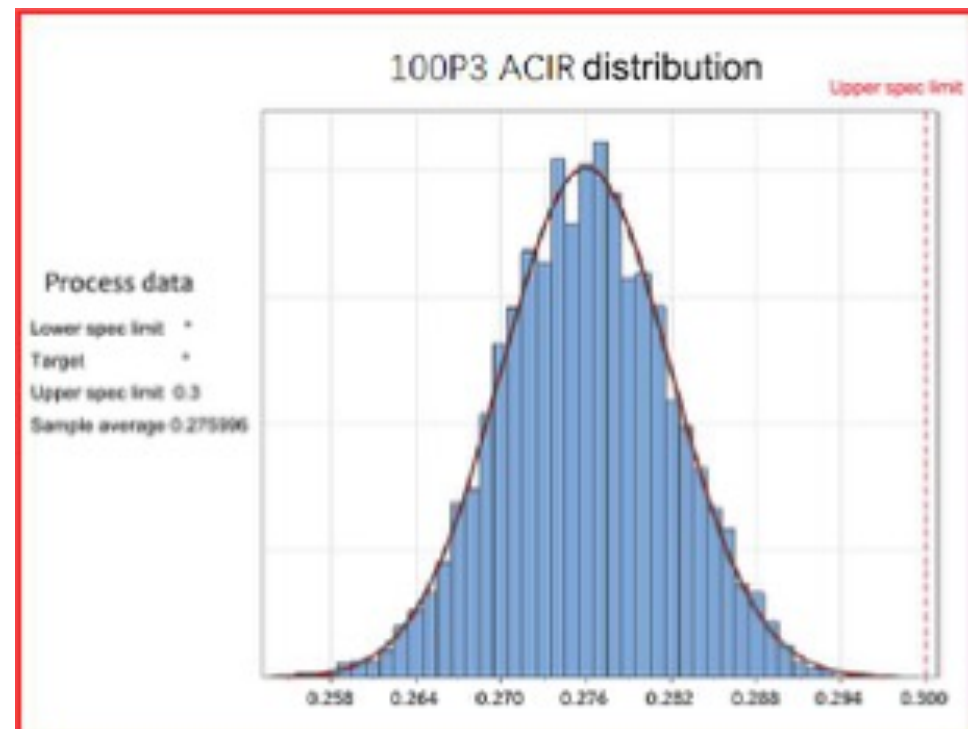


Low internal resistance Sodium-ion (polyanion)



Sodium-ion:

ESR < 0.2 to 0.4 mOhm

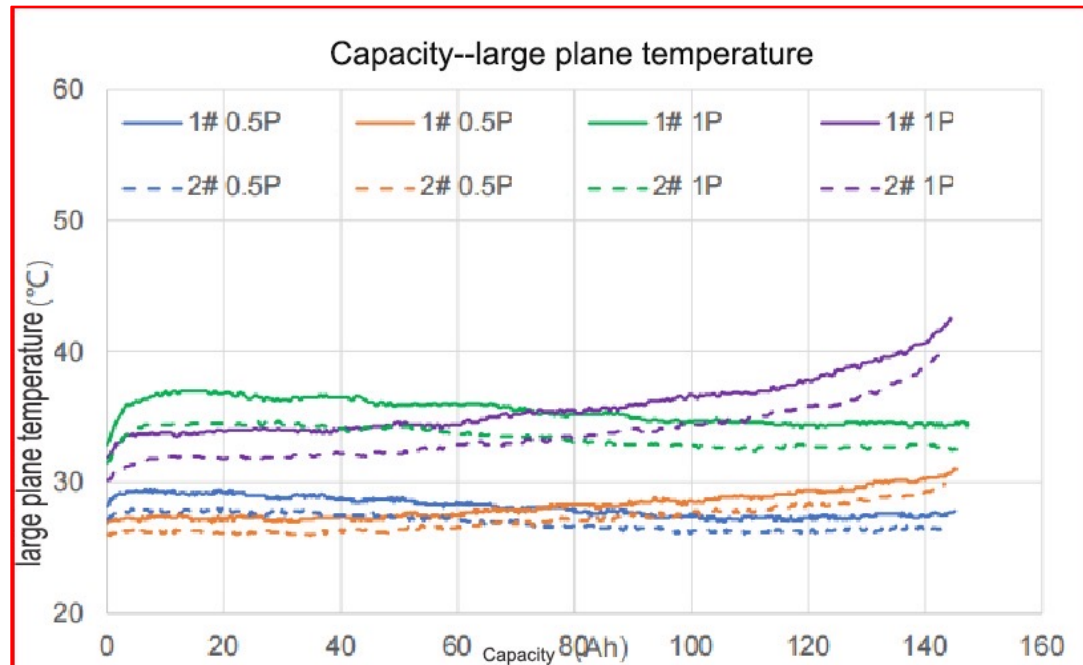


LFP:

