CRM4EV
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$LiFePO_4$ for future

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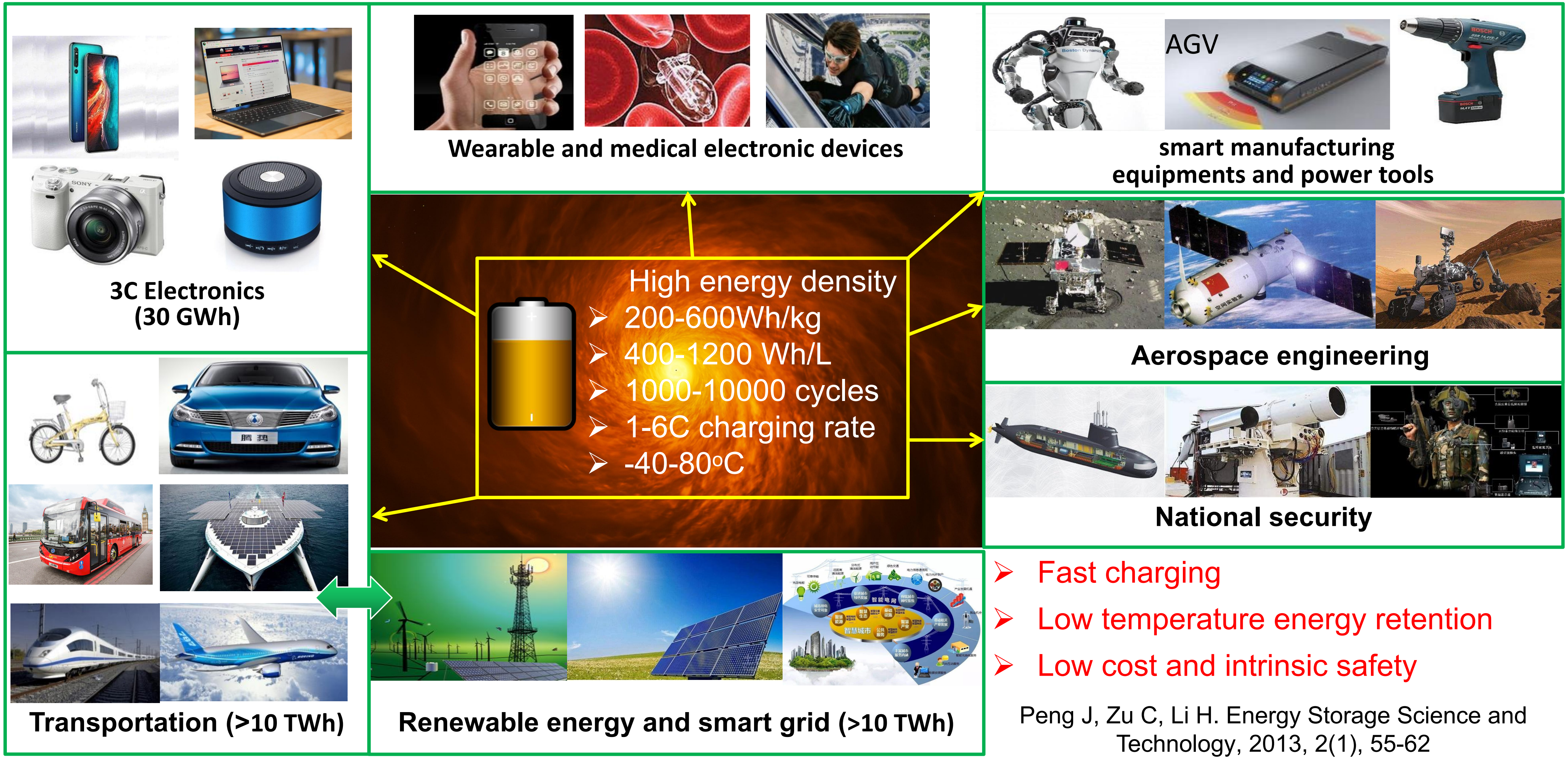
Outline

1. Status of LIB
2. Status of $LiFePO_4$
3. LFP batteries towards future

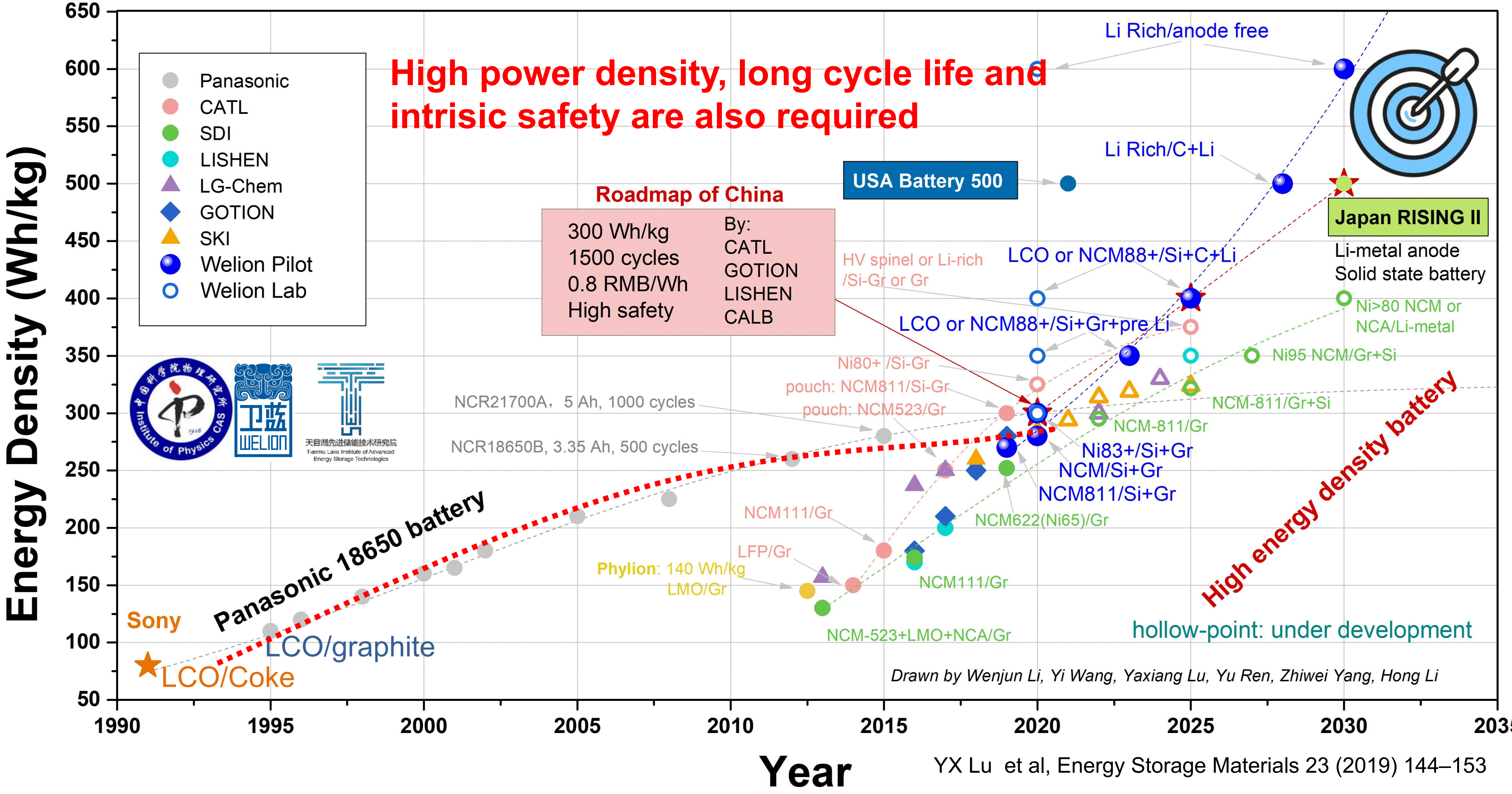
Many applications need advanced batteries



- Fast charging
- Low temperature energy retention
- Low cost and intrinsic safety

Peng J, Zu C, Li H. Energy Storage Science and Technology, 2013, 2(1), 55-62

New materials are essential for increasing energy density



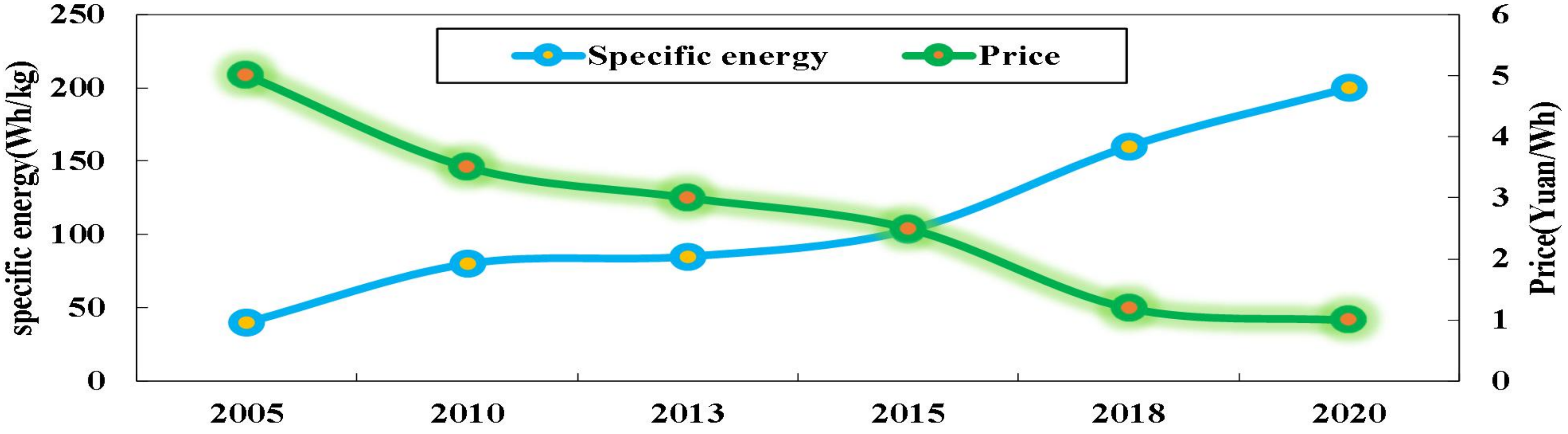
YX Lu et al, Energy Storage Materials 23 (2019) 144–153

Progress of battery for EV in China

Significant breakthrough in Lithium-ion power batteryhave been achieved

Step-by-step Development history of power batteries in China:

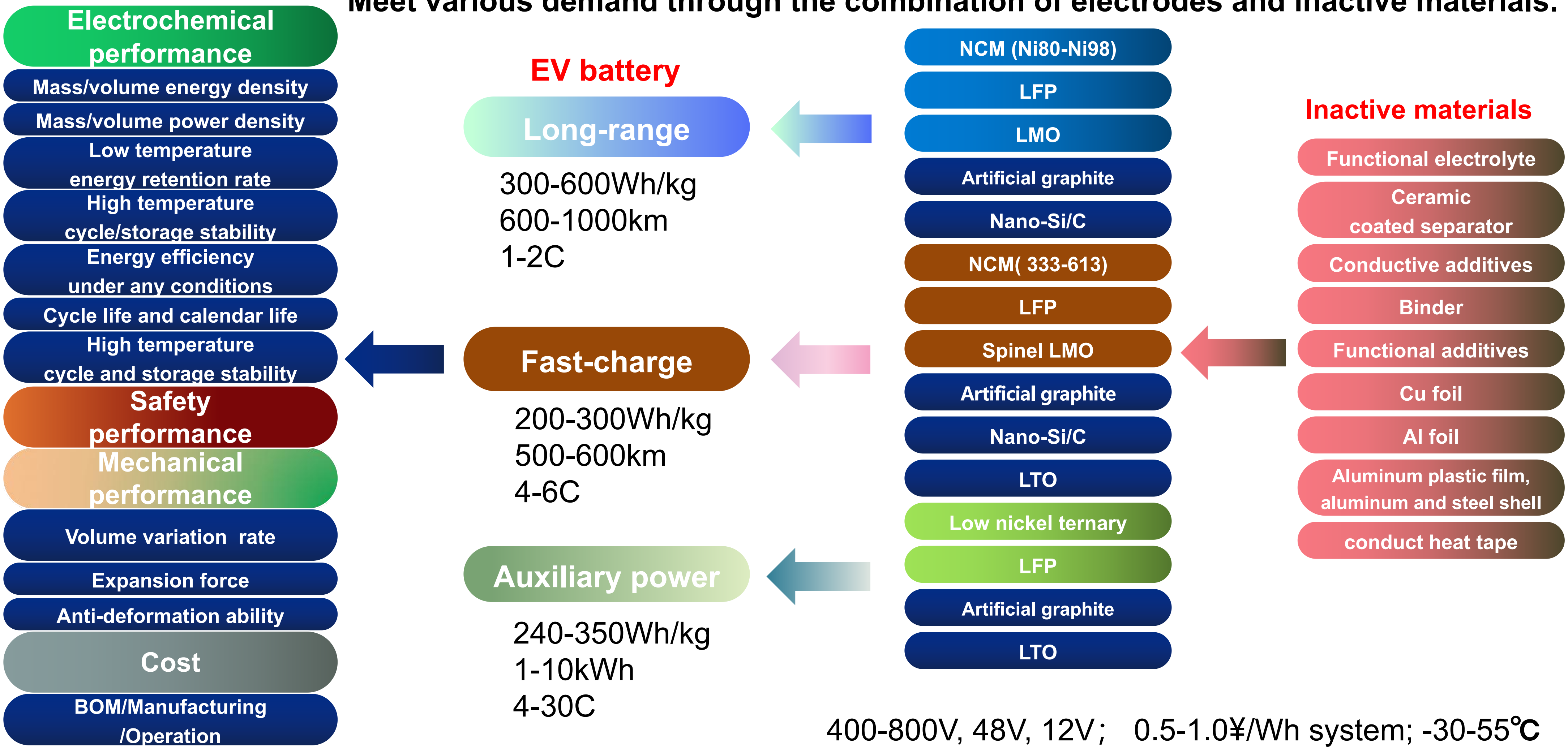
- "2001-2005" : Mainly focus on NiMH and **LMO** power batteries
- "2006-2010 " : R & D and industrialization of **LFP** power batteries
- "2011-2015" : R & D and industrialization of **NMC** power batteries
- "2016-2020" : R & D of higher energy density and **safe** batteries



Battery pack energy density have reached 200 Wh/kg now, Pack cost is down to 0.1$/Wh

Improve energy density: material, cell and pack innovation

Meet various demand through the combination of electrodes and inactive materials.



400-800V, 48V, 12V； 0.5-1.0¥/Wh system; -30-55℃

Innovation of materials is essential to increase cell energy density

NCM → 333， 424， 523， 613, 71515， 811，Ni90， Ni92, Ni95, Ni98	220-230mAh/g
LMO → Improved LMO, LNMO, Li-rich	115-330mAh/g
LFP → LFMP	150-160mAh/g
LCO → 4.6V LCO	185- 240 mAh/g

AG, NG → Hard carbon, LTO, TNO	150-400mAh/g
Si → nano-Si/C, C@SiOx, μm-Si, prelithiation	450-3500 mAh/g
Li → Li@C, Li-alloy thin film	1500-3500 mAh/g

1M $LiPF_6$, EC-DEC → LiFSI, LiTFSI，LIDFOB, SEI/CEI additive → hybrid solid/liquid, all-solid electrolyte

Al_2O_3/PE, CB, Cu/Al → LATP/PE/LATP, SWNT/graphene, MPCC，large cell format

<u>Directions</u>

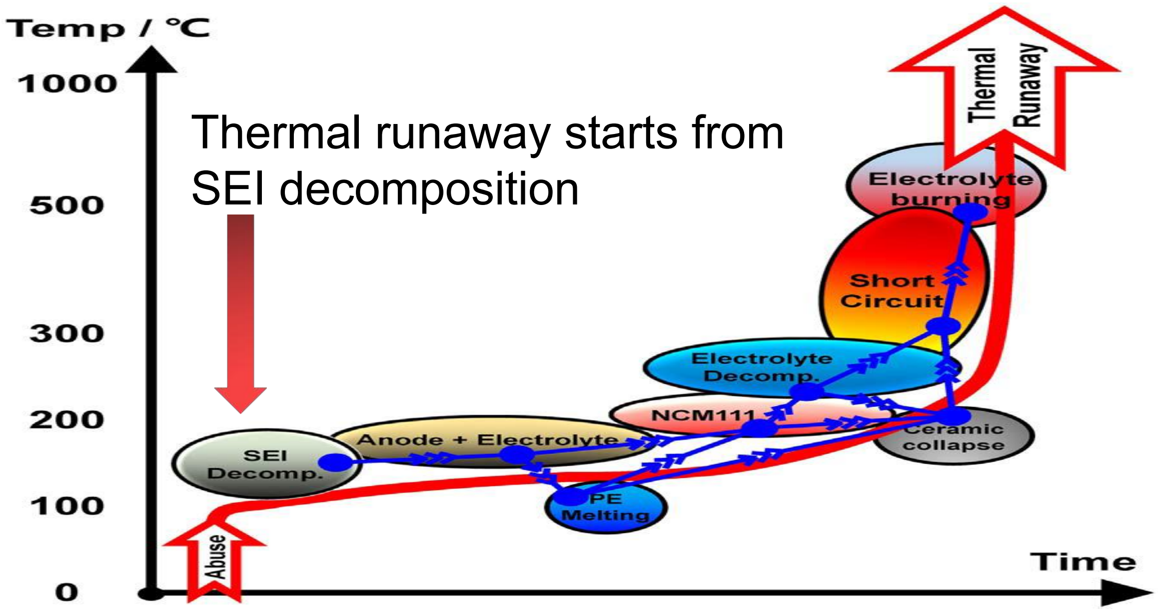
- Charging to high voltage
- Stable 3D host
- Stablizing SEI/CEI interface
- Optimized transport properties
- Preventing side reactions

→

- Increase energy density of all LIB cell
- Improve cycle life and storage performance at HT
- Inprove fast charging and LT performance
- Decrease BOM and manufacturing cost
- Improve safety and prevent thermal runaway

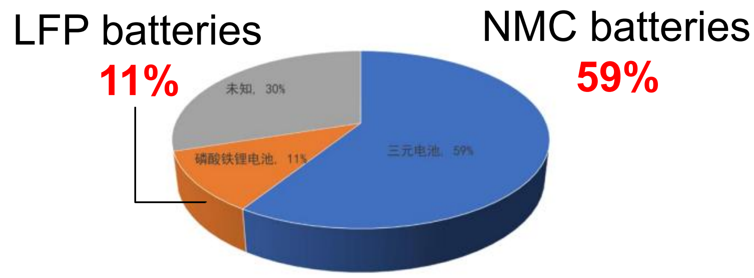
Main challenges of increasing energy density

1. Charging to high voltage: host lattice and surafce structure, O and electrolytes are not stable;
2. Si and Li are promising anode materials: unstable interface, lithium plating and large volume variation;
3. Under large current density, ion transportation in bulk and interface is sluggish
4. Probability of thermal runaway is higher



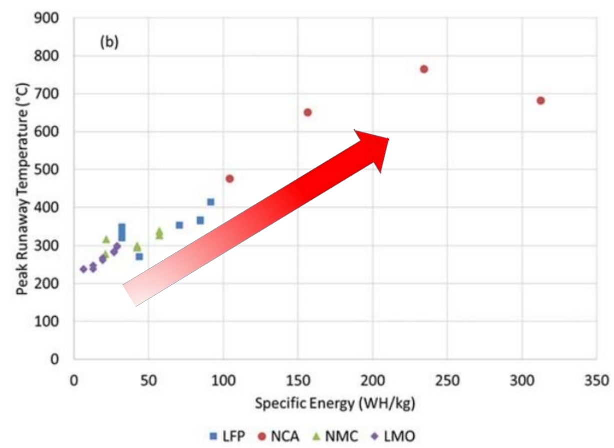
Find solid solution

Safety of LFP vs NCM

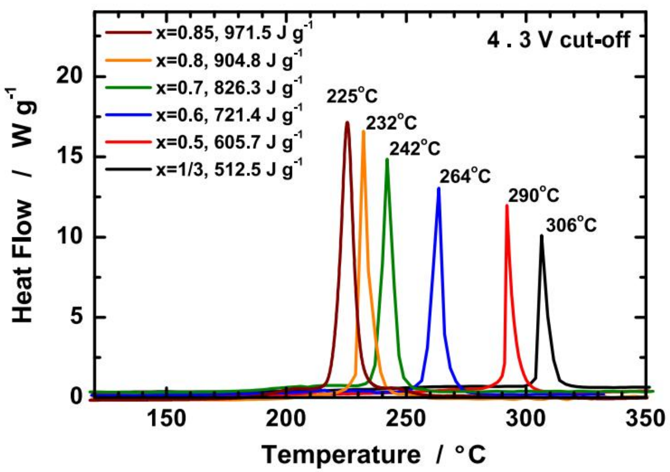


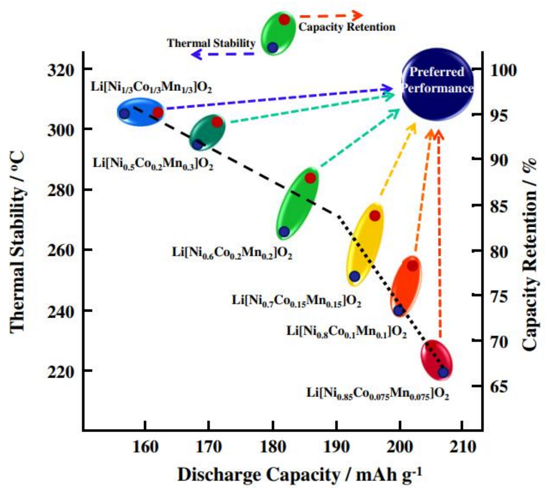
Battery accident account

From Prof. Xinping Ai

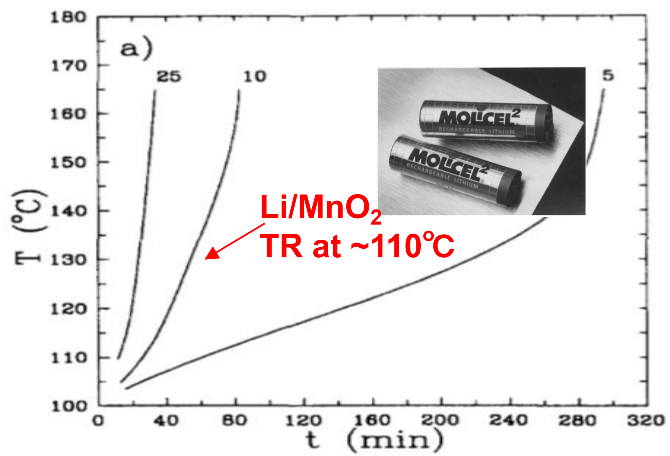


J. Electrochem. Soc. 2021,168, 060516





Journal of Power Sources 233 (2013) 121-130



Journal of Power Sources 54 (1995) 240-245

LFP battery is not absolutely safe

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Although the intrinsic safety of LFP materials is relatively good, but it does not mean that LFP battery is completely safe. Battery system is a complex system.

