
SES

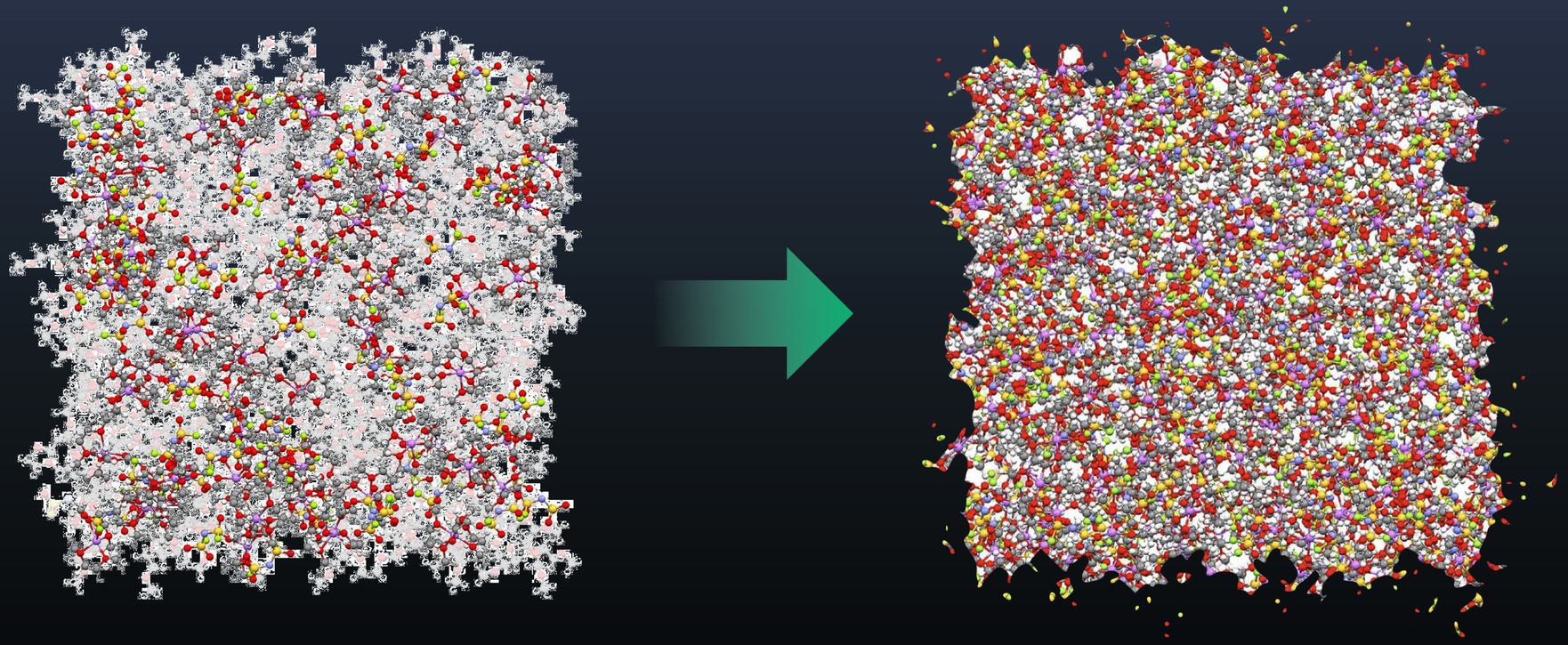
2012

Solid Polymer Ionic

Liquid Li-Metal

2015

High concentration solvent-in-salt electrolyte for Li-Metal



2017

Hermes™

High Energy Rechargeable Metal cElls for Space

2019

Avatar – Battery digital twin with full traceability

DNA (material/cell design),

Pregnancy (manufacturing),

Lifestyle (test data)

2021

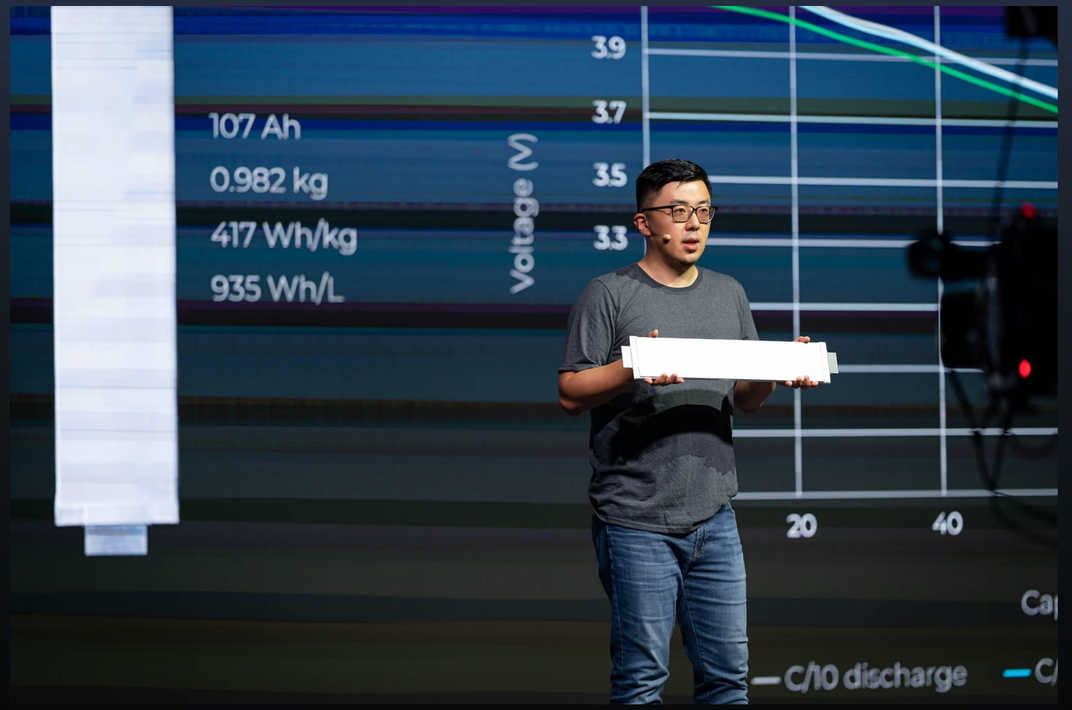
World's first automotive
A-sample JDA for Li-Metal

HONDA

HYUNDAI

gm

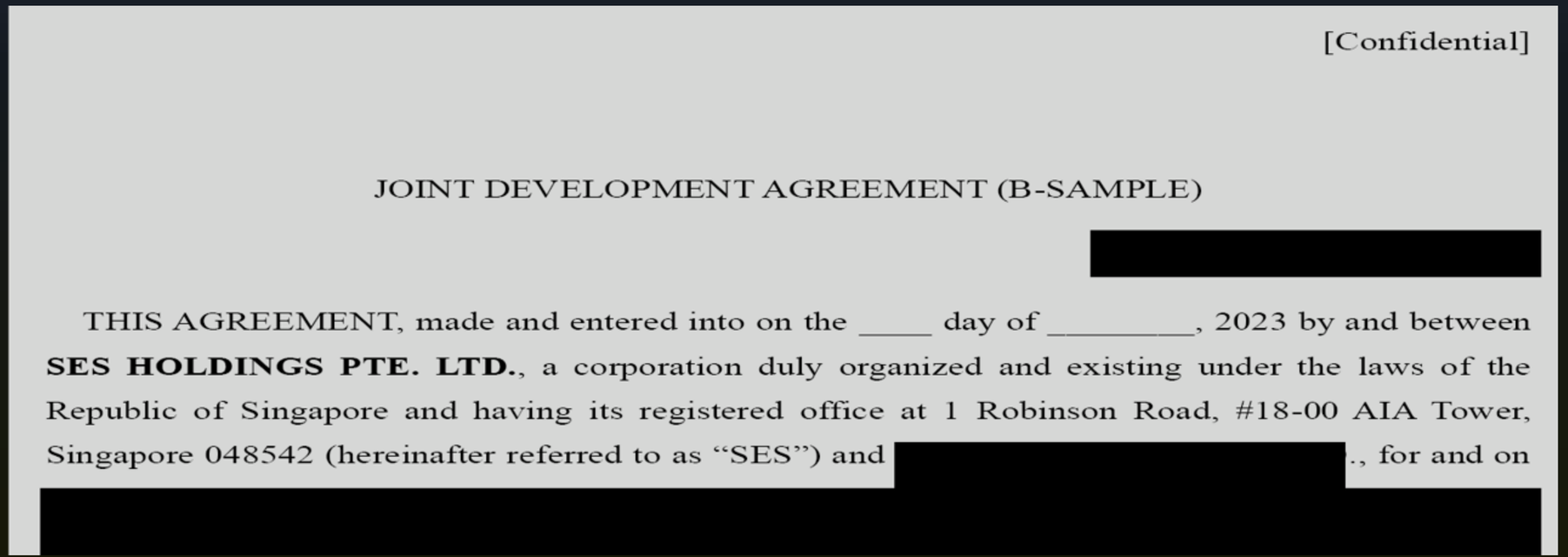
World's largest
Li-Metal cell




SES

World's first automotive B-sample JDA for Li-Metal

It's one small step for SES's Li-Metal,
one giant leap for the future of transportation both on land and in air



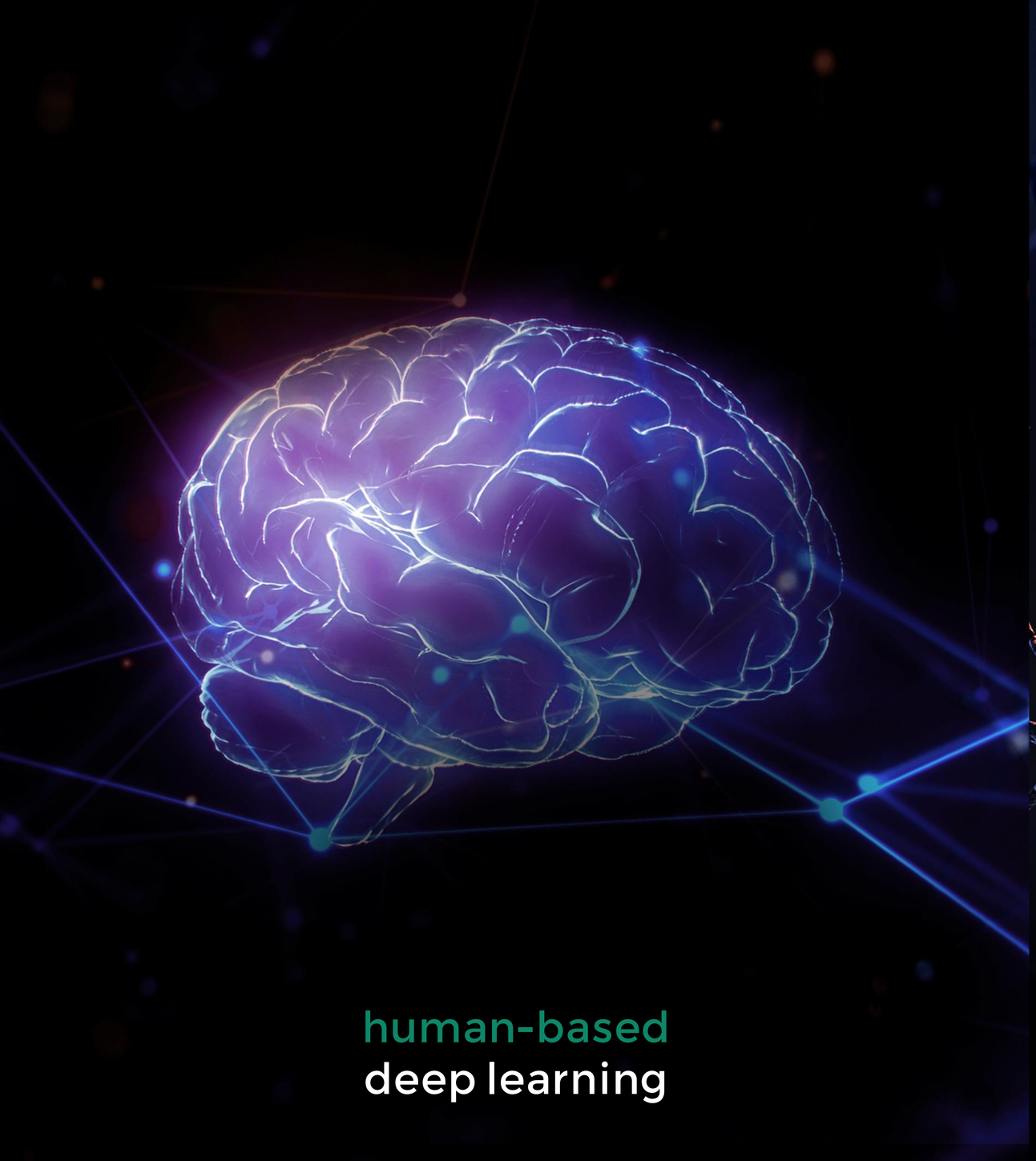
[Confidential]