ESR < 0.25 - 0.294 mOhm

Thermal behavior of Sodium-ion (polyanion)

Low resistance results in modest temperature rise

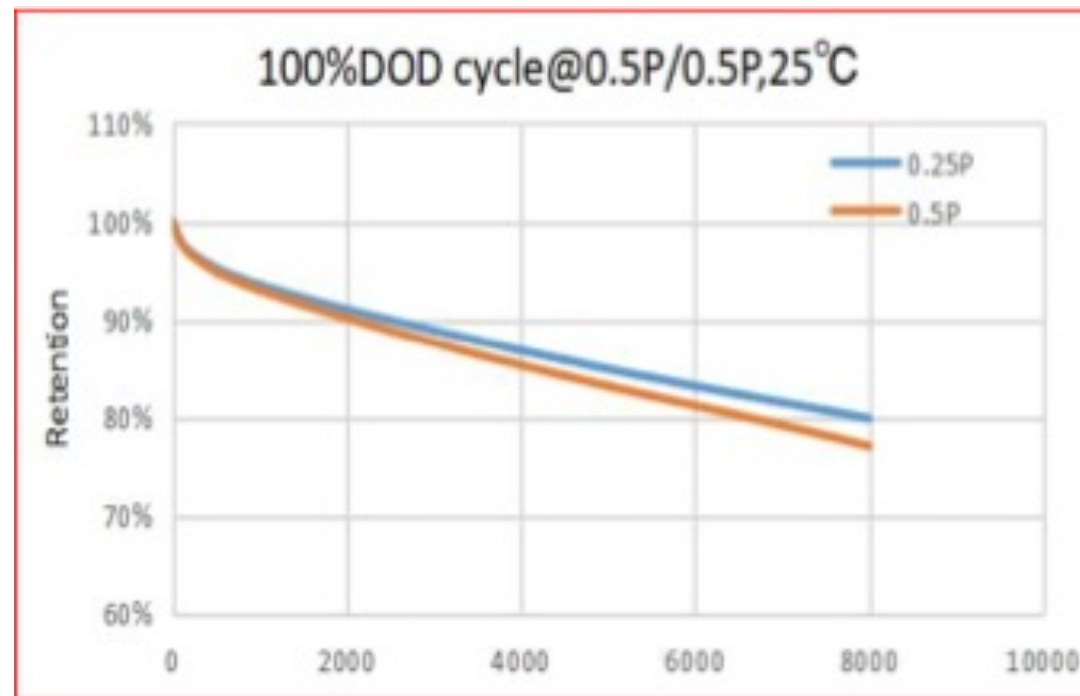


Constant Power charging / discharging	Starting temperature(°C)	Ending temperature (°C)	Adiabatic temperature rise(°C)	Polyanion sodium ion /adiabatic temperature rise(C)
0.5P power charging @25°C	24.6	43.9	19.3	-0.4
0.5P power discharging @25°C	24.6	44.0	19.4	4.1
1P charging @25°C	25.5	55.3	29.8	1.6
1 P power discharging @25°C	25.5	56.9	31.3	10.6