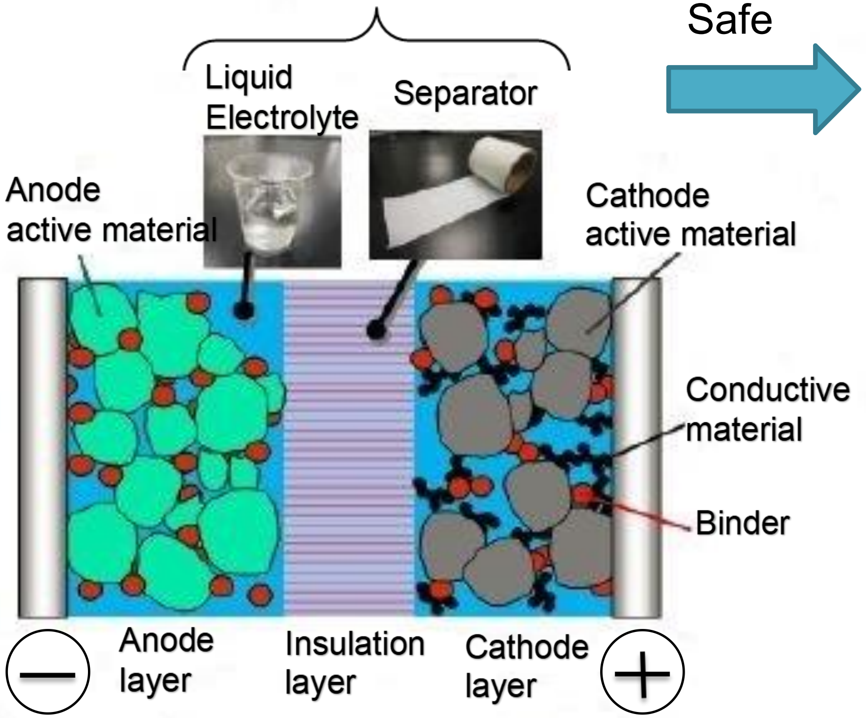
April 16th, 2021, the 25 MWh energy storage system in Fengtai District, Beijing suddenly exploded. (Battery cell chemistry: **LFP**)

August 07th, 2021, spontaneous combustion occurred in a running EV-car D1 in Kunshan. (Battery cell chemistry: **LFP**)

Source: Internet

Comparison of liquid and solid lithium batteries

1985, Yoshino — **Liquid LiB**



Safe

All solid LIB — 1978， Armand

1. Polymer
2. Oxide
3. Sulfide
4. LiPON
5. Li_3OCl
6. Li_2ZrCl_6

Challenges

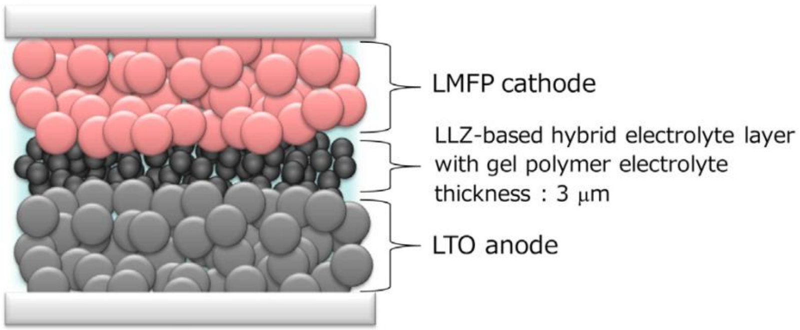
Liquid LiB:
- High voltage is difficult
- Continuous interface side reactions
- Thermal runaway from interface

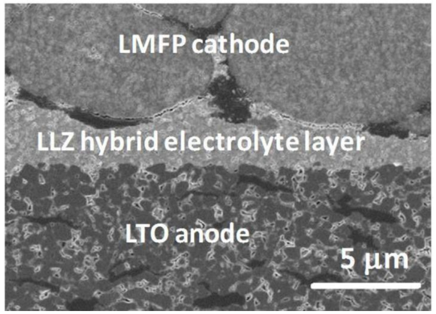
All solid LIB:
- Poor solid/solid contact interface during cycling
- Poor mechanical properties
- Poor low temperature performance

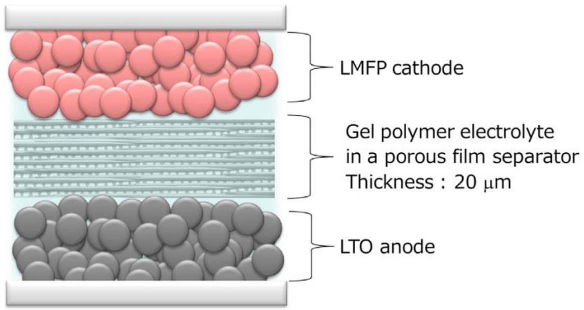
Solving interface problems is the key for liquid and solid lithium batteries

How to scale up ASSB? Hybrid solid/liquid electrolyte?

Toshiba solution
Gel interface
3.2wt% liquid







Kazuomi Yoshima, Yasuhiro Harada, Norio Takami, Journal of Power Sources 302 (2016) 283-290

How to introduce solid electrolyte into liquid batteries?
Redesign new liquid electrolye?

- coating solid electrolyte on active particles
- adding solid electrolyte particles in separator/electrodes
- forming solid electrolyte chemically
- forming solid electrolyte electrochemically

25 wt% 15wt% 10wt% 5 wt% 1wt% 0 wt% liquid in cell

Liquid | Gel | Hybrid solid-liquid electrolyte | All solid

250 Wh/kg 300 Wh/kg 350 Wh/kg 400Wh/kg 500 Wh/kg >600Wh/kg

55°C 80°C 150°C Maxium Operation Temp.

Practical solution for HELIB: from liquid to all solid via in situ solidification

25 wt% | 15wt% | 10wt% | 5 wt% | 1wt% | 0 wt% liquid in cell

Liquid | Gel | Hybrid solid-liquid electrolyte | All solid

0 wt% | 5 wt% | 30 wt% | 50 wt% | <100% Li in anode

GP/Si | Prelithiation | Li-rich anode | Li-free/rich anode

250 Wh/kg | 300 Wh/kg | 350 Wh/kg | 400Wh/kg | 500 Wh/kg | >600Wh/kg

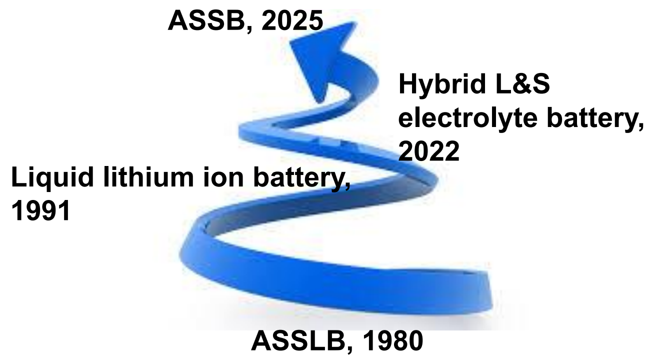
55°C | 80°C | 150 °C | Maxium operation T

	Nonaqueous (liquid)	Hybrid solid/liquid	All solid
Cathode	NCM, NCA, Li-rich, LNM	NCM, NCA, Li-rich, LNM	NCM, LCO, LI-rich, LNM, S, MFx / coating
Anode	GP, C@SiOx, C@nano-Si/C	Li+ HC, SC, C@SiOx, C@nano-Si/C /SEI	Li, Li-alloy, Li-composite / SEI
Electrolyte	EC-DEC-EMC-DMC $LiPF_6$ BP, FEC, VC, BS, LiFSI, LiODFB..	LATP, LLZO, LiSx + LiTFSI, LiODFB, LiFSI+polymer	LLZO/PMMA-LiX; sulfide Others
Separator	Al_2O_3/PE/PVDF-HFP	LATP/PE/PVDF-HFP	

Hybrid L&S electrolyte battery:
Relativie easy to realize

ASSB:
Still need basic research

ASSB's safety need to be verified.



- High Thermal-stable liquid electrolyte
- Convert liquid into solid
- Introduce solid electrolyte
- Solid electrolyte coating

Outline

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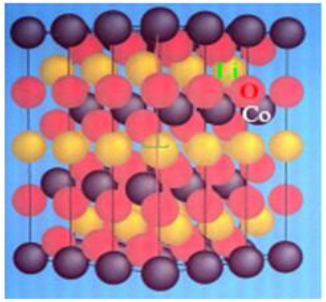
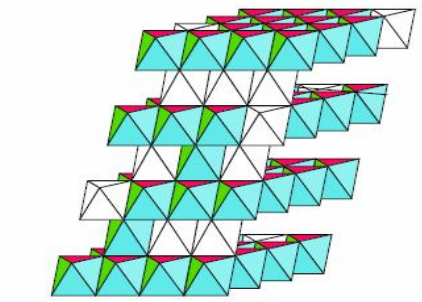
3. LFP batteries towards future

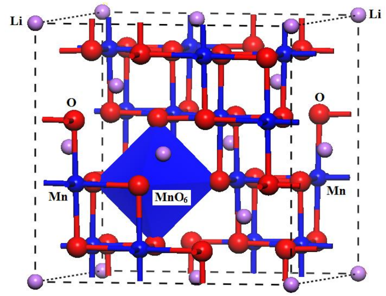
Intercalation compounds as electrode magterials for LIB



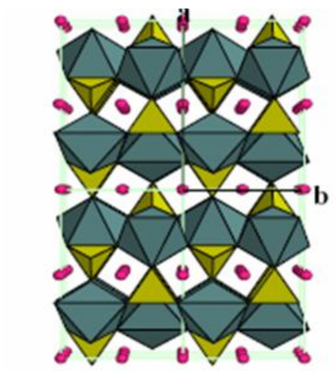
$LiCoO_2$
(0.5 Li, 140 mAh/g)
1980, J. Goodenough



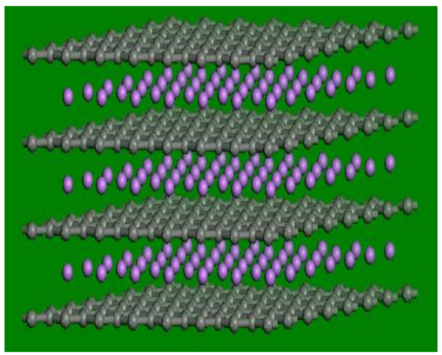
$Li_{1+x}Ni_yCo_zMn_mO_{2-n}$
(0.6-0.9 Li, 160-250 mAh/g)
1992, J. Dahn / M. Thackeray



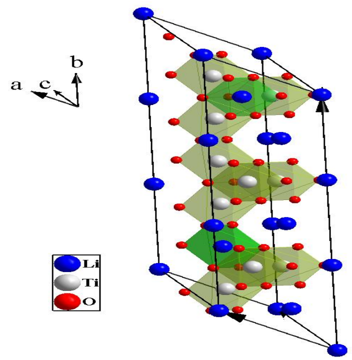
$LiMn_2O_4$
(1 Li, ~100 mAh/g)
1983, T. Ohzuku, M. Thackeray