JOINT DEVELOPMENT AGREEMENT (B-SAMPLE)

[redacted]

THIS AGREEMENT, made and entered into on the _____ day of _____, 2023 by and between **SES HOLDINGS PTE. LTD.**, a corporation duly organized and existing under the laws of the Republic of Singapore and having its registered office at 1 Robinson Road, #18-00 AIA Tower, Singapore 048542 (hereinafter referred to as "SES") and [redacted]., for and on

[redacted]



human-based
deep learning

machine-based
deep learning

+ MODEL
ARTICLE IN PRESS
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ScienceDirect
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www.keaipublishing.com/gee

Research paper

All-fluorinated electrolyte for non-flammable batteries with ultra-high specific capacity at 4.7 V

Zhe Wang [a,1], Zhuo Li [a,1], Jialong Fu [a], Sheng Zheng [a], Rui Yu [a], Xiaoyan Zhou [a], Guanjie He [b], Xin Guo [a,*]

[a] State Key Laboratory of Material Processing and Die & Mould Technology, Laboratory of Solid State Ionics, School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan, 430074, PR China
[b] Electrochemical Innovation Lab, Department of Chemical Engineering, University College London, 20 Gordon Street, London WC1E 7JE, UK

Received 3 February 2023; revised 26 May 2023; accepted 11 June 2023
Available online ■ ■ ■

Abstract

Li metal batteries (LMBs) with $LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$ (NMC811) cathodes could release a specific energy of >500 Wh kg^{-1} by increasing the charge voltage. However, high-nickel cathodes working at high voltages accelerate degradations in bulk and at interfaces, thus significantly degrading the cycling lifespan and decreasing the specific capacity. Here, we rationally design an all-fluorinated electrolyte with addictive tri(2,2,2-trifluoroethyl) borate (TFEB), based on 3, 3, 3-fluoroethylmethylcarbonate (FEMC) and fluoroethylene carbonate (FEC), which enables stable cycling of high nickel cathode ($LiNi_{0.8}Co_{0.1}Mn_{0.1}O_2$, NMC811) under a cut-off voltage of 4.7 V in Li metal batteries. The electrolyte not only shows the fire-extinguishing properties, but also inhibits the transition metal dissolution, the gas production, side reactions on the cathode side. Therefore, the NMC811||Li cell demonstrates excellent performance by using limited Li and high-loading cathode, delivering a specific capacity >220 mA h g^{-1}, an average Coulombic efficiency >99.6% and capacity retention >99.7% over 100 cycles.

Keywords: Fluorinated electrolyte; Li metal batteries; Solid electrolyte interphase; Cathode electrolyte interphase; Coulombic efficiency

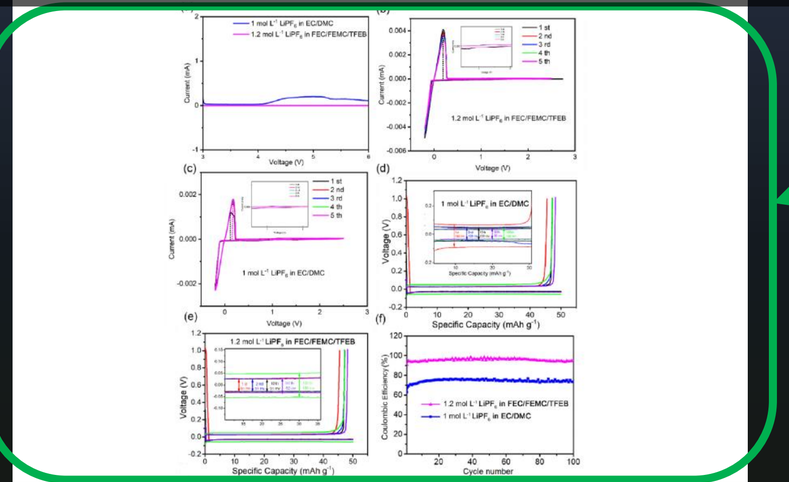
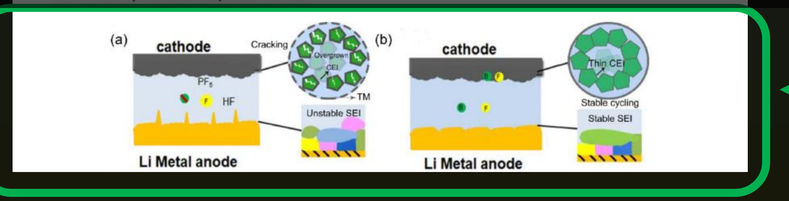


Fig. 2. (a) Oxidation stability of $LiPF_6$ FEC/FEMC/TFEB electrolyte and $LiPF_6$ EC/DMC electrolytes in Li||stainless steel cells measured by LSV at a scanning rate of 1 mV s^{-1}. (b) Oxidation/reduction stability of $LiPF_6$ EC/DMC electrolyte in Li||stainless steel cells measured by CV at a scanning rate of 2 mV s^{-1}. (c) Oxidation/reduction peak of $LiPF_6$ FEC/FEMC/TFEB fully-fluorinated electrolyte for forming SEI layer determined in Li||stainless steel cells and Oxidation/reduction stability of fully-fluorinated electrolyte by CV at a scanning rate of 2 mV s^{-1}. (d) Li-metal plating/stripping profiles on Cu foil cycled in $LiPF_6$ EC/DMC electrolyte at 0.5 mA cm^{-2}. (e, f) Li-metal plating/stripping profiles on Cu foil cycled in $LiPF_6$ FEC/FEMC/TFEB electrolyte at 0.5 mA cm^{-2}. Li plating/stripping Coulombic efficiency in different electrolytes at 0.5 mA cm^{-2}.

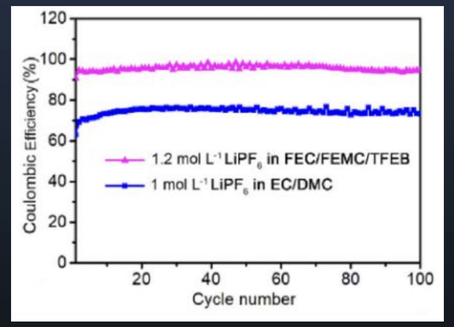


text

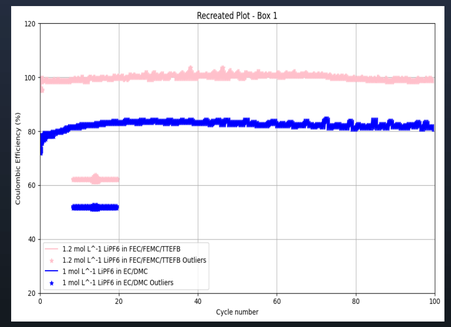
data

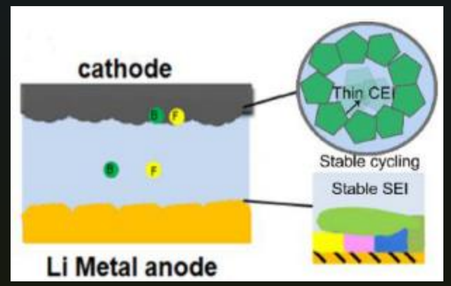
illustrations

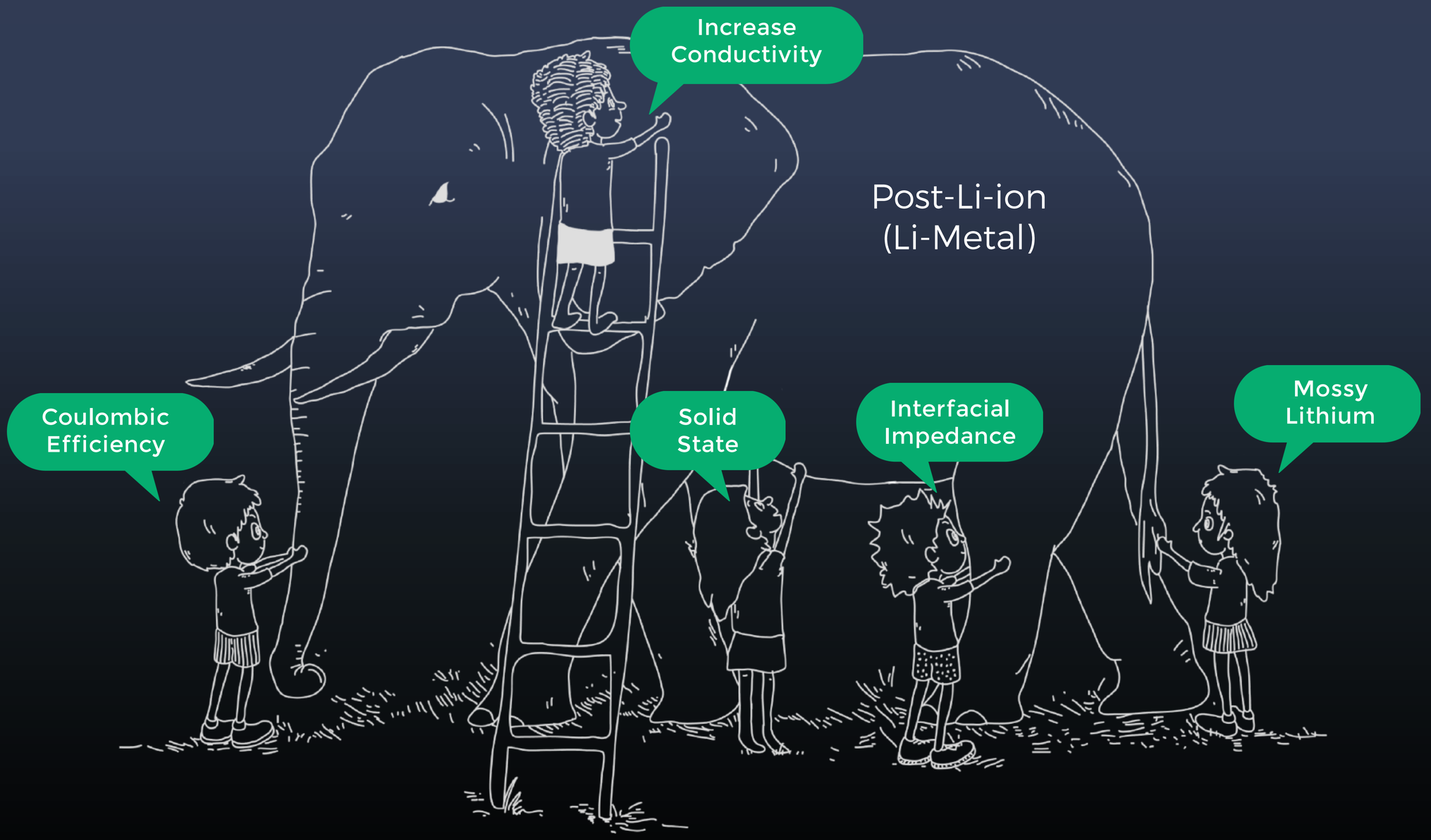
```
The electrolyte used in the research paper is a fully fluorinated electrolyte. It consists of the following components:

1. Electrolyte Solvents:
- 3,3,3-fluoroethylmethyl carbonate (FEMC)
- Fluoroethylene carbonate (FEC)
- Tri(2,2,2-trifluoroethyl) borate (TFEB)

2. Electrolyte Salt:
- Lithium hexafluorophosphate (LiPF6)

3. Additives:
- None mentioned in the paper

The ratio of the solvents and salt in the electrolyte is not explicitly mentioned in the paper.

The ion conductivity and coulombic efficiency of the electrolyte are mentioned in the paper.
The electrolyte demonstrates stable cycling performance with an average Coulombic efficiency >99.6% and capacity retention >99.7% over 100 cycles.
However, specific values for ion conductivity are not provided in the paper.
```