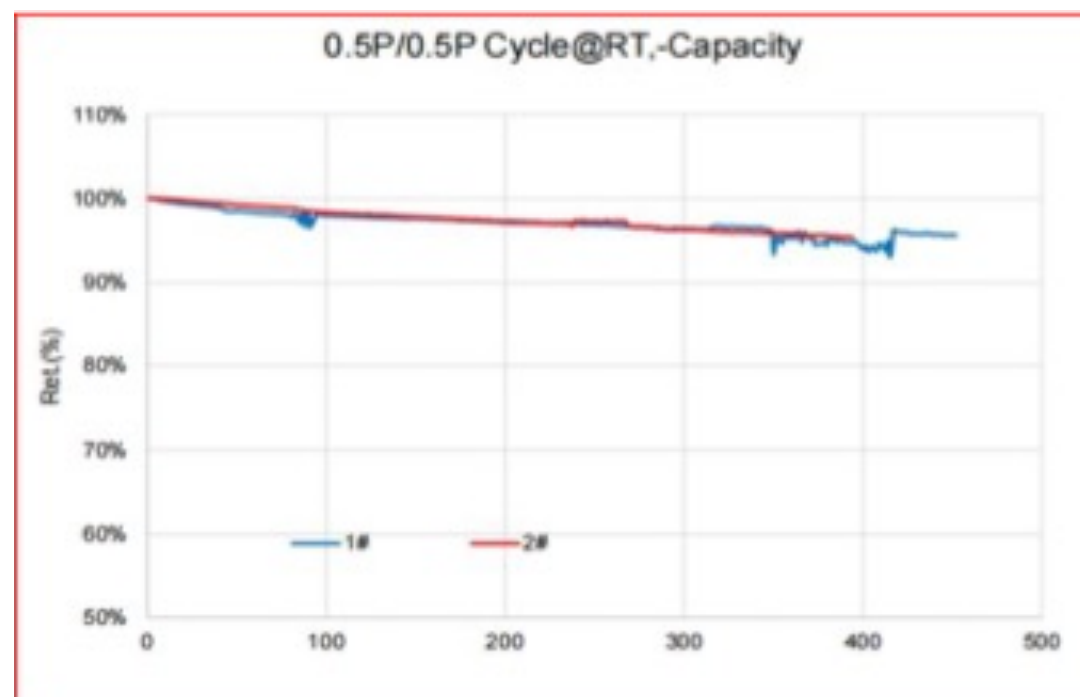


Cycle life of Sodium-ion (polyanion)