$LiFePO_4$
(1Li, 160 mAh/g)
1997, J. Goodenough



Graphite
(1Li, 300-350 mAh/g)
1983, R. Yazami



$Li_4Ti_5O_{12}$
(3 Li, ~160 mAh/g)
1995, M. Thackeray /T. Ohzuku

Introduction to $LiFePO_4$ cathode material

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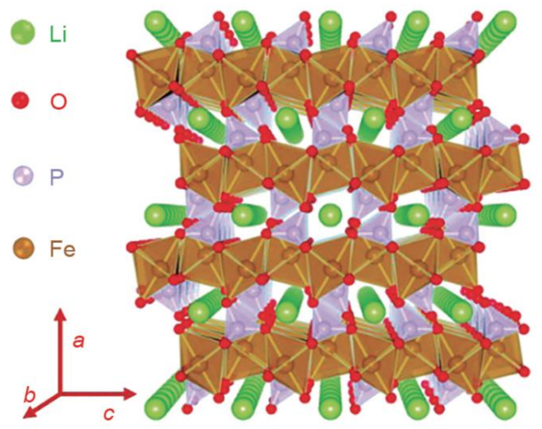
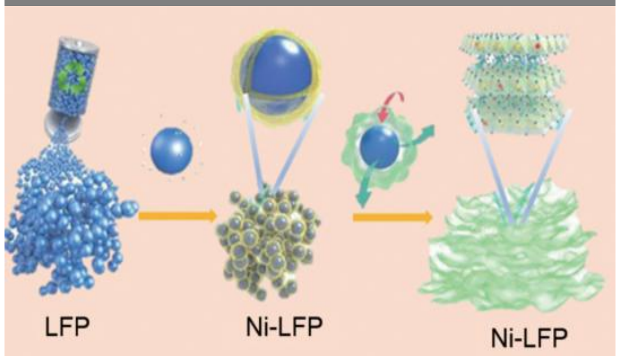


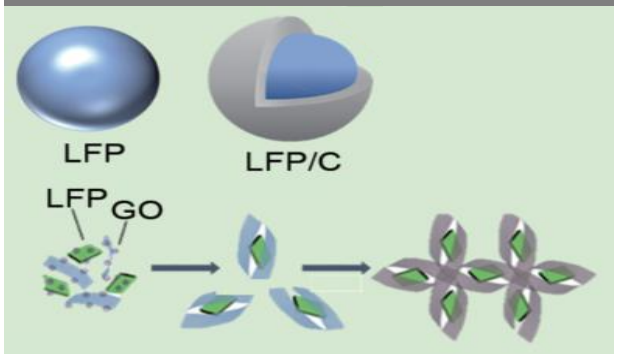
- In 1997, $LiFePO_4$ was reported as cathode material by John B. Goodenough.
- $LiFePO_4$ has a regular olivine structure (orthorhombic space group **Pnma**).
- $LiFePO_4$ converts to $FePO_4$ during charging (Theoretical capacity **170 mAh/g**).
- Limited by its crystal structure, pure $LiFePO_4$ has **poor electronic conductivity (3.7×10^{-9} S/cm, RT)** and **slow lithium ion migration rate**.

Element doping



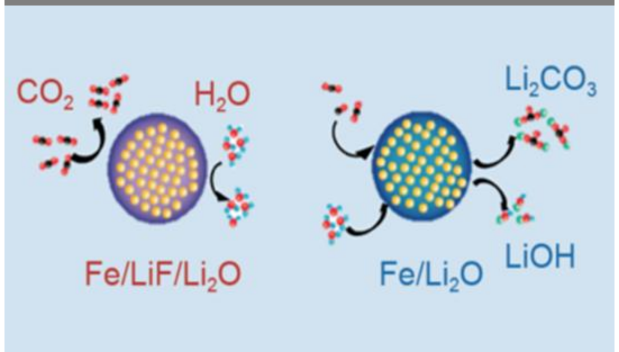
Source: Sci. China Matar., 2021.21.1682.

Surface coating modification



Source: ACS Appl. Mater. Interfaces., 2021,21,6.

Lithium supplement additive adding



Source: Adv. Energy Mater., 2020,10,7.

$LiFePO_4$ materials need to be modified for practical application

$LiFePO_4$ for commercial Li-ion batteries

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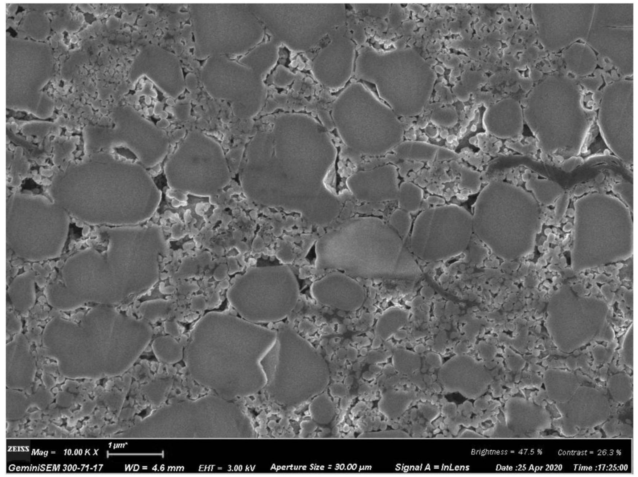
Product	LFP-1 for EV	LFP-2 for EV	LFP for ESS
D_{50}	1.3 μm	2.0±1.0 μm	0.9 μm
Characteristic	160 mAh/g PD˜2.5 g/cm³	161 mAh/g PD˜2.6 g/cm³	162 mAh/g PD˜2.4 g/cm³
Average voltage	3.40 V	3.40 V	3.40 V
Specific surface area	10.8 m²/g	10-14 m²/g	11.3 m²/g
Cost	**~24,000 USD/ton**		**~23,000 USD/ton**

Source: Internet, SMM



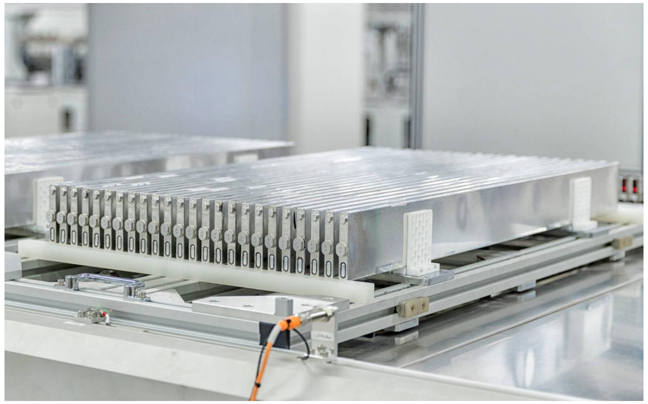
Source: BYD patent CN114068919A, PD>2.75 g/cm³

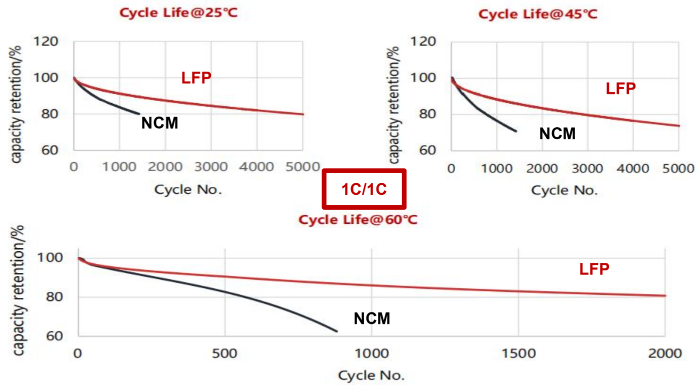
LFP materials can be divided into high energy products for EV and long-life products for energy storage

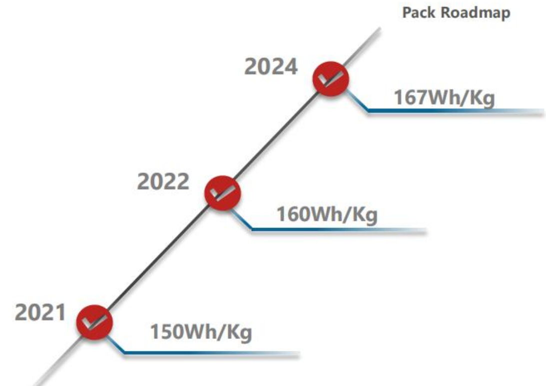
LFP Prismatic cell

	LFP	NCM
Average voltage (vs Li^+/Li)	3.4 V	3.7-3.8 V
Theoretical specific capacity	170 mAh/g	274-285 mAh/g
Typical specific capacity	˜160 mAh/g	160-215 mAh/g
Thermal stability	>350℃	190℃-310℃
Typical specific energy (EV cell)	130-195 Wh/kg	200-280 Wh/kg
Typical cycle life (EV cell)	2000-4000	1500-2000
Low temperature performance (-20℃, capacity retention rate)	50%-60%	70%~80%

LFP of BYD and CATL





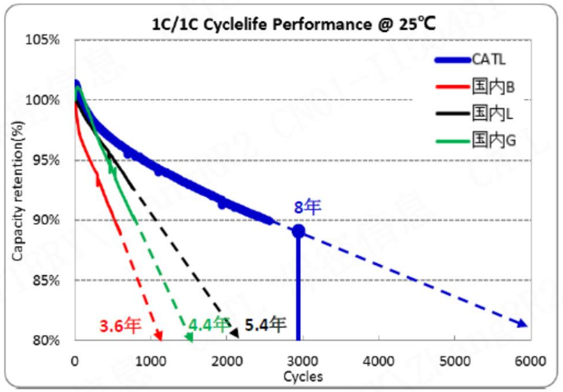


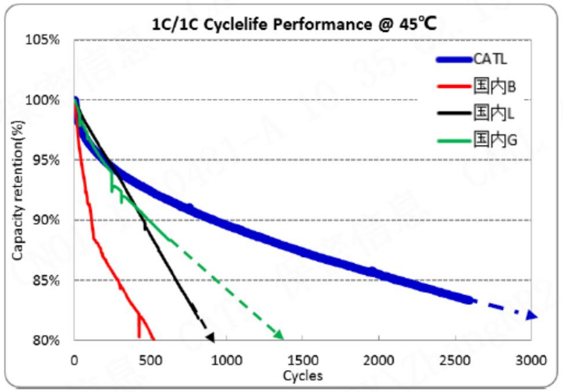
Source: FinDreams Battery

BYD

Innovative cell design and system integration endows the LFP battery systems with high energy density or ultra long cycle life

CATL





Source: CATL

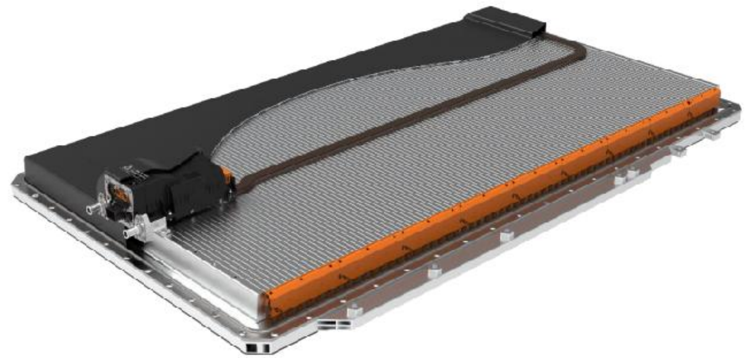
Latest application of BYD's LFP battery pack

2022 BYD HAN-EV 715 km

CLTC range: 715 km
Fast-charging time: 0.5 h (80%)
Power consumption: 12 kWh/100km
Battery pack size: 1843 x 1100 x 220 mm
Maximum motor power: 180 kW
TMS: liquid cooling

Pack Energy: 85.4 kWh
Energy density: 150 Wh/kg
Battery cells: 200 Blade batteries (1P200S)
Pack capacity: 135 Ah
Pack Voltage: 640 V

*Based on the 77kWh pack of 2021 BYD Han-EV, the maximum instantaneous discharge power is 363 kW (~4.7 C)