Reconstruct from image w/o data

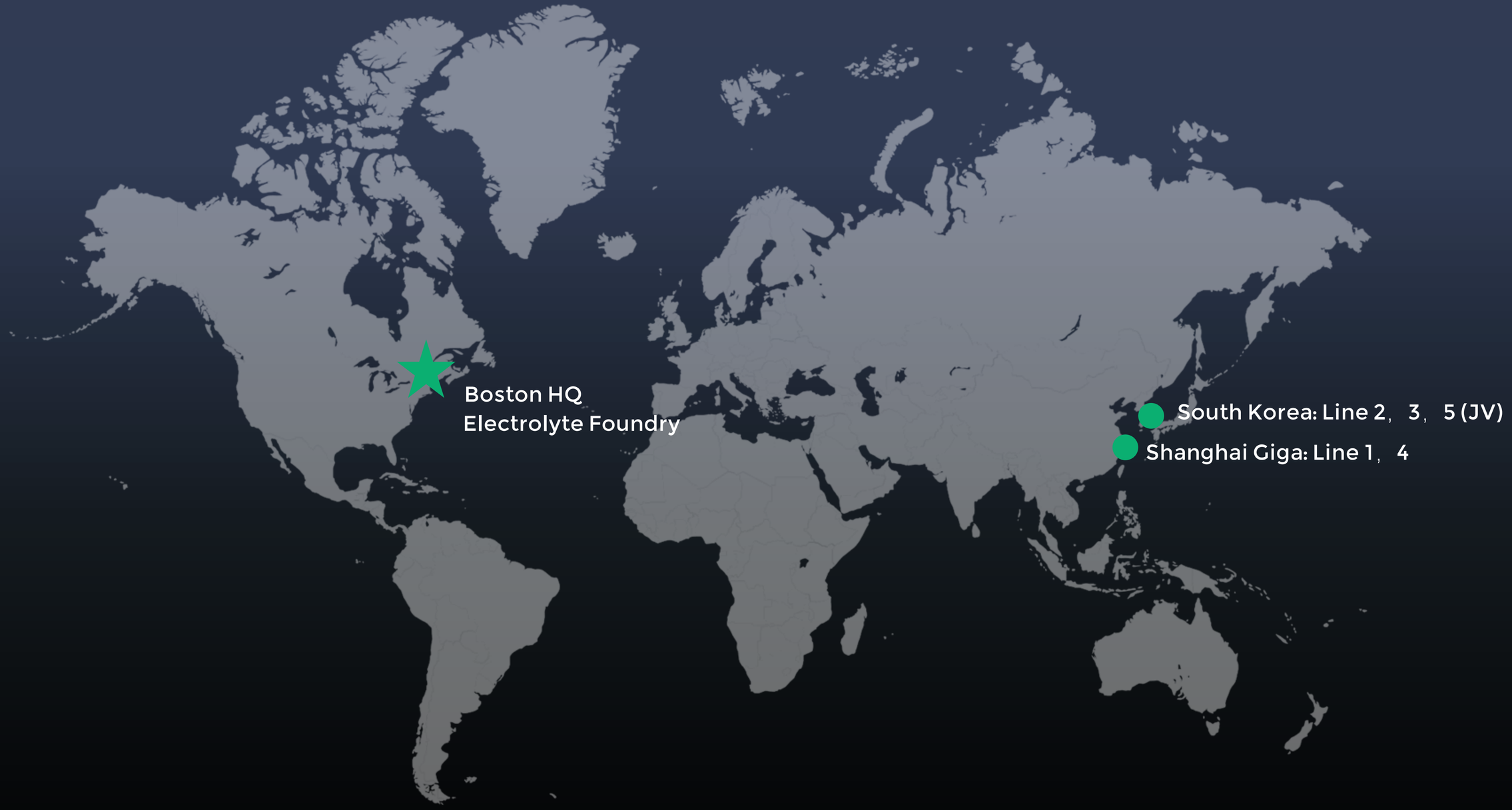





Increase Conductivity
Post-Li-ion (Li-Metal)
Coulombic Efficiency
Solid State
Interfacial Impedance
Mossy Lithium

Electrolyte Foundry

Boston, MA


Boston HQ
Electrolyte Foundry
South Korea: Line 2，3，5 (JV)
Shanghai Giga: Line 1，4

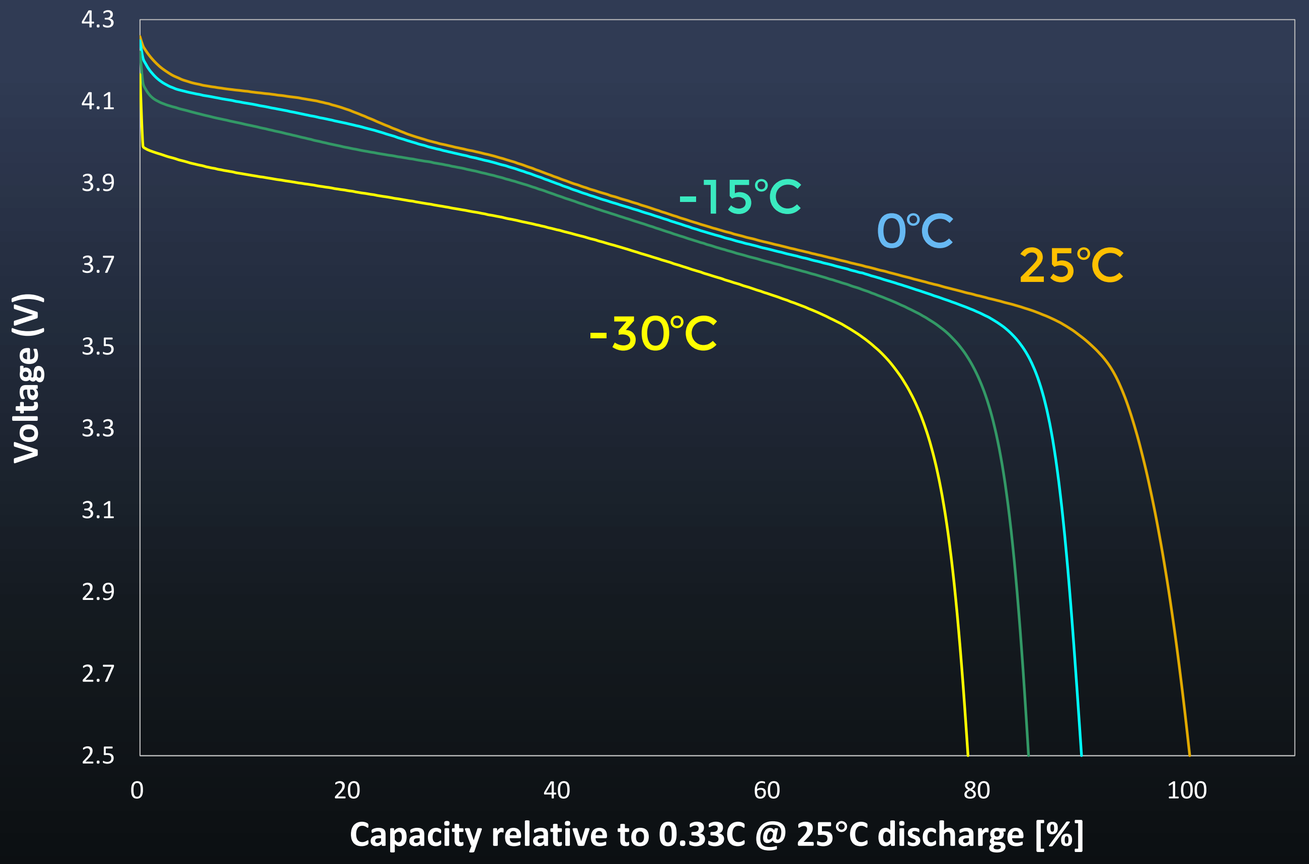
SES Chungju 100 Ah Test Bunker

SES Shanghai 100 Ah Test Bunker

	Cell Type	4.2Ah (25+ layer) at 25°C	50.7Ah (16+ layer) at 25°C	105.8Ah (32+ layer) at 25°C
Room Temperature (25℃) Energy Density	Low power C/20	> 375 Wh/Kg	-	-
	Low power C/10	375 Wh/Kg (= 700 Wh/L at SOC 0%)	357 Wh/Kg (= 773 Wh/L at SOC 30%)	399 Wh/Kg (= 862 Wh/L at SOC 30%)
	Medium power C/3	-	342 Wh/Kg (=743 Wh/L)	390 Wh/Kg (=842 Wh/L)
	Medium power 1C	339 Wh/Kg	-	370 Wh/Kg
	High power 3C	-	303 Wh/Kg	351 Wh/Kg
	High power 5C	321 Wh/Kg	-	-
Low Temperature (0℃) Energy Density	Low power C/10	324 Wh/Kg	-	-
	Medium power C/3	-	305 Wh/Kg	346 Wh/Kg
	Medium power 1C	298 Wh/Kg	-	-
	High power 5C	282 Wh/Kg	-	-
Lifetime (Ch-Dch)	C/10 – C/3	600 cycles (80% retention)	>200 cycles (Ongoing)	>300 ongoing
	C/3 – C/3	300 cycles (80% retention)	210 cycles (80% retention)	>250 ongoing
	C/5 - 1C	700 cycles (80% retention)	-	-
Fast Charging	Charge at 4C	80% in <15min	-	-
Safety	Thermal	Electrolyte is stable with Li above Li melting point	PASS TEST	PASS TEST
	Nail Penetration	PASS TEST	PASS TEST	PASS TEST
	Overcharge	PASS TEST	PASS TEST	PASS TEST
	External Short Circuit	PASS TEST	PASS TEST	PASS TEST
Certification		UN38.3	UN38.3, IATF16949	UN38.3
Manufacturability		(highly similar process to Li-ion)		
Tested Operating Temperature		-30 °C to 60 °C	-10 °C to 45 °C	-10 °C to 45 °C