Cycle-life @ 25°C comparable wit LFP
Note: temperature and current dependent



Cycle-life @ 25°C for good LFP cell:
8000 cycles till 80% capacity left



**Cycle-life @ 25°C for Na-ion
polyanion cell:**
Estimated 6000 cycles:
394 cycles gives 95.4 % left

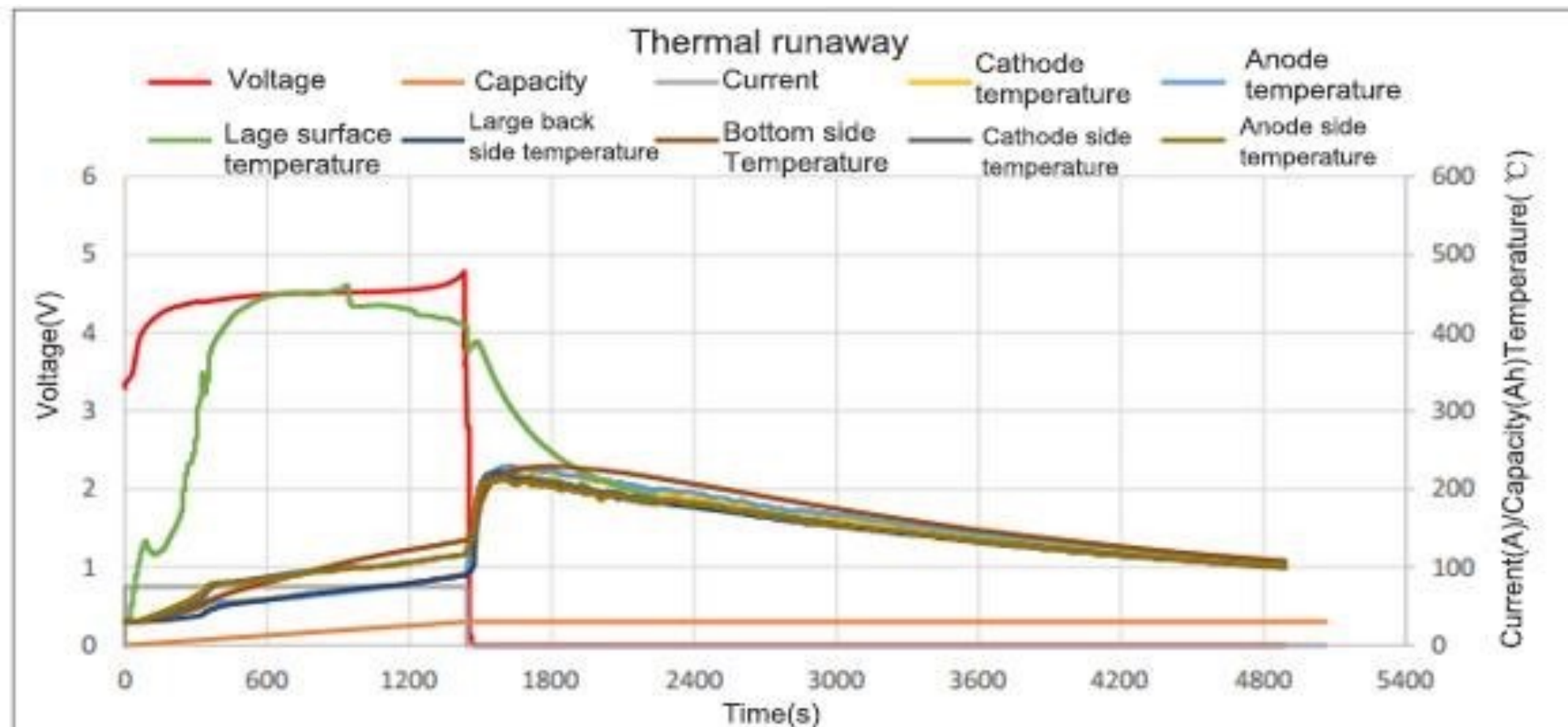


Safety tests (polyanion)

Test		Specification	Result
1	Short circuit	No explosion, no fire	Passed
2	Over charging	No explosion, no fire	Passed
3	Over discharging	No explosion, no fire	Passed
4	Crush test	No explosion, no fire, no leakage	Passed
5	Humidity cycling	No explosion, no fire, no leakage	Passed
6	Thermal abuse	No explosion, no fire, no leakage	Passed
7	Nail penetration	No explosion, no fire, no leakage	Passed
8	Low pressure	No explosion, no fire, no leakage	Passed
9	Vibration	No explosion, no fire, no leakage	Passed

Reference:
GB / T36276-2018
Lithium Ion Battery for
Electric Energy Storage

Safety tests (polyanion):): overcharging + heating



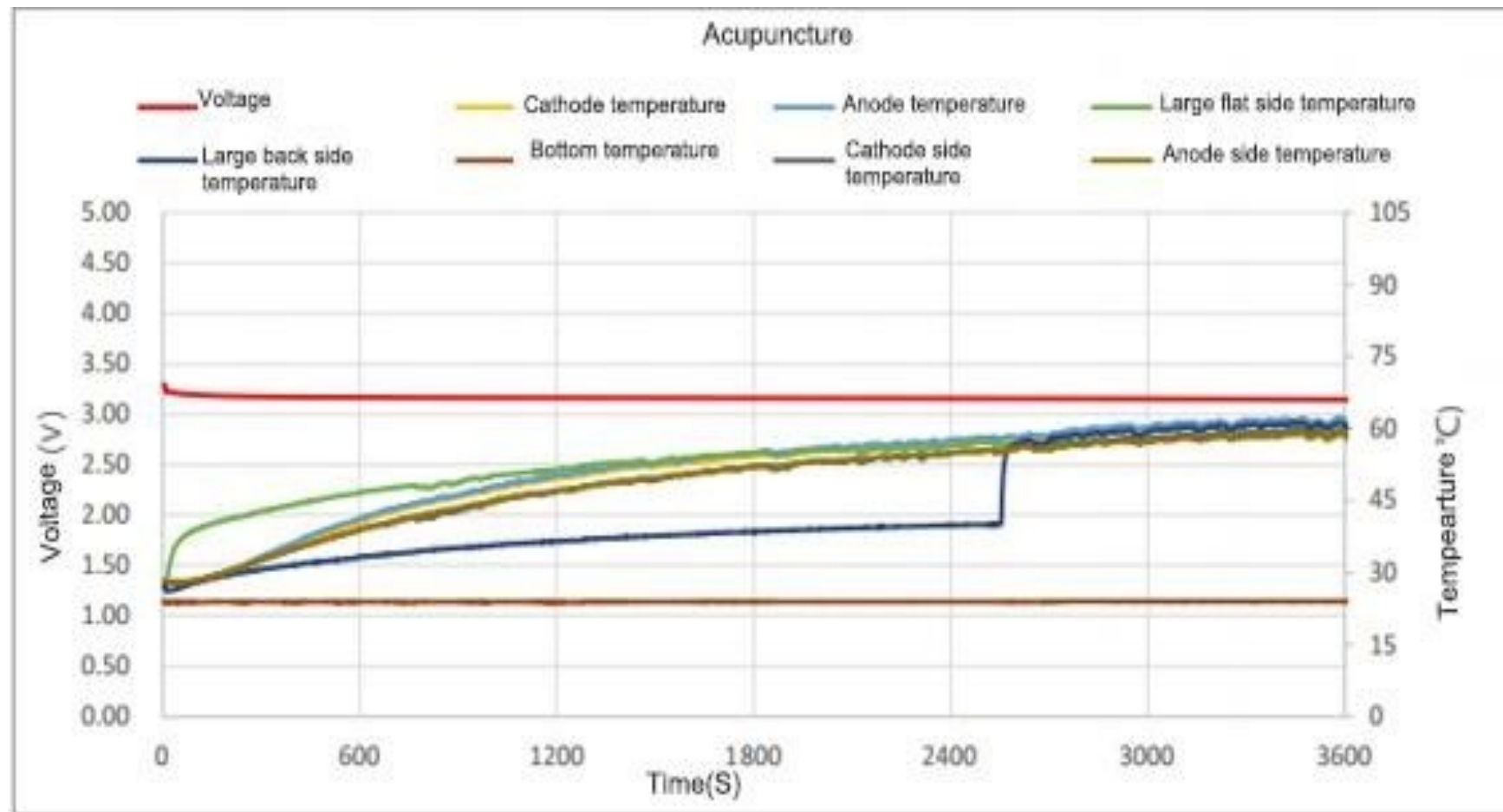
Fully charged cell is overcharged + heated till thermal runaway (Voltage = 0)