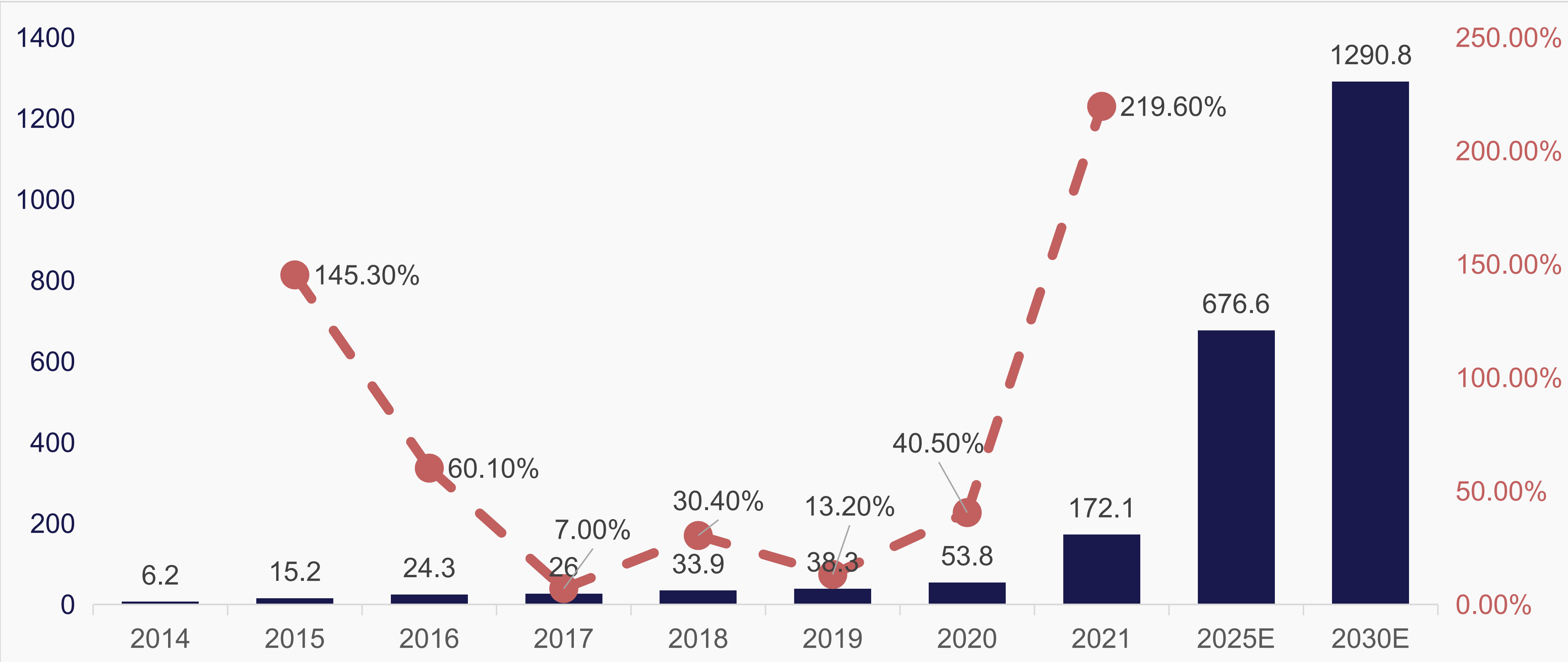


Source: Internet

Global market trend of LFP batteries

In 2021, the global LFP battery shipment was 172.1 GWh, with a significant year-on-year increase of 219.6%.
The proportion of LFP battery in all lithium-ion battery shipments increased from 18.3% in 2020 to 30.6% in 2021.

Figure: Statistics and forecast of the global shipment of LFP batteries from 2014 to 2030 (GWh)



Source: EVTank, April 2022

Installed capacity of LFP EV batteries in China

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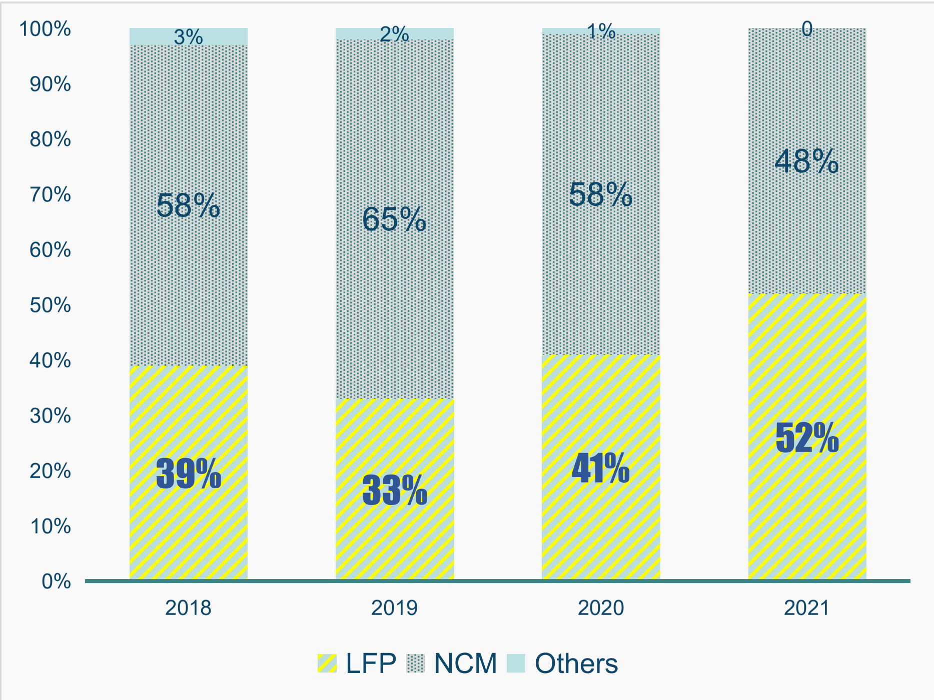
From the perspective of China, the EV battery market was inverted by LFP in 2021.

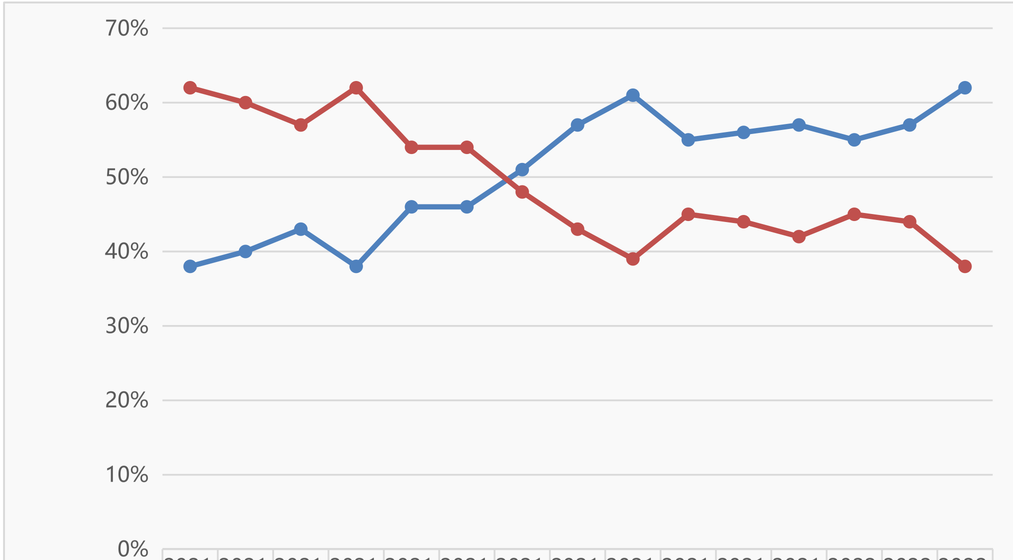
LFP battery officially surpassed NCM battery with 52% installed capacity.

Figure: Proportion of installed capacity of various batteries in China's EV battery market from 2018 to 2021



Source: TrendForce, April 2022

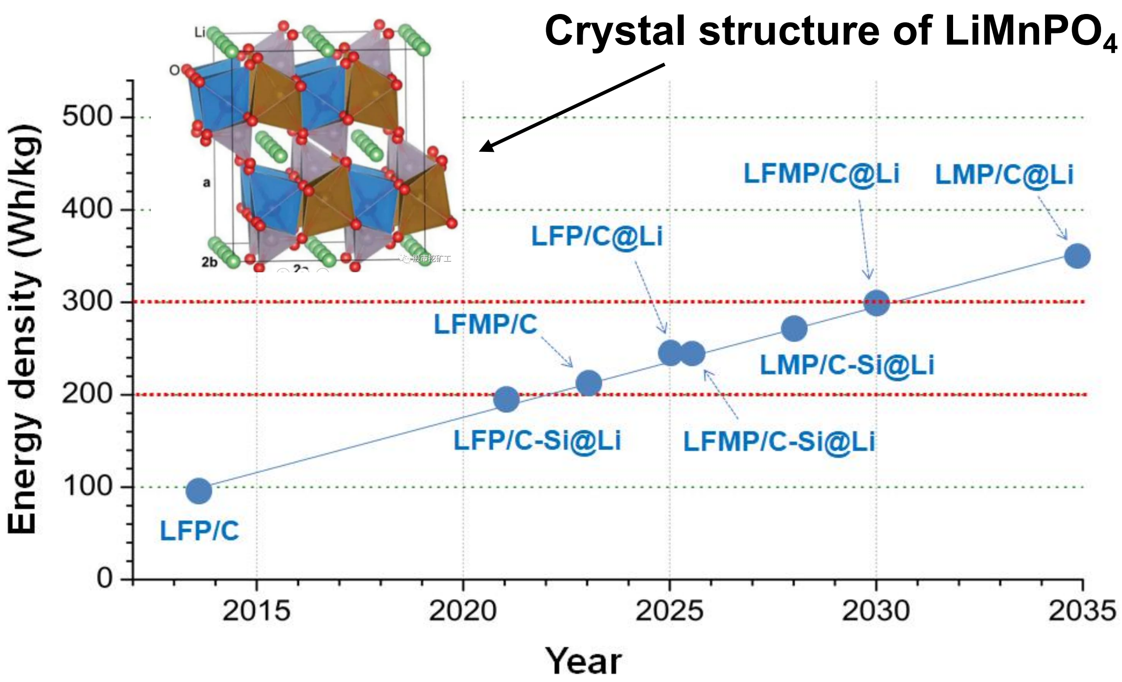
Figure: Proportion of installed capacity of various batteries in China's EV battery market from 2021.01 to 2022.03



	2021.01	2021.02	2021.03	2021.04	2021.05	2021.06	2021.07	2021.08	2021.09	2021.1	2021.11	2021.12	2022.01	2022.02	2022.03
LFP	38%	40%	43%	38%	46%	46%	51%	57%	61%	55%	56%	57%	55%	57%	62%
NCM	62%	60%	57%	62%	54%	54%	48%	43%	39%	45%	44%	42%	45%	44%	38%

Source: CABIA, 2022

$LiMnPO_4$ Material Introduction



1. Similar to $LiFePO_4$, $LiMnPO_4$ exhibits an olivine crystal structure
2. Electrical conductivity is poor and affected by the Jahn-Teller effect
3. Low actual capacity and poor cycle stability

The comparison of $LiMnPO_4$, $LiMnFePO_4$ and $LiFePO_4$

	$LiMnPO_4$	$LiMnFePO_4$	$LiFePO_4$
Theoretical specific capacity (mAh/g)	170	170	170
Voltage plateau (V)	4.1	4.1	3.4
Theoretical energy density (Wh/kg)	700	697	578
Compacted density (g/cm³)	2.4	2.4	2.3
Conductivity	poor	medium	good
Thermal stability	relatively stable	stable	stable
Toxicity	low	low	low
Cost	low	low	low

- Partially replacing Mn with Fe can improve the conductivity of $LiMnPO_4$, which can be described as $LiMn_yFe_{1-y}PO_4$, abbreviated LMFP.