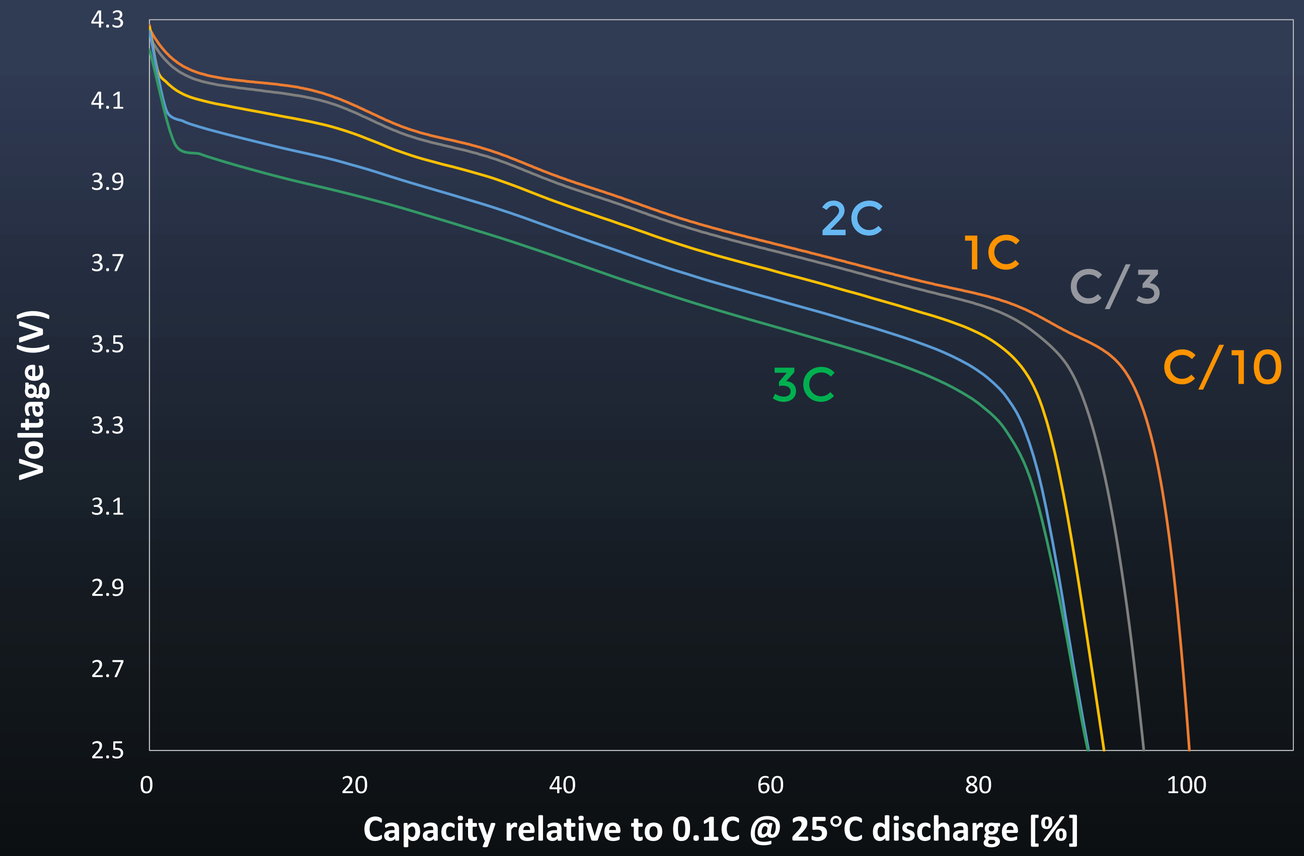
Excellent performance in cold weather

Retains 80% capacity (C/3 at 25°C) even at -30°C



Excellent performance in high power requirements

Retains 90% capacity (C/3 at 25°C) even at 3C

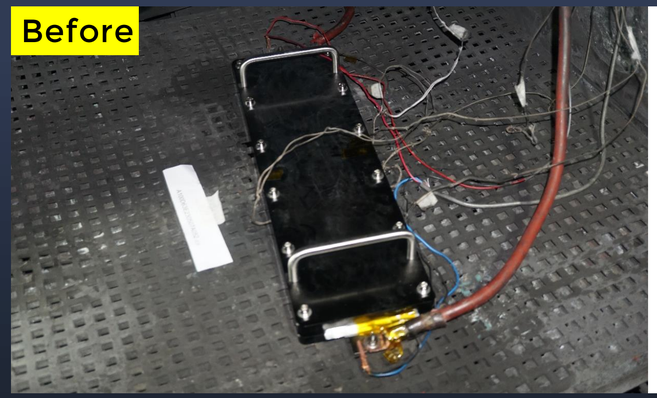


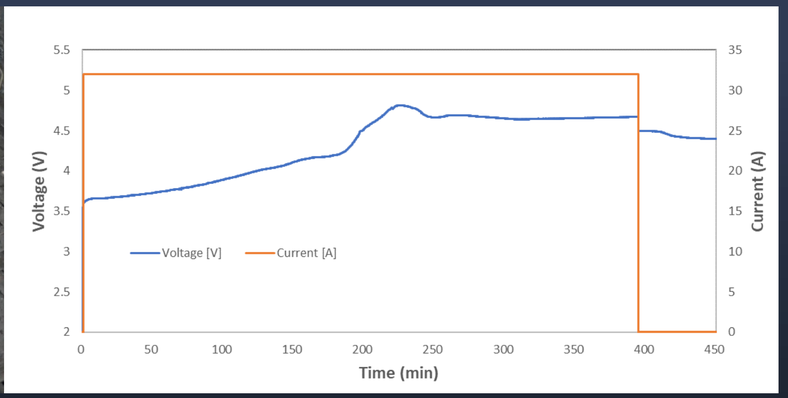
Overcharge

✓ Passed

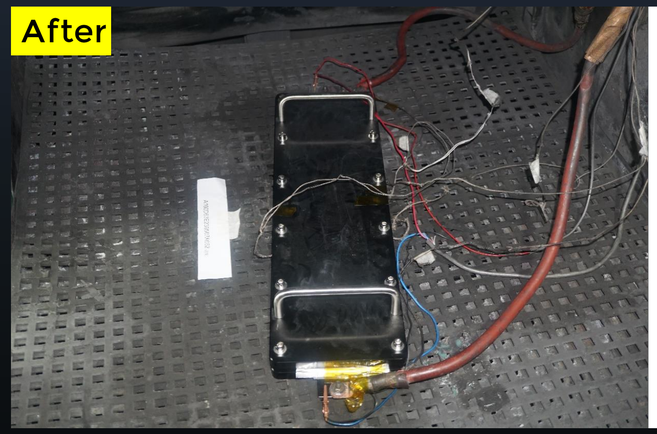
(3rd party test)

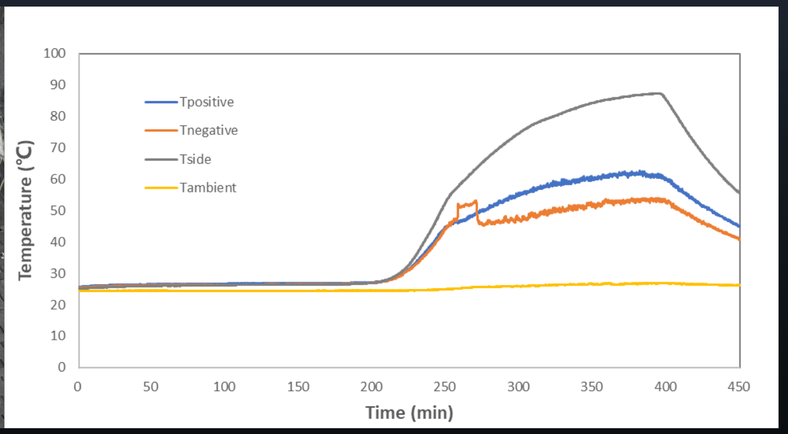
Before





After

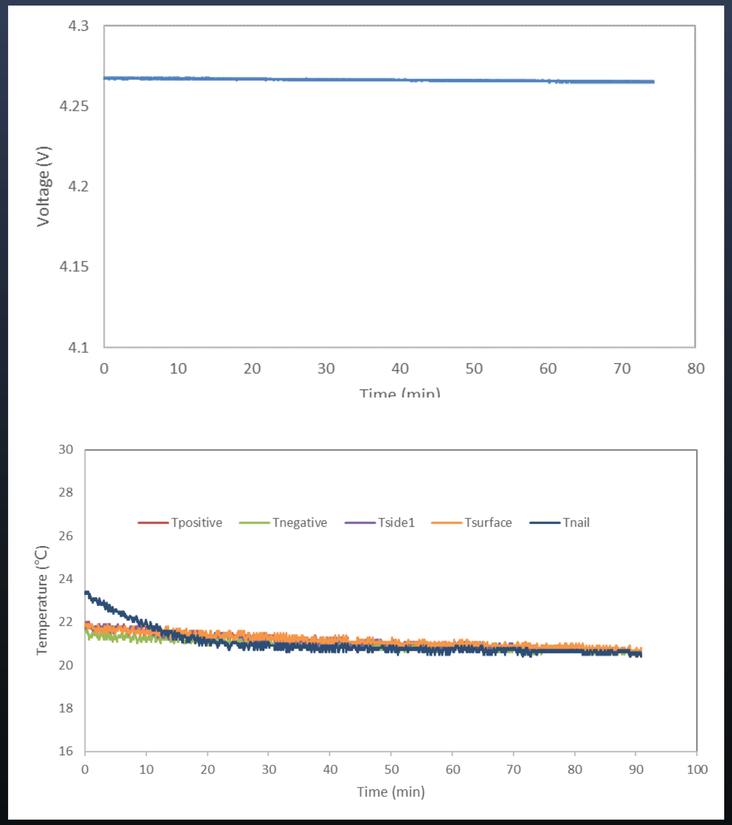




Nail Penetration

✓ Passed

(3rd party test)

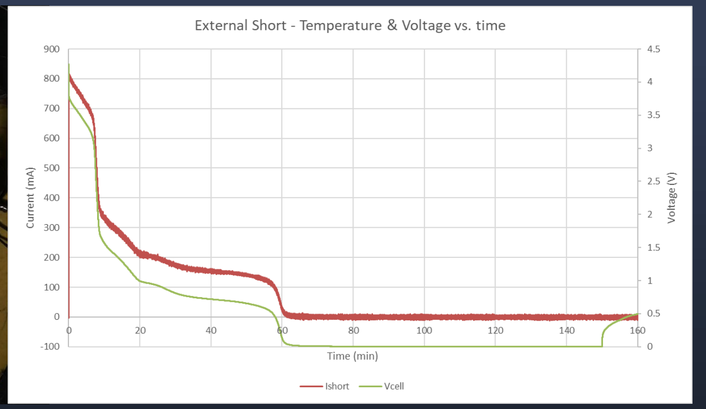


External Short Circuit

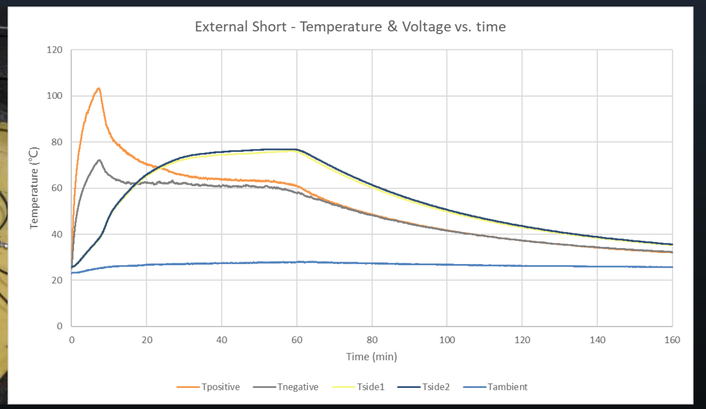
✓ Passed

(3rd party test)