Result No fire, no explosion

Thermal runaway temperature: about 220 °C



Safety tests (polyanion): nail penetration test



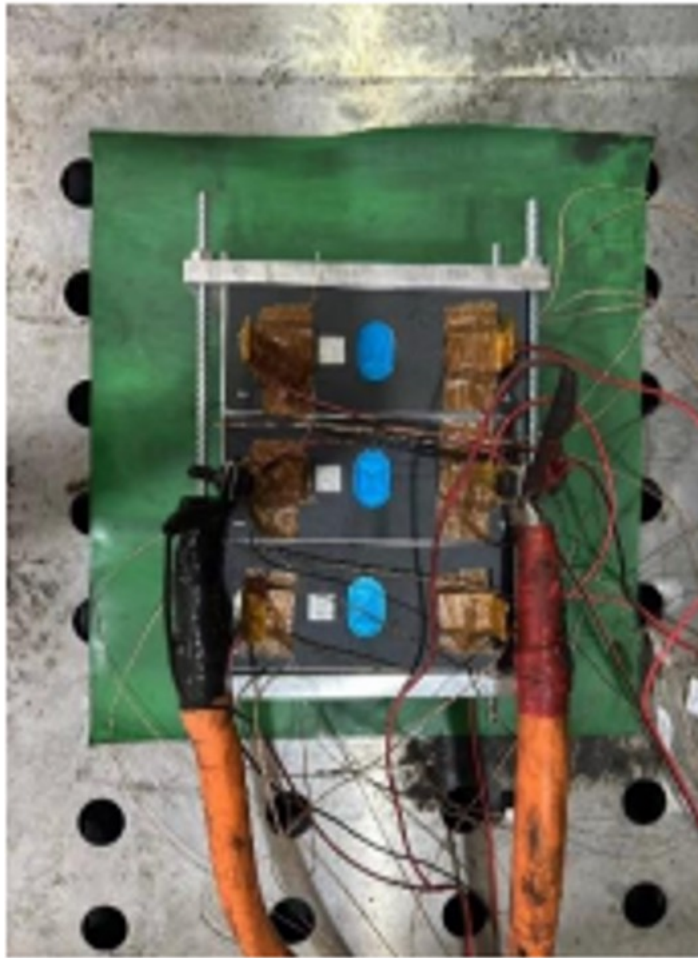
Fully charged cell is nail penetrated during 60 minutes