$LiMn_xFe_{1-x}PO_4$ of future Li-ion batteries

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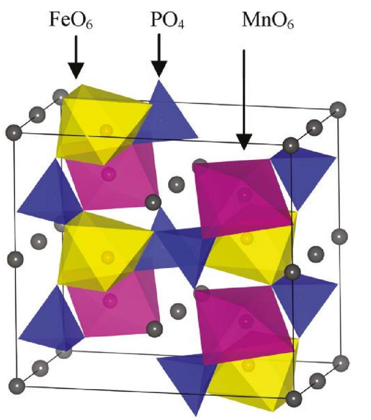
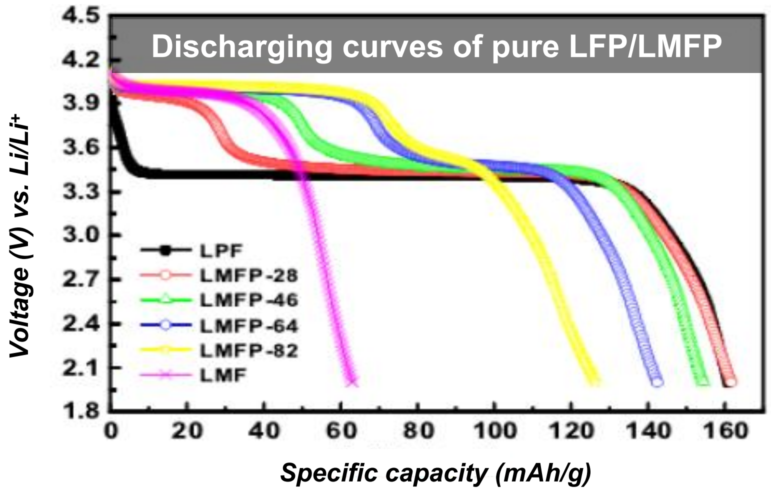
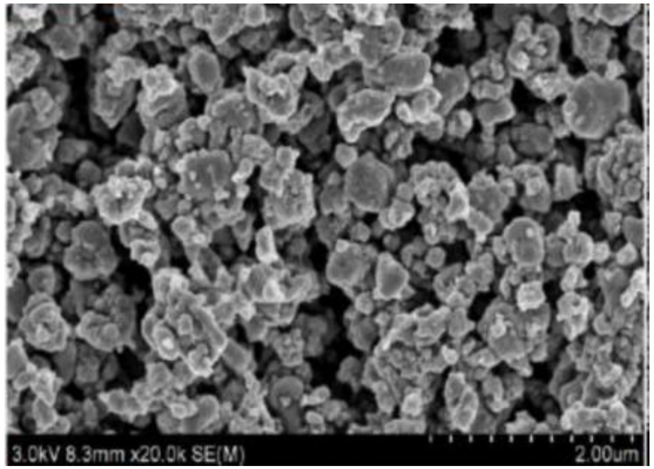


Olivine-type $LiFe_{0.5}Mn_{0.5}PO_4$

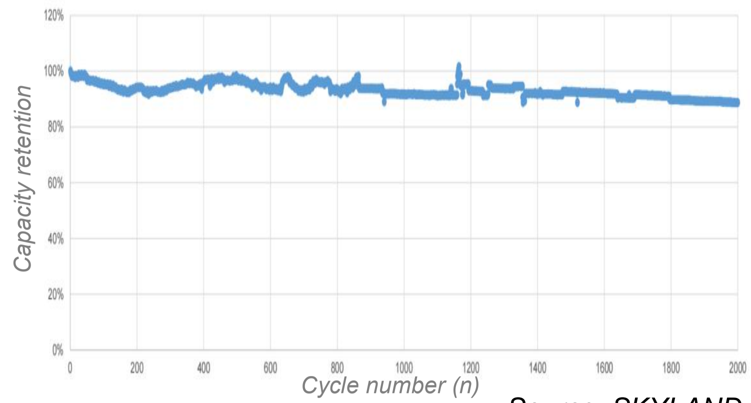
	LMFP	LFP
Crystal structure	Olivine	Olivine
Conductivity (S/cm)	10^{-13}	10^{-9}
Voltage Platform (V)	4.1/3.4	3.4
Pellet density (g/cm³)	2.3	2.4-2.65
Theoretical specific capacity (mAh/g)	170-171	170
Typical specific capacity (mAh/g)	~150	~160



Product Name	LMFP-64
D_{50}	0.5-1.5 μm
Characteristics	≥155 mAh/g PD ≥ 2.2 g/cm³
Average voltage	3.80 V
ICE	≥90%
Specific surface area	15-25 m²/g



LMFP-64 electrochemical performance at 1C



Source: SKYLAND

The bottleneck of poor electronic conductivity of LMFP must be overcome for practical application

Material Advantages and Disadvantages of LFMP

Advantages	Disadvantages
High energy density	Poor electrical conductivity
Low cost of raw materials	Side effects with electrolytes
High safety	Jahn-teller effect, resulting in reduced material capacity
Long cycle life	Production barriers

The core of LMFP technology lies in the synthesis method

Typical synthesis patents of lithium ferromanganese phosphate

patent number	Company	Mixing mode	Performance description (capacity: mAh/g)
CN107732176B	Dynanonic Co., Ltd.	Liquid phase mixing	~160 (0.2C), 150 (1C), 140 (3C)
CN104124453B	Dynanonic Co., Ltd.	Liquid phase mixing	~160 (0.2C), capacity retention 99.9% (125 cycles)
CN109354002A	Dynanonic Co., Ltd.	Liquid phase mixing	>150 (0.2C), >140 (1C)
CN108987749A	Dynanonic Co., Ltd.	Liquid-solid mixing	>150 (0.2C), 140 (1C)
CN108923090A	Dynanonic Co., Ltd.	Liquid phase mixing	>150 (0.2C), 140 (1C)
CN105226273B	BYD Co., Ltd.	Liquid phase mixing	>160 (0.1C), ~140 (1C, 2C)
CN104752720A	BYD Co., Ltd.	Liquid phase mixing	>160 (0.1C)
CN106935851B	BYD Co., Ltd.	Liquid phase mixing	>160 (1C)
CN105702954A	BYD Co., Ltd.	Liquid-solid mixing	~160 (0.1C)
CN109309207A	BYD Co., Ltd.	Solid phase mixing	~150 (0.1C), capacity retention 97% (500 cycles)
CN103268938A	Gotion High tech Co., Ltd.	Liquid-solid mixing	>150 (0.1C), <150 (0.2C), 140 (1C)
CN103280579A	Gotion High tech Co., Ltd.	Liquid phase mixing	>160 (0.1C), 140 (0.2C)
CN103794789A	Gotion High tech Co., Ltd.	Solid phase mixing	~150 (0.2C), capacity retention 88% (250 cycles)
CN106058220B	Gotion High tech Co., Ltd.	Liquid phase mixing	>140 (0.2C), 140 (1C), ~140 (3C)
CN111908442A	Huayi (Group) Co., Ltd.	Liquid phase mixing	~140 (0.1C), ~140 (1C)
CN111268664A	Huayi (Group) Co., Ltd.	Liquid phase mixing	~150 (0.1C)
CN111048760A	Pulead Technology Industry Co., Ltd.	Liquid phase mixing	>150 (0.2C), 140 (1C), 130 (5C)
CN104681795A	Pulead Technology Industry Co., Ltd.	Liquid phase mixing	>150 (0.2C), >140 (1C)
CN110323434A	Lithitech Co., Ltd.	Liquid phase mixing	>150 (0.1C), >140 (2C)
CN110982682A	Lithitech Co., Ltd.	Liquid phase mixing	150 (0.1C), ~140 (2C)
CN113148969A	Lithitech Co., Ltd.	Solid phase mixing	~150 (0.1C), ~140 (1C)

Data source: Dynanonic, BYD, Gotion High tech, Huayi (Group), Pulead Technology Industry, Lithitech

Applications of LFMP

Index	Application mode	Advantages and disadvantages	Application scenarios
1	LMFP only	Advantage：High voltage platform and high energy density Disadvantage: Capacity is slightly lower than LFP material	electrical tools, energy storage
2	LMFP+LMO	1、High safety；2、cost-effective；3、Improved cycle stability 4、High compacted density；5、Improved low-temperature performance	electric two-wheeler, Electrical car, electrical tools, energy storage
3	LMFP+NCM+LMO	1、High safety; 2、cost-effective; 3、Improved cycle stability; 4、Improved low-temperature performance	Electric vehicles, electric two-wheeler, electrical tools
4	LMFP+NCM	1. High safety; 2. Manufacturing cost reduction; 3. Improved cycle stability	Electrical car、3C
5	LMFP+LCO	1. Comprehensive performance improvement; 2. Manufacturing cost reduction; 3. Improve safety	3C

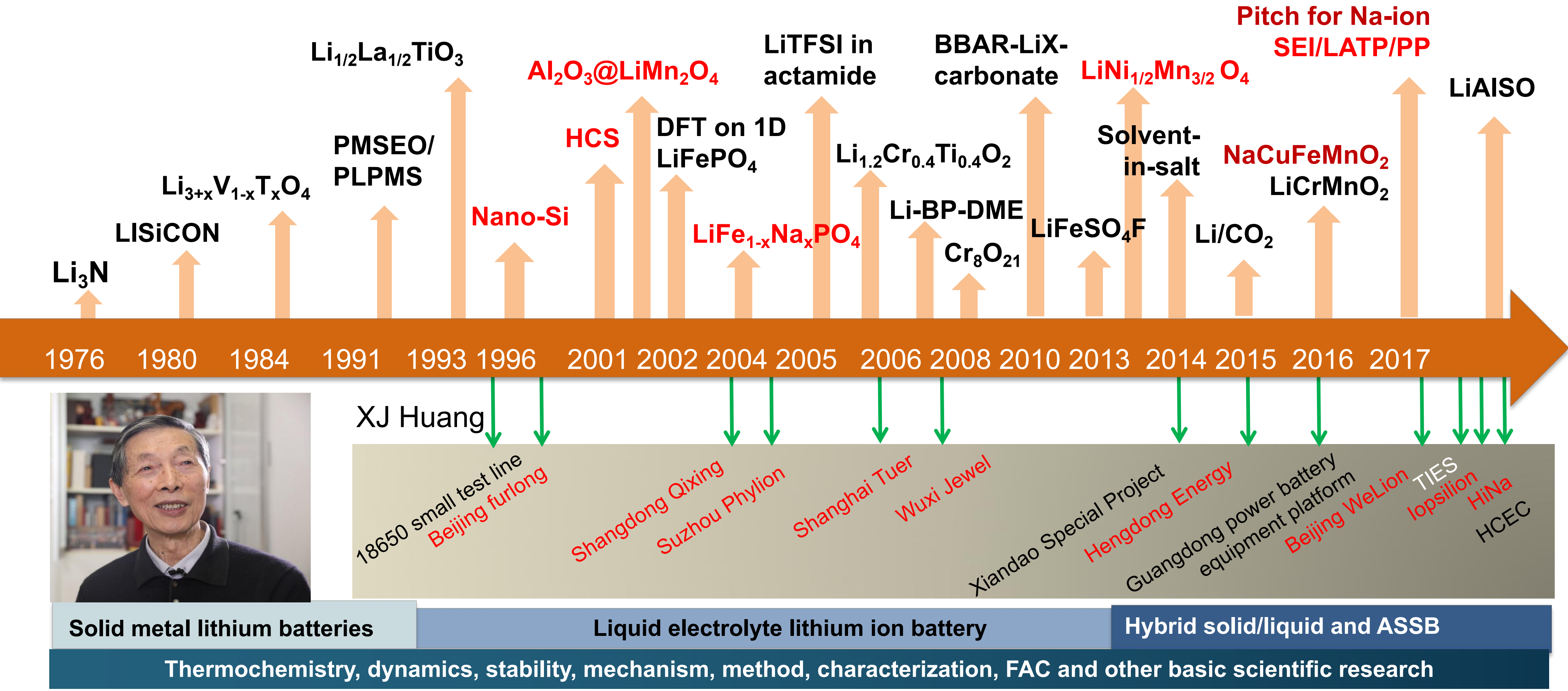
Industrial layout of LFMP

Index	Company	Layout
1	Dynanonic Co., Ltd.	1. The company's new type of lithium iron manganese phosphate has started to deliver samples, and it is expected to achieve industrialization in 1-2 years. 2. The battery's energy density can be increased by 20% and its cycle life can reach 10,000 times 3. Productivity: 120,000 tons by the end of 2021 and 180,000-200,000 tons by 2022.
2	Xinguorong Co., Ltd.	It has achieved mass production of tonnage and stable material performance.
3	Phylion Battery Co.,Ltd	The development of LMFP which makes the battery cycle performance outstanding through continuous iteration and can achieve a five-year warranty; Excellent low temperature performance, and safety performance (passing through the full electric acupuncture and 150℃ hot box test).
4	Pulead Technology Industry Co., Ltd.	The company is developing high-performance LFP and LMFP materials for electric vehicles and energy storage markets.
5	Shanghai Synica Co.,Ltd.	The company has a production line of 2,000 tons of LFMP now and is planned to build an additional equipment with an annual output of 3,000 tons of lithium ferromanganese phosphate.
6	Gotion High tech Co., Ltd.	1. The company's independent research "FP1865140-15AH square LFMP lithium ion battery" won the honor of Anhui Province new products; 2. The company has applied for a large number of cathode materials related patents, focusing on the distribution of LFP, LFMP and NMC materials.
7	Tianneng Group Co., Ltd.	The company is developing 18650 LMFP cell.
8	Wuxi Baichuan Chemical Industrial Co.,Ltd.	In 2020, the overall product scale of related projects of the company is 100,000 tons of iron phosphate, 15,000 tons of LFP, 15,000 tons of LFMP and 30,000 tons of NMC precursor materials.