Before



After

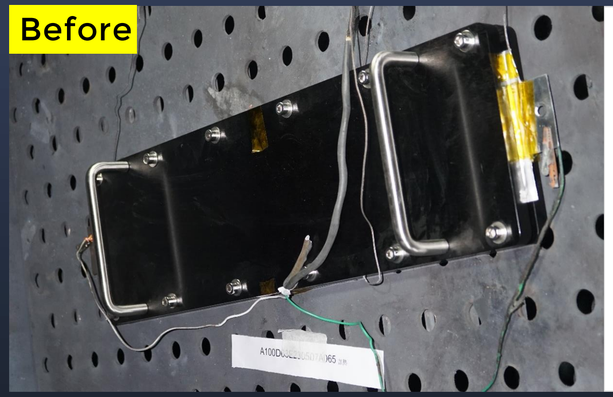


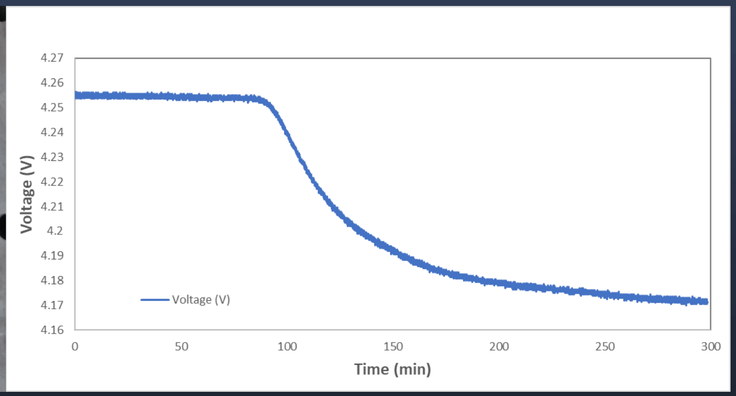
Thermal Stability

✓ Passed

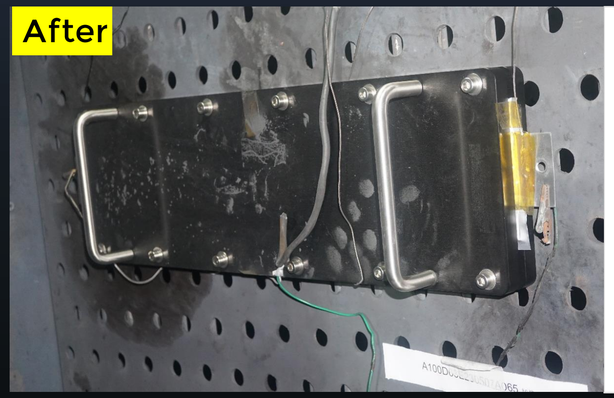
(3rd party test)

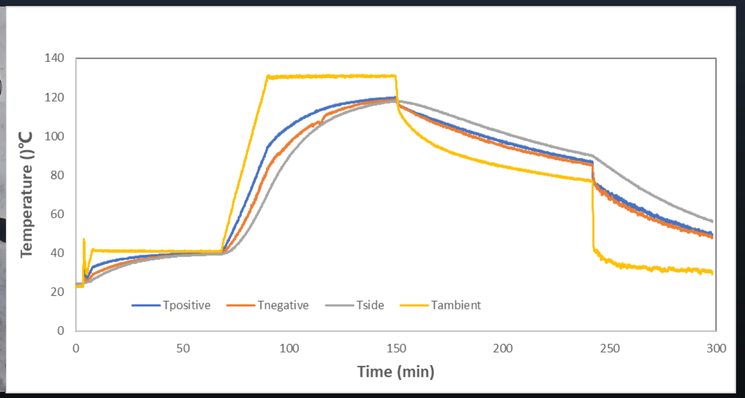
Before





After





UN38.3 试验概要

LITHIUM CELLS OR BATTERIES TEST SUMMARY
IN ACCORDANCE WITH SUB-SECTION 38.3
OF UN MANUAL OF TESTS AND CRITERIA

中认英泰检测技术有限公司
CQC Intime Testing Technology Co.,Ltd.

NO. CQCIT2206J0297

样品描述(Sample Description)：

电池名称(Cell/battery Name)：
可充电二次锂电池芯
Rechargeable lithium battery cell

质量(Mass)：
0.51kg

规格参数(Specification Parameter)：
■锂离子电池/电芯 3.82 V 47.4 Ah 181 Wh
□锂金属电池/电芯 ___ V ___ Ah ___ g

物理形状(Physical Description)：
袋装电池 Pouch Cell

型号(Model Numbers)：
37B0582

委托单位(Applicant)：
麻省固能（上海）新能源科技有限公司
SES AI(Shanghai) Co., Ltd
上海市嘉定区招贤路 1581 号
Zhaoxian road 1581, Jiading district, Shanghai
021-59901136
victorsun@ses.ai
www.ses.ai

样品生产厂商(Sample Manufacturer)：
麻省固能（上海）新能源科技有限公司
SES AI(Shanghai) Co., Ltd
上海市嘉定区招贤路 1581 号
Zhaoxian road 1581, Jiading district, Shanghai
021-59901136
victorsun@ses.ai
www.ses.ai

UN38.3 测试实验室(UN38.3 Test Lab)：
中认英泰检测技术有限公司
CQC Intime Testing Technology Co., Ltd.
江苏省苏州市吴中区吴中大道 1368 号东太湖科技金融城
East Taihu Technology and Finance City, No.1368 Wuzhong Dadao Road, Wuzhong Economic Development Zone, Suzhou, Jiangsu.
0512-66303623 cqc_jszlb@126.com
http://www.cqc-it.com

样品测试信息(Sample Test Information)：

试验报告编号(Test Report Number)：
20220706J18449

试验报告签发日期(Date of Test Report)：
2022-09-06

所用《试验和标准手册》版本(Edition of UN Manual of Tests and Criteria Used)：
《关于危险货物运输的建议书 试验和标准手册》第七版修订 1 第 38.3 节
Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, ST/SG/AC.10/11/Rev.7/Amend.1/Section 38.3

所进行的试验及其结果(即：通过/未通过)一览表(List of Tests Conducted and Results(Pass/Fail))：

T1	高度模拟(Altitude simulation)	Pass
T2	温度试验(Thermal test)	Pass
T3	振动(Vibration)	Pass
T4	冲击(Shock)	Pass
T5	外部短路(External short circuit)	Pass
T6	撞击/挤压(Impact/Crush)	Pass
T7	过度充电(Overcharge)	Not applicable
T8	强制放电(Forced discharge)	Pass

是否符合集成锂电池的测试要求(Assembled Lithium Battery Test Requirement)：
□38.3.3(f) □38.3.3(g) ■不适用 N/A

技术负责人(Technical Leader)
签发日期(Date of issue)：2022-09-06

检测专用章

50 Ah
UN 38.3: Passed

UN38.3 试验概要

LITHIUM CELLS OR BATTERIES TEST SUMMARY
IN ACCORDANCE WITH SUB-SECTION 38.3
OF UN MANUAL OF TESTS AND CRITERIA

中认英泰检测技术有限公司
CQC Intime Testing Technology Co.,Ltd.

NO. CQCIT2306J0442

样品描述(Sample Description)：

电池名称(Cell/battery Name)：
可充电二次锂电池芯
Rechargeable lithium battery cell

质量(Mass)：
0.98kg

规格参数(Specification Parameter)：
■锂离子电池/电芯 3.82 V 105.3 Ah 402 Wh
□锂金属电池/电芯 ___ V ___ Ah ___ g

物理形状(Physical Description)：
袋装电池 Pouch Cell

型号(Model Numbers)：
71B0582

委托单位(Applicant)：
麻省固能（上海）新能源科技有限公司
SES AI(Shanghai) Co., Ltd
上海市嘉定区福海路 1699 号
Fuhai road 1699, Jiading district, Shanghai
021-59901136
victorsun@ses.ai
www.ses.ai

样品生产厂商(Sample Manufacturer)：
麻省固能（上海）新能源科技有限公司
SES AI(Shanghai) Co., Ltd
上海市嘉定区福海路 1699 号
Fuhai road 1699, Jiading district, Shanghai
021-59901136
victorsun@ses.ai
www.ses.ai

UN38.3 测试实验室(UN38.3 Test Lab)：
中认英泰检测技术有限公司
CQC Intime Testing Technology Co., Ltd.
苏州市吴中经济开发区吴中大道 1368 号
No.1368 Wuzhong Dadao Road, Wuzhong Economic Development Zone, Suzhou, Jiangsu.
0512-66303621
jszlb@cqc-it.com
http://www.cqc-it.com

样品测试信息(Sample Test Information)：

试验报告编号(Test Report Number)：
20230805J23561

试验报告签发日期(Date of Test Report)：
2023-10-20

所用《试验和标准手册》版本(Edition of UN Manual of Tests and Criteria Used)：
《关于危险货物运输的建议书 试验和标准手册》第七版修订 1 第 38.3 节
Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, ST/SG/AC.10/11/Rev.7/Amend.1/Section 38.3

所进行的试验及其结果(即：通过/未通过)一览表(List of Tests Conducted and Results(Pass/Fail))：

T1	高度模拟(Altitude simulation)	Pass
T2	温度试验(Thermal test)	Pass
T3	振动(Vibration)	Pass
T4	冲击(Shock)	Pass
T5	外部短路(External short circuit)	Pass
T6	撞击/挤压(Impact/Crush)	Pass
T7	过度充电(Overcharge)	Not applicable
T8	强制放电(Forced discharge)	Pass

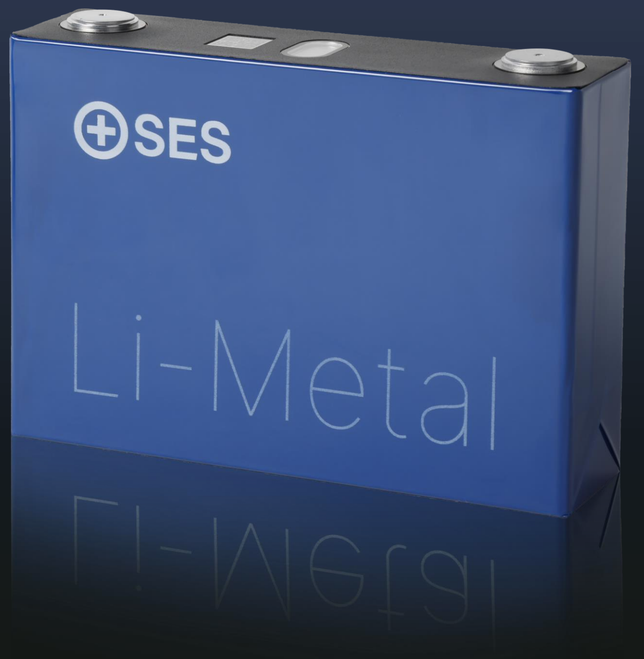
是否符合集成锂电池的测试要求(Assembled Lithium Battery Test Requirement)：
□38.3.3(f) □38.3.3(g) ■不适用 N/A