Result No fire, no explosion

Temperature after 60 minutes: about 60 °C



Safety tests (polyanion): forced thermal runaway in battery modules

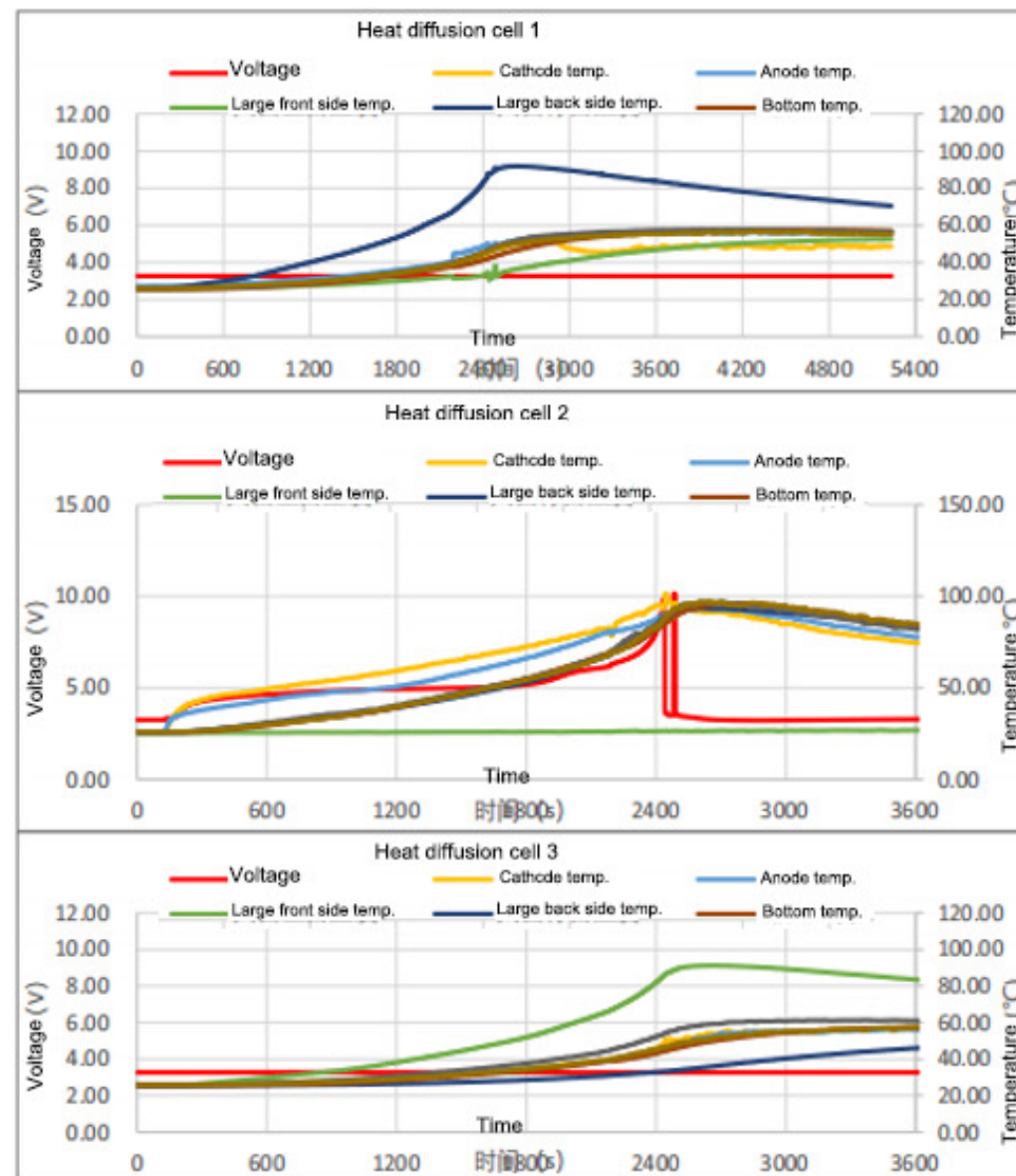


3 fully charged cells in module

Overcharge middle cell till thermal runaway ($V = 0$)

Result No fire, no explosion

Temperature after 45 minutes: about 100 °C, 60°C for adjacent cells



Game-changing Sodium-ion batteries for sustainability

A practical and sustainable battery must meet many criteria combined

Lithium-ion battery cells

Fire risk

BMS

No charging $< 0^{\circ}\text{C}$

Active cooling/heating

Short time limited power

Energy, 60 to 80 % usable

Limited temperature range

Fast charging is problematic

3000 to 8000 cycles

Sustainable?