Outline

1. Status of LIB
2. Status of $LiFePO_4$
3. LFP batteries towards future

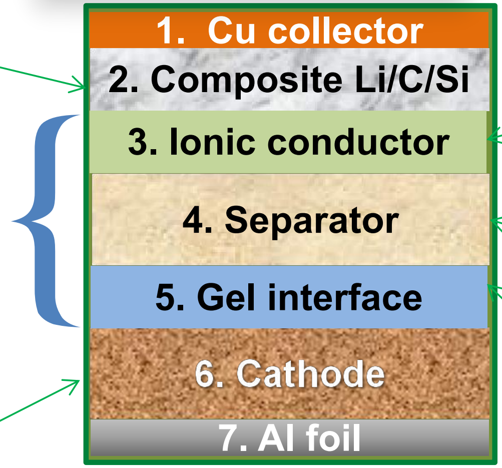
Research history of IoP-CAS on LIB



Solution of IOP-CAS: in-situ solidification

1. Prelithiation+ anode+ SE + SEI
C@Li, C/SiOx@Li, C/nano-Si/C@Li, Li-alloy

Coated or perforated copper foil



2. Inorganic solid electrolyte coating (LLZO, LATP) layer + SEI

3. Polymer support membrane（PP, PET）Or in situ polymerized polymer composite electrolyte（Polymer+ Li salt+ LLZO)

5. Solid electrolyte modified cathode + SE +Li salt /polymer + CEI
NCM811, NCA, Li-rich, LNMO, LMO, LFP, LFMP, LCO, others

Carbon coated aluminum foil

4. Multifunctional coating: PVDF-HFP, PMMA, LATP

Key idea：The electrolyte is kept in atomic level contact with the electrode material by liquid injection → then the liquid electrolyte is partially or completely converted into solid electrolyte by chemical or electrochemical reaction（Between surface and particles) → to solve the problems of high voltage, high safety, inhibition of lithium dendrite, control of volume expansion and reduction of contact resistance

Hybrid solid/liquid electrolyte LIB technologies

In situ solidification

Solve solid/solid interface problems

Nano-SE coated cathode

Decrease surface oxidation and stablize surface

Low expansion Si-based anode

Longer cycle life and low volume variation of the cell

Low expansion Li-composite anode

Longer cycle life and low volume variation of the cell

Nanosized solid electrolyte

Improve safety and rate

Solid electrolyte coated separator

Improve safety and decrease interfacial resistence

Modified current collector

Improve safety and decrease weight of CC

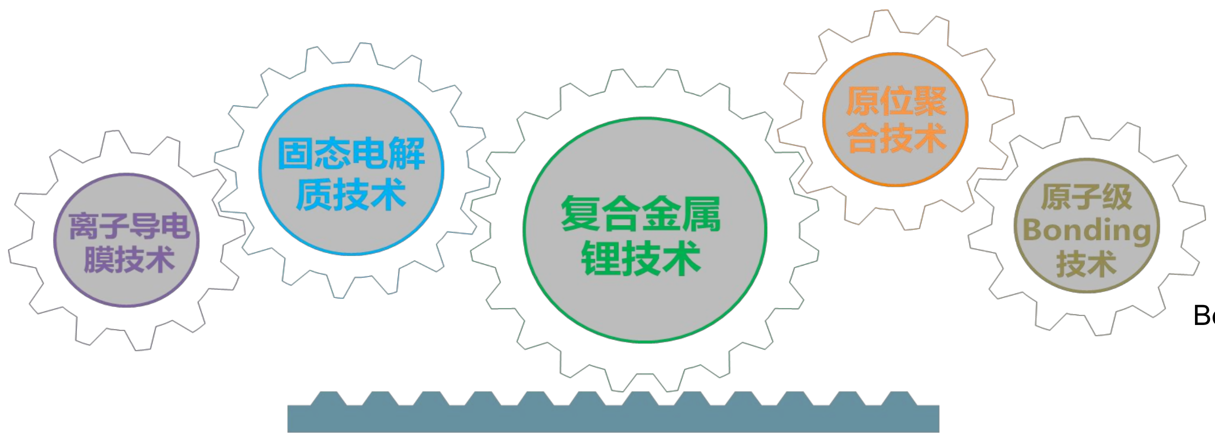
New machines

Prelithiation
dry electrode,
thermal lamination,
solidification

Solutions from Beijing WeLion New Energy Ltd.

Develop simplified materials and processes for advanced lithium batteries with deepest thought

Core technologies of solid state battery by Beijing Welion

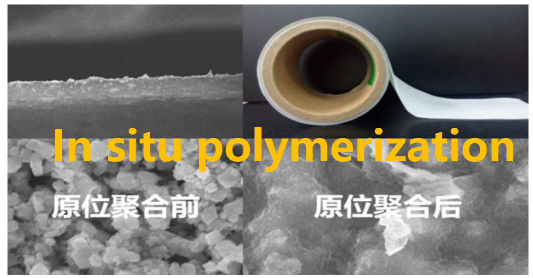


国际领先的固态电池五大核心技术平台，打造产品核心竞争力

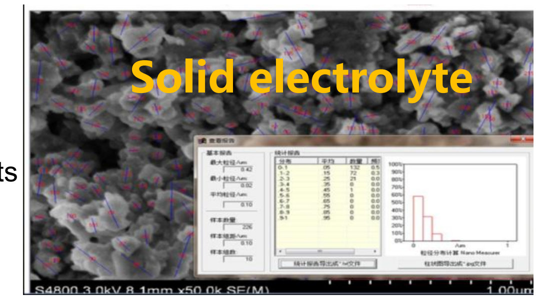
Leading solid-state battery 5 core technology platforms to create core competitiveness of products

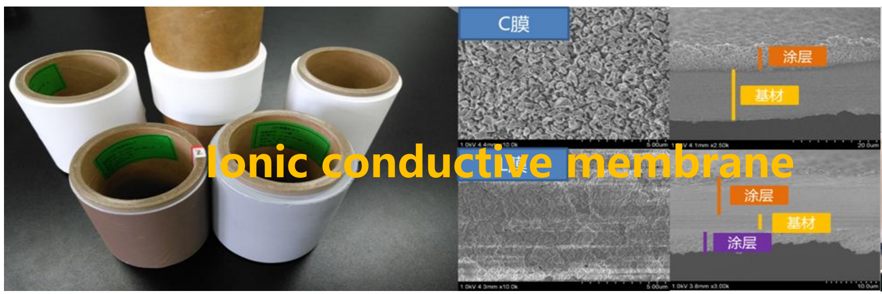
对标国际领先技术 → TOYOTA BOSCH BOLLORE

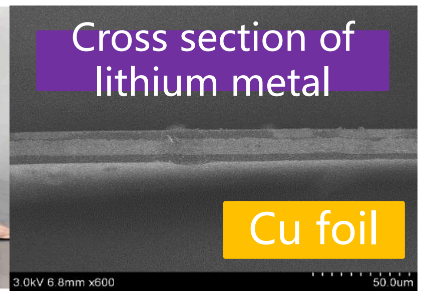
Benchmarking international leading technology



Before polymerization After polymerization





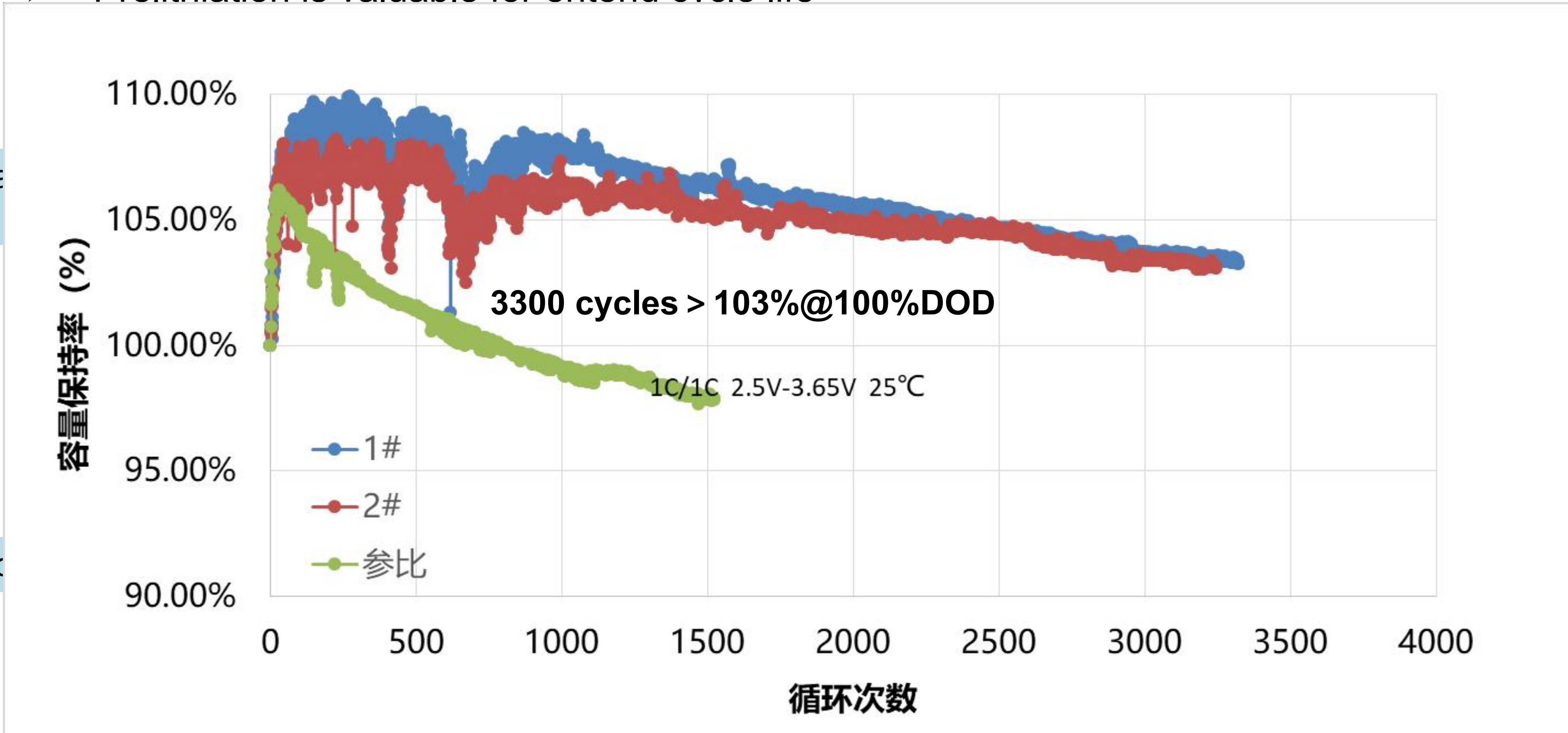


Compatible with existing power battery production line, adaptive to continuous intelligent manufacturing production

1. Coating technology;
2. Roll to roll electrodes and membrane;
3. Low-cost prelithiation;
4. Transfer of negative electrodes;
5. Slitting;
6. Laminating;
7. Electrolyte Injection;
8. Formation;
9. In situ solidification;
10. Packaging;
11. Dry environment process;
12. New module;
13. New pack.