技术负责人(Technical Leader)
签发日期(Date of issue)：2023-10-20

检测专用章

100 Ah
UN 38.3: Passed


SES


SES
Li-Metal

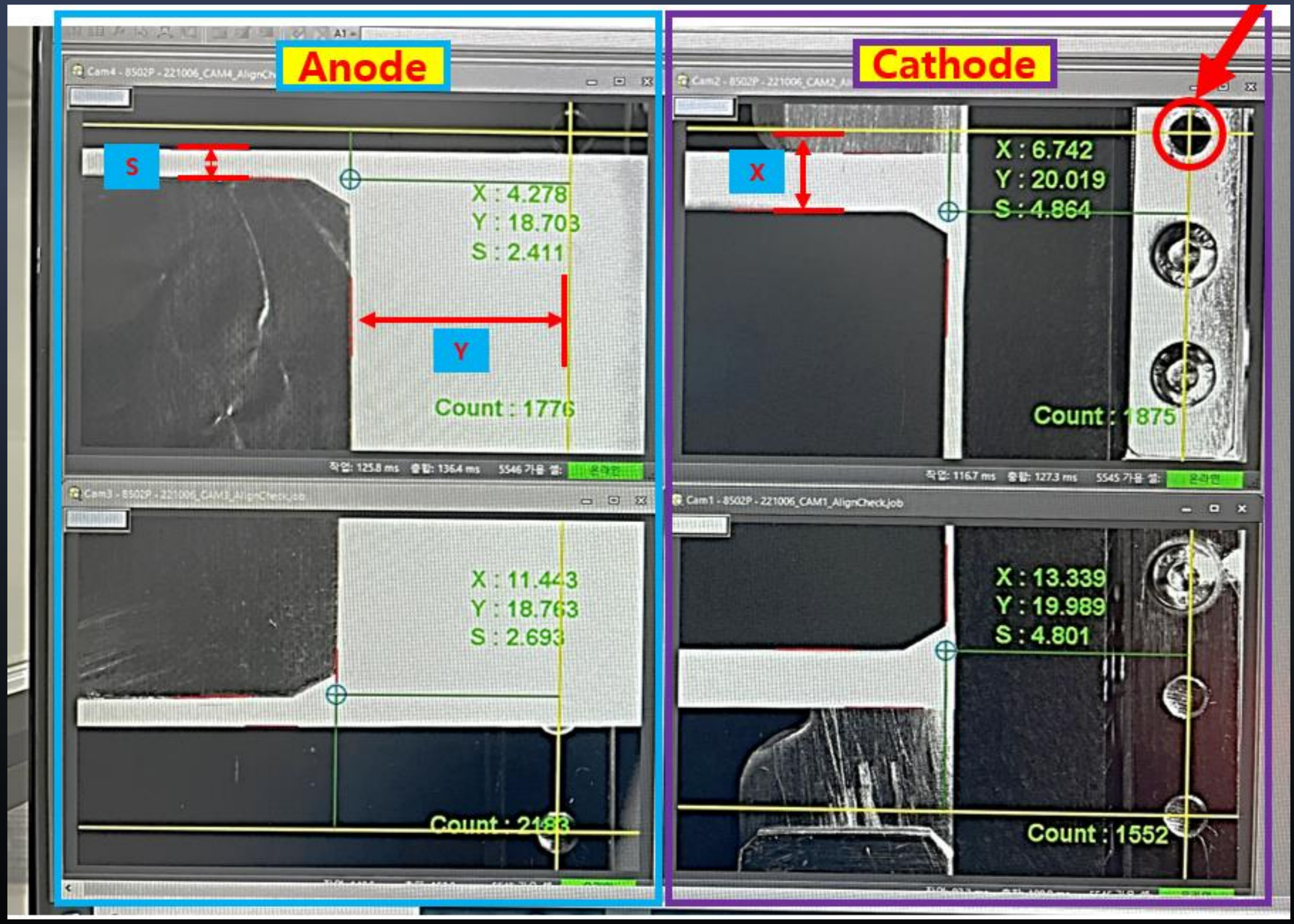

Boston HQ
Electrolyte Foundry
South Korea: Line 2.5, 3, 5 (JV)
Shanghai Giga: Line 1.5, 4

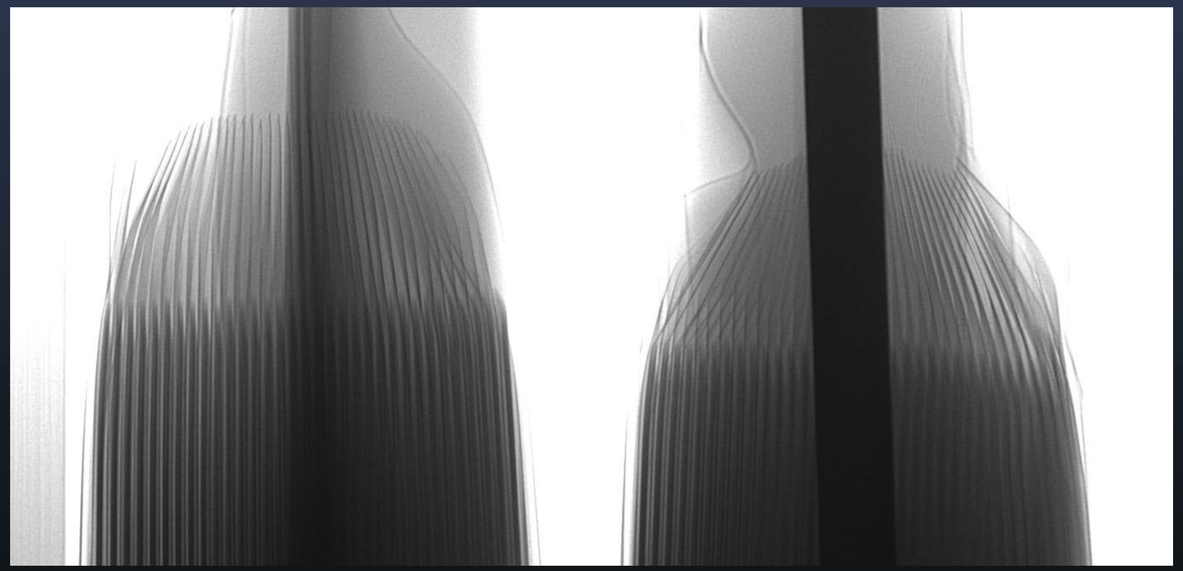
A-sample

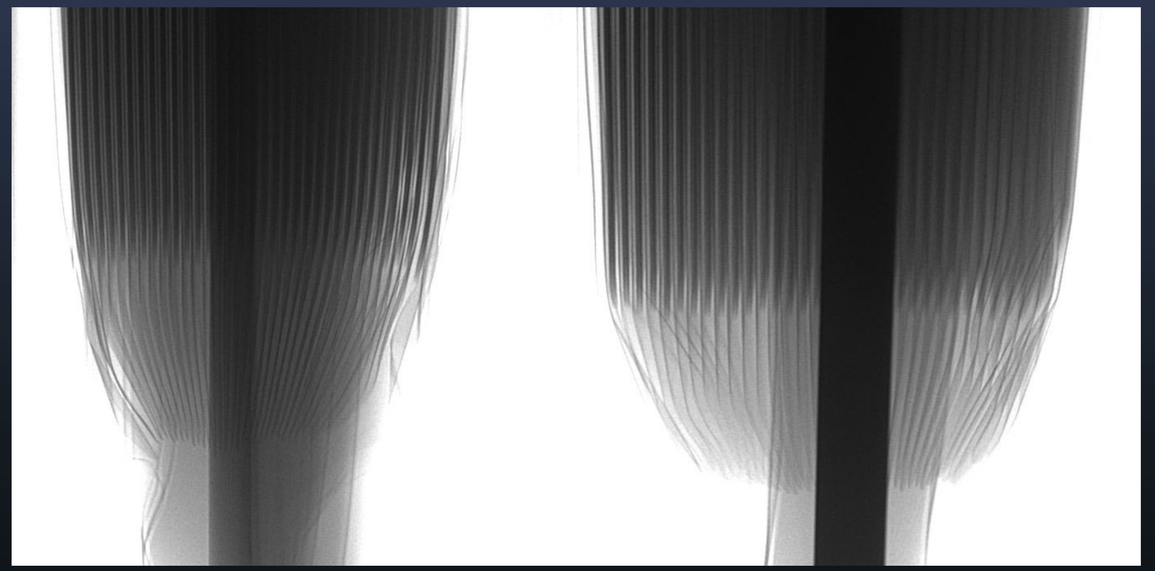
Items	control points
IQC	126
Process	260
Total	**386**

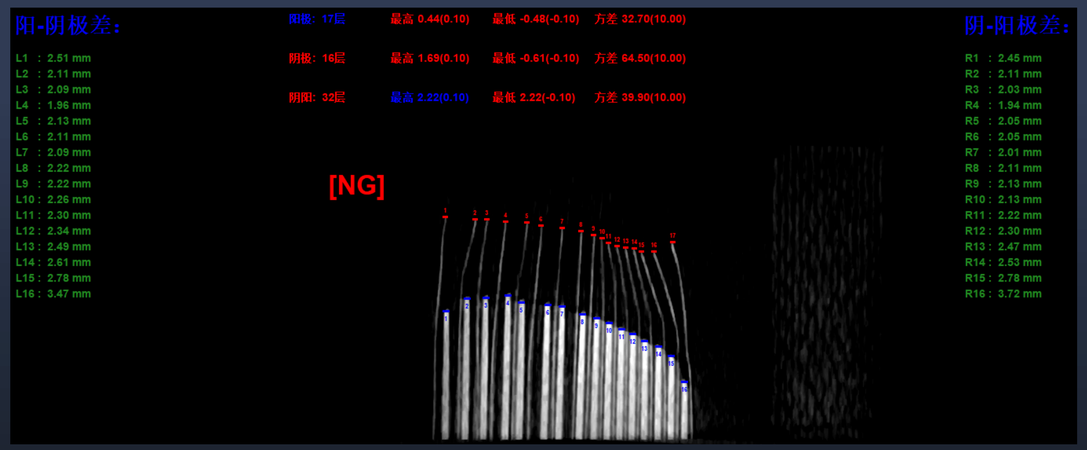
B-sample

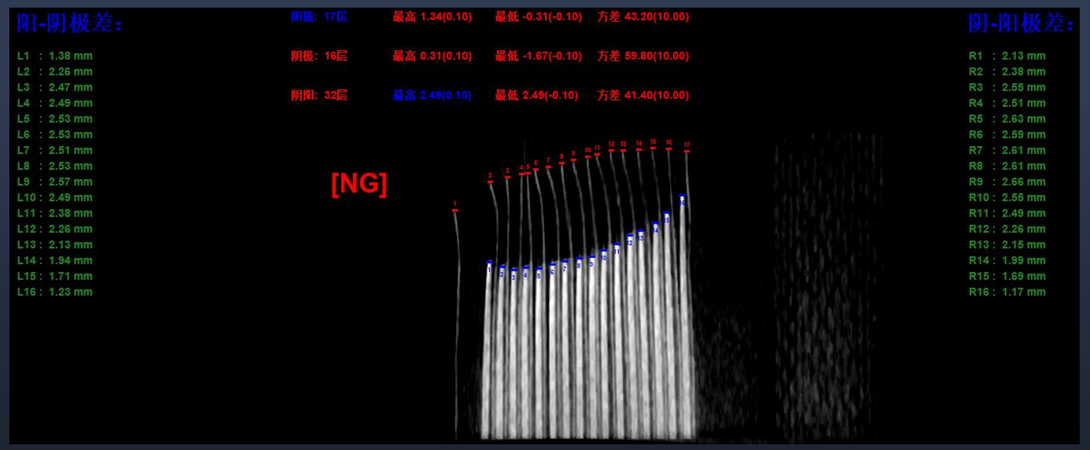
Items	control points
IQC	286
Environment	29
Cathode Line	401
Anode Line	131
Assembly 1	327
Assembly 2	269
Total	**1443**