Cost efficient

Many announcements

Sodium-ion battery cells

NO spontaneous fire risk

BMS, charger modulates power $< 5^{\circ}\text{C}$

Can charge at -10°C , current modulation $< 5^{\circ}\text{C}$

Often no need for active thermal management

Higher power, up to 20°C at all temperatures

Energy, 100% usable

Works from -40°C to $+60^{\circ}\text{C}$

Charging in 20-30 min possible

3000 to > 6000 cycles

No Lithium, no Nickel, no Cobalt, easy recycling

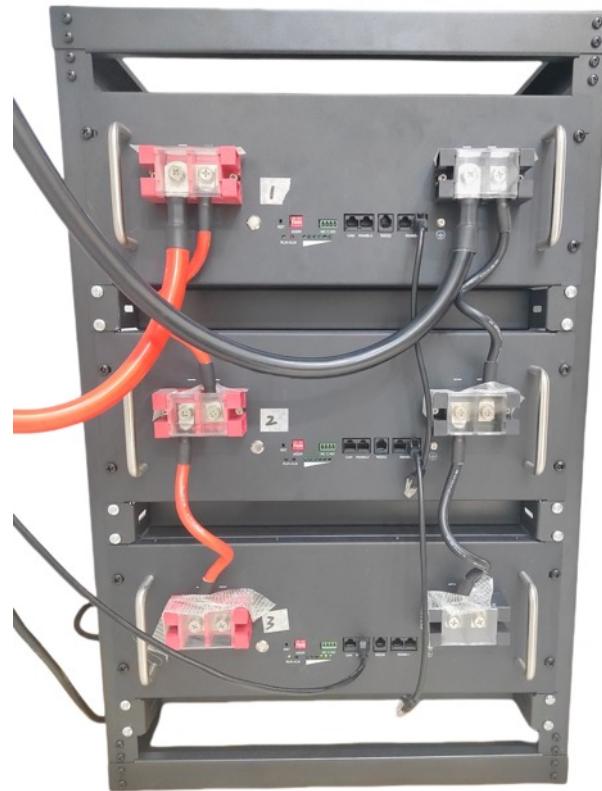
Cost efficient

In production since 2 years

Applications:

Solar energy storage

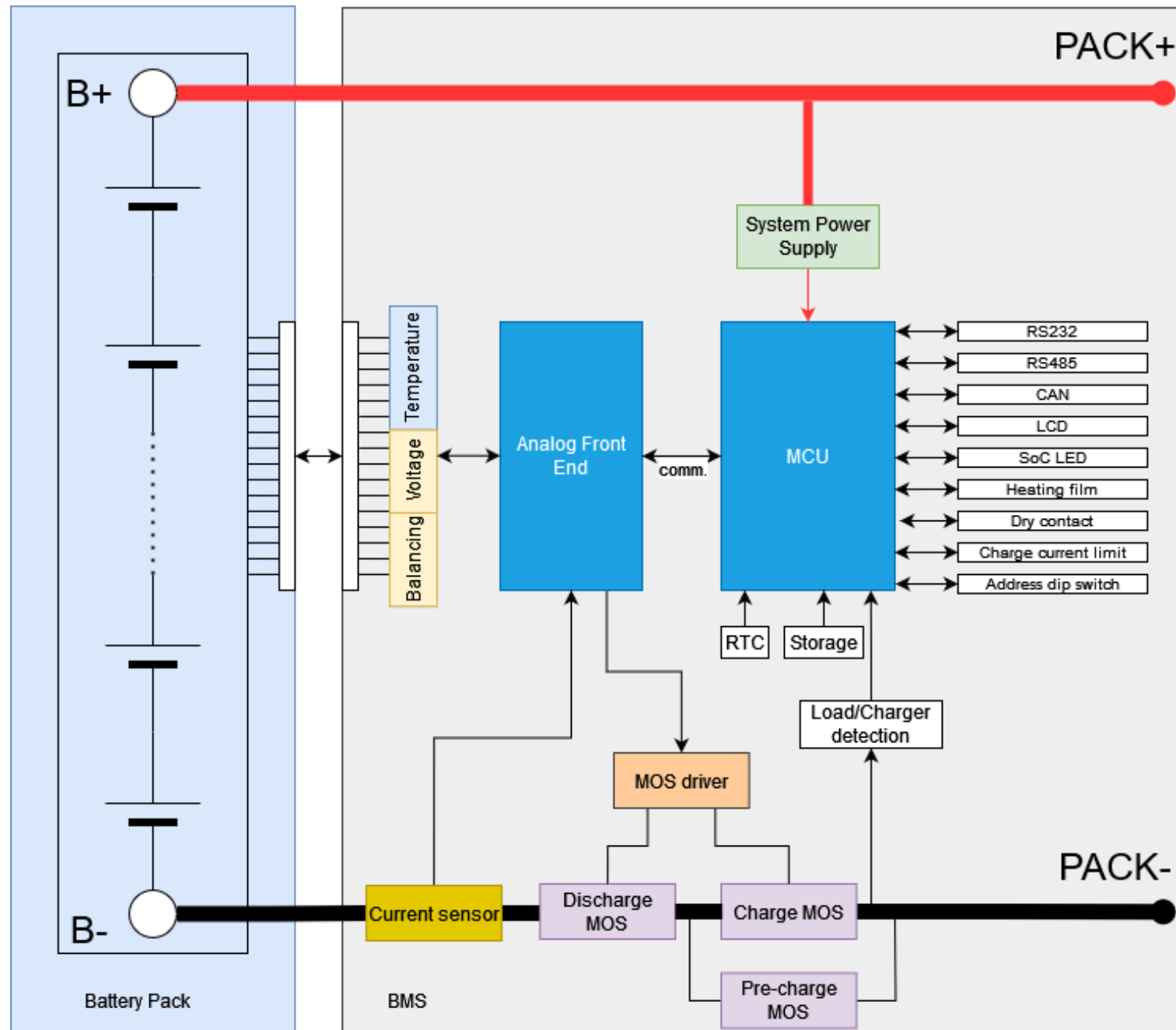
Light / small electric vehicles



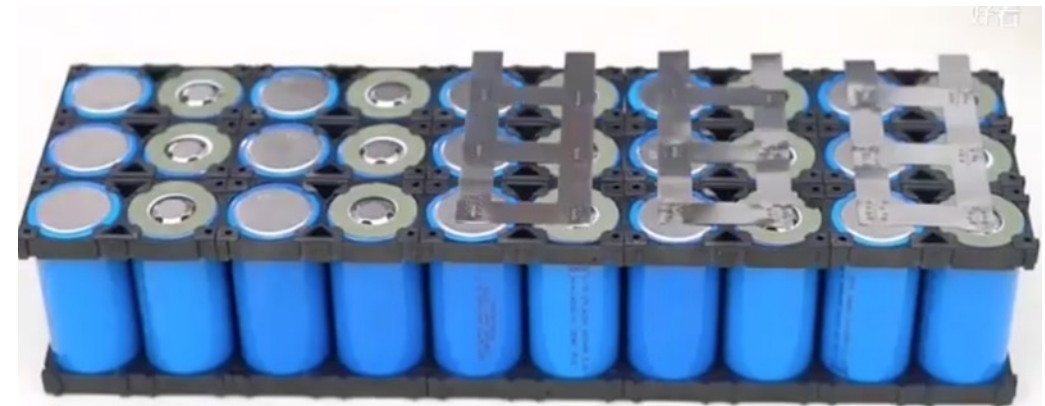
Retrofitting existing systems



Battery construction



- Parallel first, then serial at module level
- BMS (active balancing)
- Battery Monitoring sufficient
- Parallel modules only at battery level to increase capacity
- Heat absorbing silicon gel inside
- Or forced airflow



For illustration only

Process flow for customer specific solutions

- **Requirements collection:**
 - **Understanding the application and the system**
 - **Understanding the boundary conditions**
- **Feasibility study:**
 - **Selecting cell types**
 - **Initial battery configuration: (S xP), multi-module, ...**
- **Load profile simulations**
 - **Beginning of Life – End of Life**
 - **Calendar lifetime calculations**
- **CAD design**
 - **Enclosure, safety devices, etc.**
- **Assembly and test**

Kurt.energy division of Altreonic

Questions?

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