Prelithiation effects

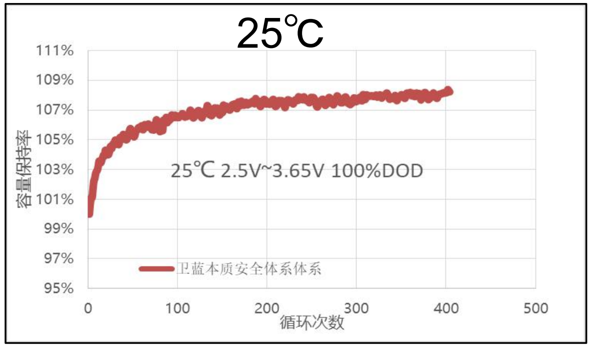
- Prelithiation is valuable for entend cvcle life

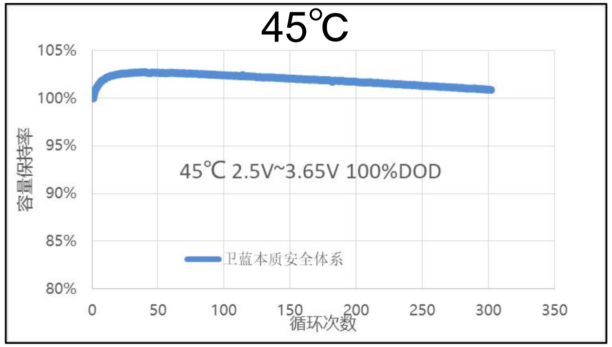


Initia
Cou
Cyc
循环次数
放电倍率/C

High safety Li-ion batteries

Item	Designed cell parameters
size	9.6*100*310
nominal capacity	30Ah（1C）
nominal voltage	3.2（1C）
charging cut-off	3.65 V
discharging cut-off	2.5 V
working temperature	-20°C ~ 60°C
Safety	**Welion ultra high safety standard** Superior than LFP, reaching the level of LTO battery
energy density	Specific energy：≥140 Wh/kg (Standard charge and discharge)
internal resistance	≤1.5 mΩ





Rate	Capacity retention/%	Temperature /℃
0.5C	106.49	26.4
1C	100.00	27.9
2C	92.67	31.6
3C	90.68	34
5C	93.30	40.7
7C	91.53	46.2

Intrinsically safe cell has excellent cycling and rate performance

High safety hybrid solid state battery system

category	item	liquid LFP	Welion safe$^{Gen.1}$ system	Competitive liquid LTO
Basic Information	1C capacity (Ah)	≥30	≥30	≥29
	internal resistance (mΩ)	≤1.0	≤1.0	≤0.5
	specific energy (Wh/kg)	> 140	> 140	> 70
Welion ultra high safety standard (**Some safety tests**)	nail penetration	No fire, no explosion, no smoke	No fire, no explosion, no smoke	No fire, no explosion, no smoke
	200℃ oven for 1 h	Bulge (temperature rise)	Bulge (voltage drops to 3.2V)	Bulge (voltage drops to 0V)
	50V overcharge	**on fire**	**a small amount of smoke**	**explosion**
	heavy impact	smoke	no smoke	no smoke
	extrusion (break)	no smoke	no smoke	no smoke
	100℃ high temperature short circuit	Bulge	Bulge	Bulge
	thermal runaway (high power heating)	232s	**6h**	1h
		Smoke (voltage drops to 0)	Smoke (voltage drops to 2.8V)	Smoke (voltage drops to 0)

Enterprises put forward more stringent new standards for the safety test of hybrid solid-state batteries

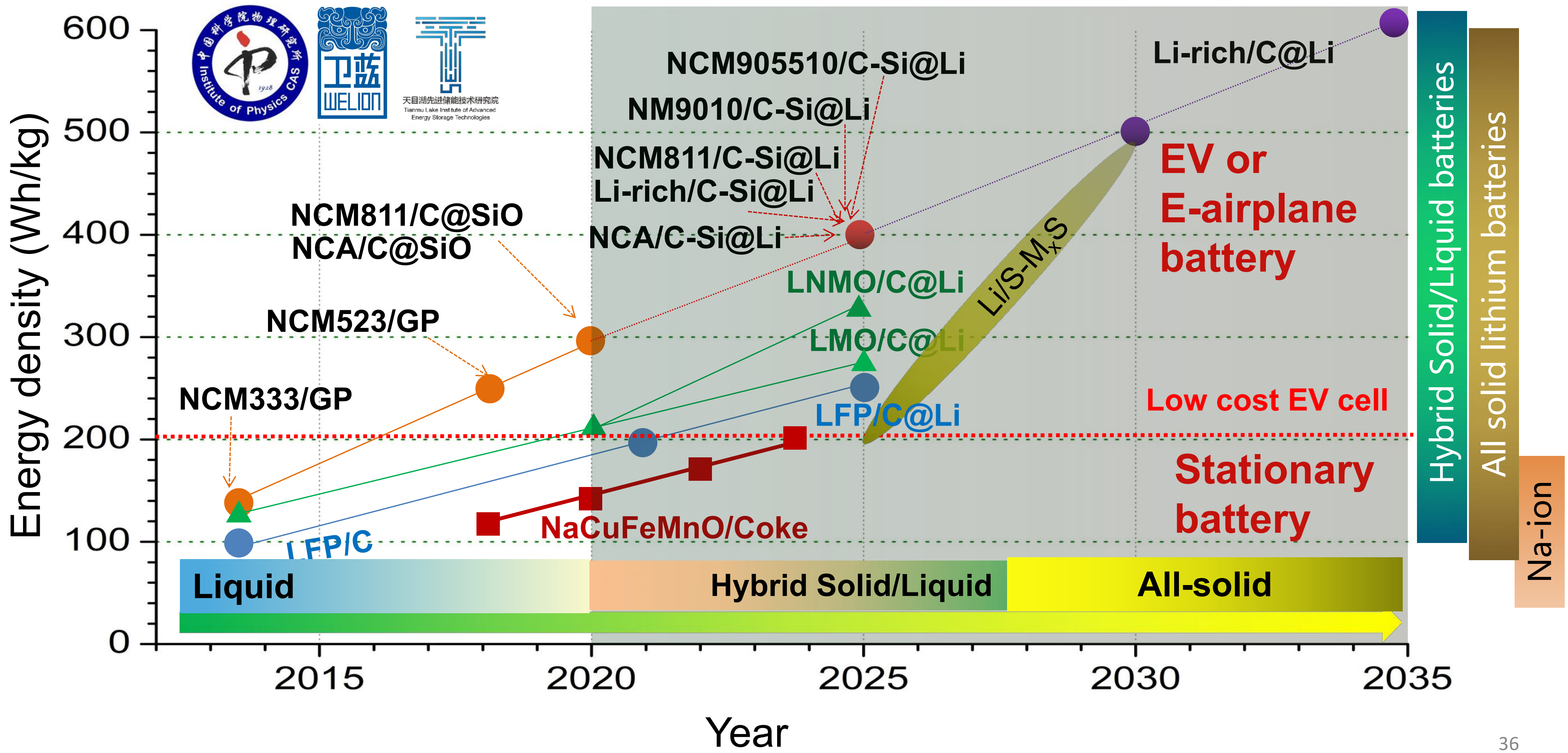
The intrinsic safety gen.1 battery (Welion safe$^{Gen.1}$) system can pass the "Welion ultra high safety standard"

Targets of "2016-2020" AND "2021-2025" on energy storage

Performances	2016-2020	2021-2025	Effect
LCOS	0.4-0.6 RMB/kWh	0.1 ~ 0.2 RMB/kWh	3 times lower
Service life	8 ~ 10 year	> 20 year	1 time longer
Cycle life	5-10 k	> 15 k	1.5 time
Scale of station	< 100 MWh	> 1 GWh	10 times large
Safety	Relatively safe	Intrinsic safe	
Intelligent control	weak	strong	new requirement
Intelligent testing	weak	Strong	new requirement
Smart sensor	none	Strong	new requirement

For main applications, support short-period(<30 minutes), normal-period (< 4 hours) and long period (>4hours) energy storage technologies with intrisic safety, low LCOS, long life and smart control

Roadmap of batteries for EV and stationary applications



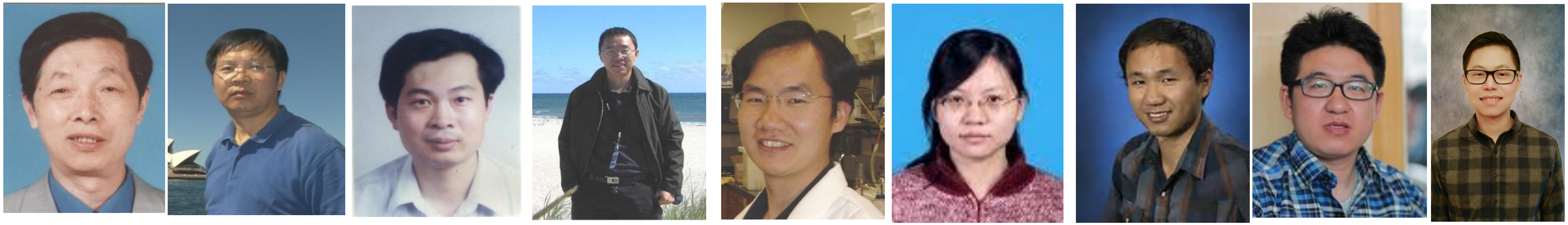
Summary

LFP for 600 km EV is practical with new Si anode and solid solutions:

1. *In situ* solidification: SEI/CEI + *in situ* polymerization
2. Li-containing Si and C-based anode
3. Mixed ionic conductors coated separator
4. SSE coated cathode particles
5. SSE nanoparticles filled in cathode and anode
6. Control safety at molecular and atomic level

It is expected that hybrid solid/liquid LFP batteries and all solid lithium batteries via *in situ* solidification will be commercialized for various applicaitons at 2022-2025 based on current efforts.

Thanks: SSB team member in IoP and collborators



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Team members
4 engineers
5 Post. Doctor:
55 master/Ph.D students
National:
11 CAS institutes
8 univ.,
5 IoP companies
13 other companies
International:
BNL, LBNL, PNNL, ORNL, SLAC, MPI, Julich, POSTEC
+ LG Chem

Huigen Yu Wenjun Li Jiuming Li
Zheng Geng Jin Xiang Yao Fu

WeLion R&D Team for SLB
Totally > 500 persons

Fei Luo Geng Chu Bonan Liu
Hao Lu Yingying Yin Minjun Pan

Team for Si-based anode
Totally > 140 persons

Jieyun Zheng Lifei Li Deyu Wang
Xiaosong Liu Lilu Liu Liang Yin

Team in TIES
Totally>200 persons

Thanks to the colleagues and collborators!

Thanks for your attention!