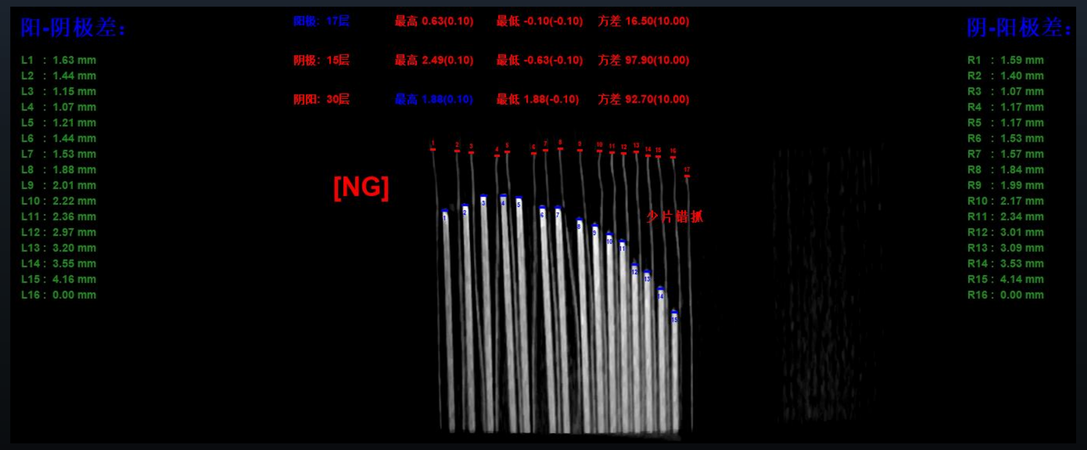

Anode
S
X : 4.278
Y : 18.703
S : 2.411
Y
Count : 1776
X : 11.443
Y : 18.763
S : 2.693
Count : 2183
Cathode
X
X : 6.742
Y : 20.019
S : 4.864
Count : 1875
X : 13.339
Y : 19.989
S : 4.801
Count : 1552

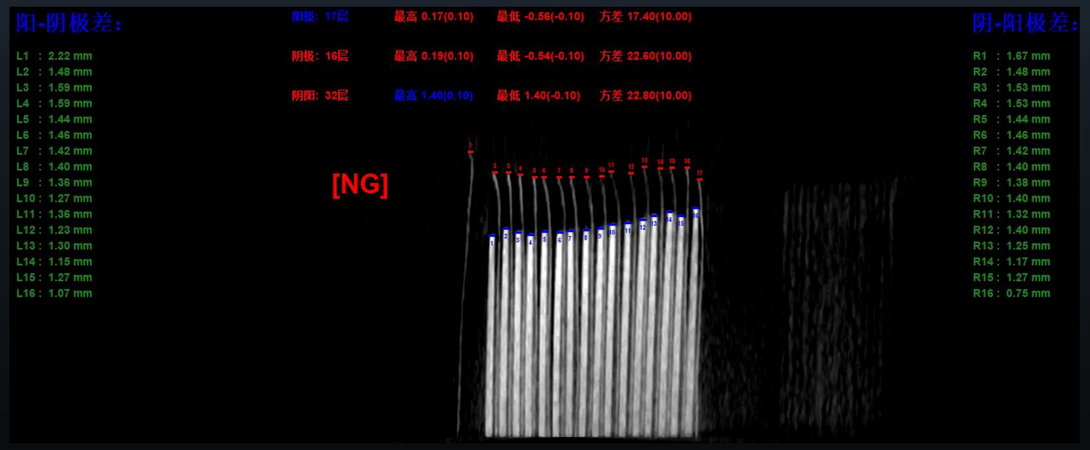




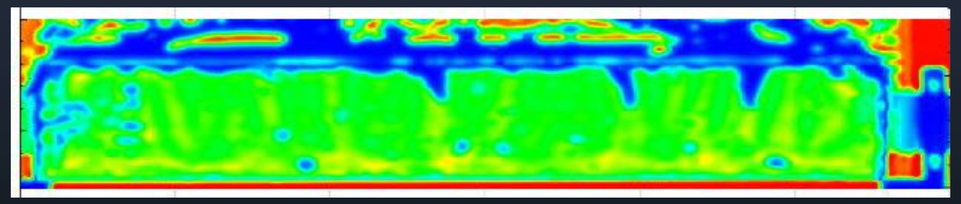

阳-阴极差：
L1 ： 2.51 mm
L2 ： 2.11 mm
L3 ： 2.09 mm
L4 ： 1.96 mm
L5 ： 2.13 mm
L6 ： 2.11 mm
L7 ： 2.09 mm
L8 ： 2.22 mm
L9 ： 2.22 mm
L10： 2.26 mm
L11： 2.30 mm
L12： 2.34 mm
L13： 2.49 mm
L14： 2.61 mm
L15： 2.78 mm
L16： 3.47 mm
阳极：17层 最高 0.44(0.10) 最低 -0.48(-0.10) 方差 32.70(10.00)
阴极：16层 最高 1.69(0.10) 最低 -0.61(-0.10) 方差 64.50(10.00)
阴阳：32层 最高 2.22(0.10) 最低 2.22(-0.10) 方差 39.90(10.00)
[NG]
阴-阳极差：
R1 ： 2.45 mm
R2 ： 2.11 mm
R3 ： 2.03 mm
R4 ： 1.94 mm
R5 ： 2.05 mm
R6 ： 2.05 mm
R7 ： 2.01 mm
R8 ： 2.11 mm
R9 ： 2.13 mm
R10： 2.13 mm
R11： 2.22 mm
R12： 2.30 mm
R13： 2.47 mm
R14： 2.53 mm
R15： 2.78 mm
R16： 3.72 mm

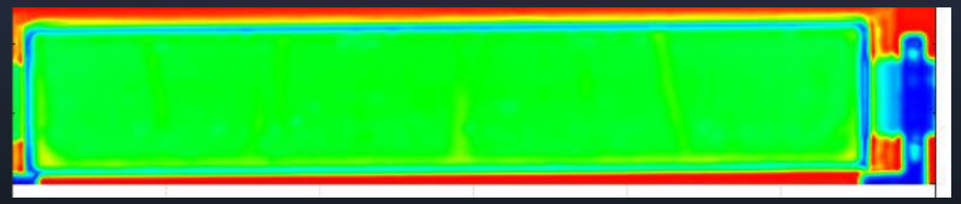

阳-阴极差：
L1 ： 1.38 mm
L2 ： 2.26 mm
L3 ： 2.47 mm
L4 ： 2.49 mm
L5 ： 2.53 mm
L6 ： 2.53 mm
L7 ： 2.51 mm
L8 ： 2.53 mm
L9 ： 2.57 mm
L10： 2.49 mm
L11： 2.38 mm
L12： 2.26 mm
L13： 2.13 mm
L14： 1.94 mm
L15： 1.71 mm
L16： 1.23 mm
阳极：17层 最高 1.34(0.10) 最低 -0.31(-0.10) 方差 43.20(10.00)
阴极：16层 最高 0.31(0.10) 最低 -1.67(-0.10) 方差 59.80(10.00)
阴阳：32层 最高 2.49(0.10) 最低 2.49(-0.10) 方差 41.40(10.00)
[NG]
阴-阳极差：
R1 ： 2.13 mm
R2 ： 2.38 mm
R3 ： 2.55 mm
R4 ： 2.51 mm
R5 ： 2.63 mm
R6 ： 2.59 mm
R7 ： 2.61 mm
R8 ： 2.61 mm
R9 ： 2.66 mm
R10： 2.55 mm
R11： 2.49 mm
R12： 2.26 mm
R13： 2.15 mm
R14： 1.99 mm
R15： 1.69 mm
R16： 1.17 mm

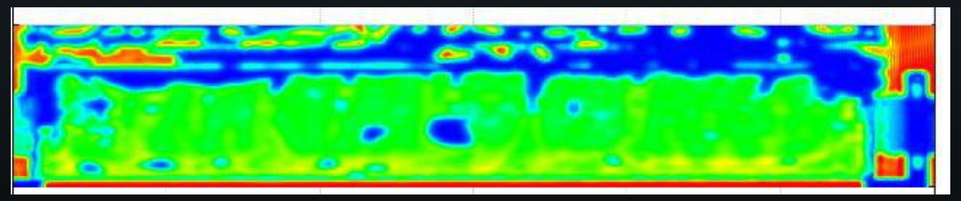

阳-阴极差：
L1 ： 1.63 mm
L2 ： 1.44 mm
L3 ： 1.15 mm
L4 ： 1.07 mm
L5 ： 1.21 mm
L6 ： 1.44 mm
L7 ： 1.53 mm
L8 ： 1.88 mm
L9 ： 2.01 mm
L10： 2.22 mm
L11： 2.36 mm
L12： 2.97 mm
L13： 3.20 mm
L14： 3.55 mm
L15： 4.16 mm
L16： 0.00 mm
阳极：17层 最高 0.63(0.10) 最低 -0.10(-0.10) 方差 16.50(10.00)
阴极：15层 最高 2.49(0.10) 最低 -0.63(-0.10) 方差 97.90(10.00)
阴阳：30层 最高 1.88(0.10) 最低 1.88(-0.10) 方差 92.70(10.00)
[NG]
少片错抓
阴-阳极差：
R1 ： 1.59 mm
R2 ： 1.40 mm
R3 ： 1.07 mm
R4 ： 1.17 mm
R5 ： 1.17 mm
R6 ： 1.53 mm
R7 ： 1.57 mm
R8 ： 1.84 mm
R9 ： 1.99 mm
R10： 2.17 mm
R11： 2.34 mm
R12： 3.01 mm
R13： 3.09 mm
R14： 3.53 mm
R15： 4.14 mm
R16： 0.00 mm

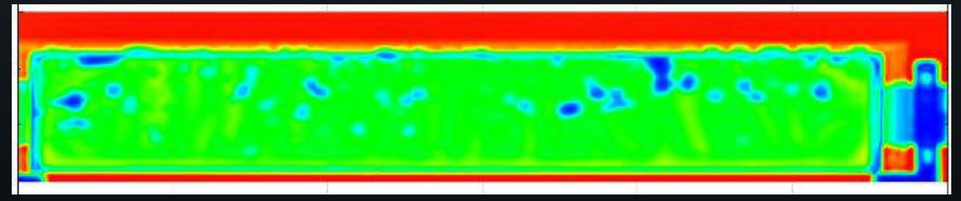

阳-阴极差：
L1 ： 2.22 mm
L2 ： 1.48 mm
L3 ： 1.59 mm
L4 ： 1.59 mm
L5 ： 1.44 mm
L6 ： 1.46 mm
L7 ： 1.42 mm
L8 ： 1.40 mm
L9 ： 1.36 mm
L10： 1.27 mm
L11： 1.36 mm
L12： 1.23 mm
L13： 1.30 mm
L14： 1.15 mm
L15： 1.27 mm
L16： 1.07 mm
阳极：17层 最高 0.17(0.10) 最低 -0.56(-0.10) 方差 17.40(10.00)
阴极：16层 最高 0.19(0.10) 最低 -0.54(-0.10) 方差 22.60(10.00)
阴阳：32层 最高 1.40(0.10) 最低 1.40(-0.10) 方差 22.80(10.00)
[NG]
阴-阳极差：
R1 ： 1.67 mm
R2 ： 1.48 mm
R3 ： 1.53 mm
R4 ： 1.53 mm
R5 ： 1.44 mm
R6 ： 1.46 mm
R7 ： 1.42 mm
R8 ： 1.40 mm
R9 ： 1.38 mm
R10： 1.40 mm
R11： 1.32 mm
R12： 1.40 mm
R13： 1.25 mm
R14： 1.17 mm
R15： 1.27 mm
R16： 0.75 mm


SES









Safety = Quality

	DNA Cell/Material Design	Life Style Cell Test		Pregnancy Manufacturing Quality			
No	barcode	Has Signal	HI Result	Exp I	Exp II RF	Exp II LGB	Summary
1	A100D67E230507B018					X	X
2	A050M7CE3A065	X			X	X	X
3	A050M7BE3A033			X	X	X	X
4	A100N4NS230405D004	X	X				X
5	A100M9DE1A1019	X			X	X	X
6	A100M9DE1A1020				X	X	X
7	A100M9ME4A002	X				X	X
8	A100M9DE1A1016	X	X				X
9	A100MARS3A006	X	X				X
10	A100MARS3A003	X				X	X
11	A050M8PE4A005					X	X
12	A050M8PE4A006						
13	A100M9DE1A1018				X	X	X
14	A100M9EE1A1030				X		X
15	A050M69E1D014	X	X	X			X
16	A050M59E1C009	X	X	X			X
17	A050M57E1A025			X	X	X	X
18	A050M69E1D001	X		X	X		X
19	A050M58E1B001	X	X	X			X
20	A050M57E1A014	X	X	X			X
21	A050M38E1E004	X	X	X			X
22	A050M59E1C024	X		X	X		X
23	E211203B006	X	X				X
24	A050M37E1B001						
25	A050M59E1C013	X	X				X

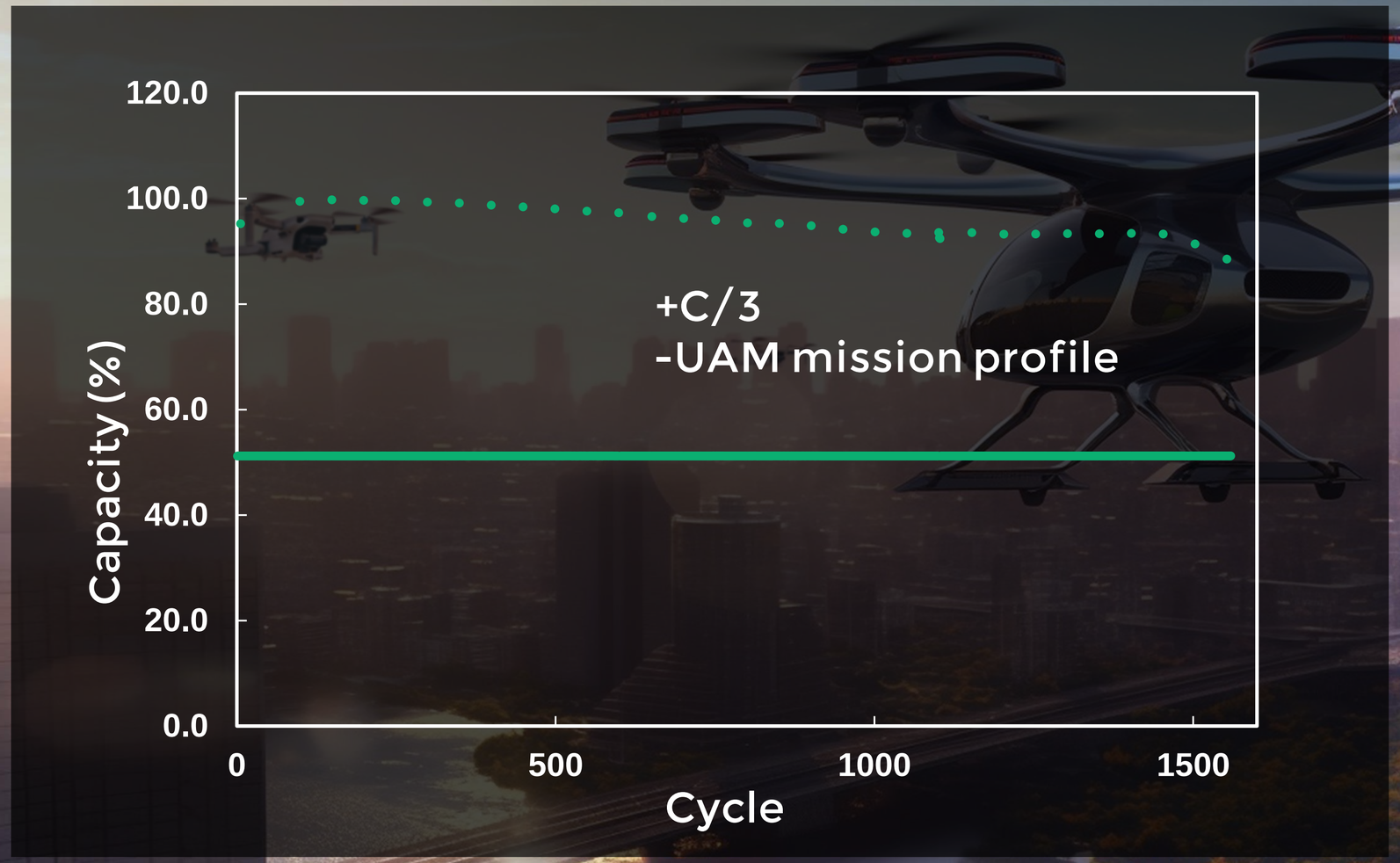
92%

Incident prediction accuracy on large 100Ah Li-Metal cells (23/25), increase from 60% a year ago

If we don’t fail quick enough, often enough, we don’t innovate fast enough


SES


Urban Air Mobility

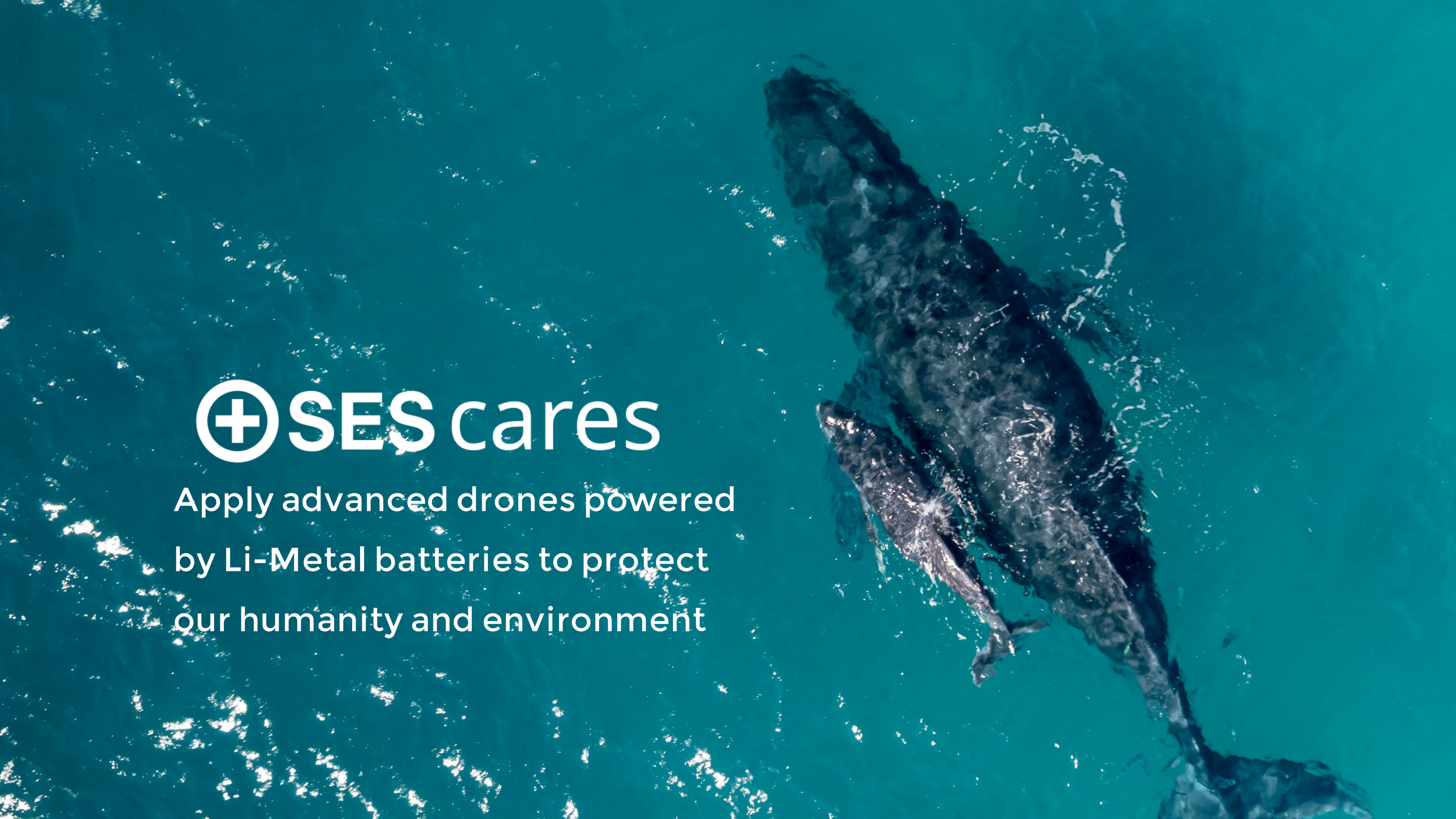

120.0
100.0
80.0
60.0
40.0
20.0
0.0
Capacity (%)
0
500
1000
1500
Cycle
+C/3
-UAM mission profile

Lack of serious competition


Chance to set
industry standards


1990s
Li-ion → Consumer Electronics
2020s
Li-Metal → UAM


1
Subsize aircraft
2
Fullsize aircraft (unmanned)
3
Fullsize aircraft (manned)


SES cares
Apply advanced drones powered
by Li-Metal batteries to protect
our humanity and environment

World’s first automotive B-sample JDA for Li-Metal

Test data on 100Ah Li-Metal cells

New human and machine-based deep learning tools for material discovery

Enhanced Avatar prediction accuracy

Prismatic Li-Metal cell offering more options to OEMs

SES cares


“A person often meets his destiny on the road he took to avoid it.”
Jean de la Fontaine

2017

2023

World's first automotive A-sample and B-sample in Li-Metal


Destiny has a way of keep calling you


Today, SES is officially re-entering UAM

SES

Born to Fly