

State of Batteries Report 2020

January 16, 2021

“The battery is the technology of our time.” - The Economist

In this inaugural report, we summarize what we consider to be the most significant developments in the battery industry in 2020. This report seeks to provide a comprehensive and accessible overview of the current state of battery research, industry, talent, and policy. We hope to catalyze in-depth conversations on the state of batteries and trajectory for the future.

We consider the following key dimensions in our report:

Section 1: Industry	Commercial milestones in battery development and manufacturing
Section 2: Research	Academic breakthroughs in fundamental battery science
Section 3: Talent	Supply, demand, and insights on talent working in the field
Section 4: Policy	Government targets, incentives, regulations, and their implications
Section 5: Predictions	Trends we believe are likely to happen in the next 12 months

Produced by the [Volta Foundation](#)

***Disclaimer:** The views expressed herein are solely those of the authors, and have not been reviewed or approved by any other organization, agency, employer or company. The primary purpose of this work is to educate and inform.

Section 1: Industry

Introduction

Industry players are moving rapidly to pursue higher energy density and lower cost. Strategies include utilizing Si anodes and leapfrogging to solid-state battery (SSB) technologies. Significant trends include battery and auto manufacturers forming joint ventures (JV) and ramping up production capacity. As public and private investments in the battery industry accelerate, some challenges remain in the supply chain.

In this section, we review the following:

**Industry
Movement**

**Company
Spotlights**

**Technology
Map**

**Manufacturing
Map**

**Supply Chain
Insights**

**Energy
Investment**

Industry Movement: Q4 2020

Dec

[Indonesia](#): LG Chem and CATL to invest billions in battery plants in Indonesia.

[Apple](#): Targets car production by 2024 and eyes "next level" battery technology

[Toyota](#): To unveil solid-state battery EV prototype in 2021

[Solid Power](#): Now producing a multi-layer 20 Ah solid-state battery

[QuantumScape](#): Releases performance data for its solid-state battery technology



Nov

[LG Chem](#): To go module-less using new battery platform

[QuantumScape](#): SPAC merger with Kensington Capital is approved

[Tesla](#): To build massive 100+ GWh battery plant at Giga Berlin

[SVOLT](#): To build EV battery factory in Germany



Oct

[Foxconn](#): Promises to sell a solid-state battery in 2024

[Mercedes-Benz](#): eCitaro uses all-solid-state batteries from BlueSolutions

[NIO](#): Completes 1 millionth battery swap

[Solid Power](#): Begins delivering its 1st generation all-solid-state battery

[Northvolt](#): Raises additional \$600 million in equity



Industry Movement: Q3 2020

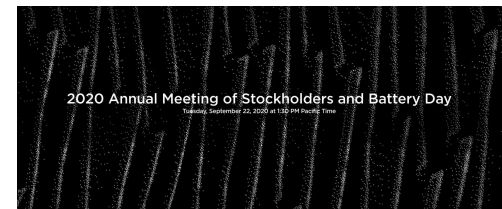
Sep

[Tesla](#): 2020 annual meeting of shareholders and Battery Day

[LG Chem](#): Li-Sulfur battery successfully tested in high altitude aircraft

[GM](#): Future electric cars to feature wireless battery management system

[BYD](#): Launches battery production plant in Brazil



Aug

[Panasonic](#): To invest \$100 million for Tesla batteries in U.S.

[SK Innovation](#): Targets 88% nickel content by 2023 and 98% by 2030

[CATL](#): Hints at cell-to-chassis EV batteries for 500+ miles of range

[Lucid](#): Announces 113-kWh lithium ion battery in Lucid Air for 500 mile range

[Britishvolt](#): Battery gigafactory to be located in South Wales



Jul

[Wanxiang A123](#): To supply batteries to Volkswagen Group

[BMW](#): Announces €2 billion battery supply deal with Northvolt

[Honda & CATL](#): Form comprehensive strategic EV battery alliance

[Mercedes-Benz & Farasis Energy](#): Announce strategic partnership



Industry Movement: Q2 2020

Jun

[Volkswagen](#): Increases stake in solid-state battery specialist QuantumScape

[Tesla & Panasonic](#): Enter 3-year battery pricing agreement

[Umicore](#): Secures €125 million loan from EIB for battery materials plant

[Tesla](#): Tesla approved to produce Model 3 with LFP batteries in China

May

[OXIS Energy](#): To build world's first Li-S manufacturing plant in Brazil

[SK Innovation](#): Announces 2nd battery gigafactory in Georgia

[Battery500 Consortium](#): Hits 350 Wh/kg and 350 cycles

[Farasis Energy](#): To launch \$480 million IPO

Apr

[SK Innovation](#): To supply electric car batteries to BAIC

[Nissan](#): Licenses all-polymer battery tech to APB

[Enovix](#): Raises \$45 million to launch 3D silicon lithium-ion battery



Industry Movement: Q1 2020

Mar

Volkswagen: Increases stake in solid-state battery specialist QuantumScape

BYD: Reveals ultra-safe blade battery: pierces it with a nail

Sion Power: Li-metal batteries to offer 420 Wh/kg commercially

LG Chem: Secures €480 million loan from EIB for battery plant in Poland

Volvo: Launches EV battery pack assembly line in Belgium



Feb

Tesla: Made-in-China Tesla Model 3 will have prismatic LFP cells

Toyota & Panasonic: Announce JV for automotive prismatic batteries

CATL: Confirms battery supply agreement with Tesla

BASF: To launch battery materials production in Germany



Jan

Tesla: Partners with LG Chem and CATL for EV batteries

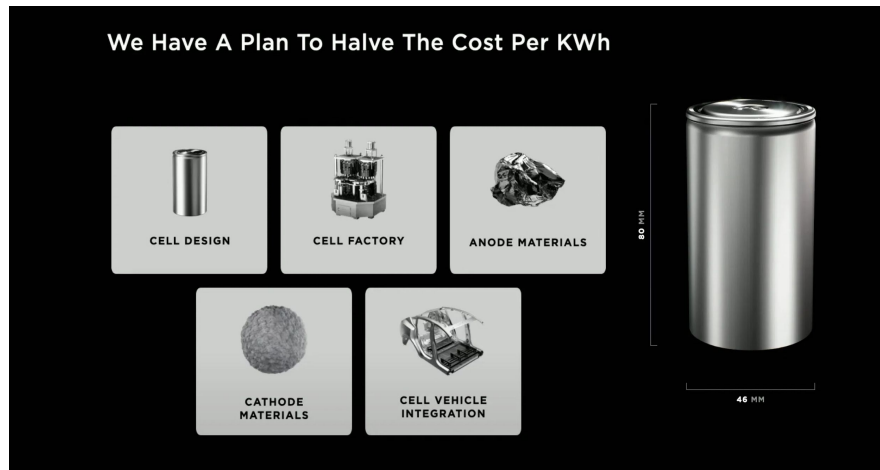
OXIS Energy: Li-S cells: almost at 500 Wh/kg, new target 600 Wh/kg

Enegate: Announces commercialization of a superb battery anode

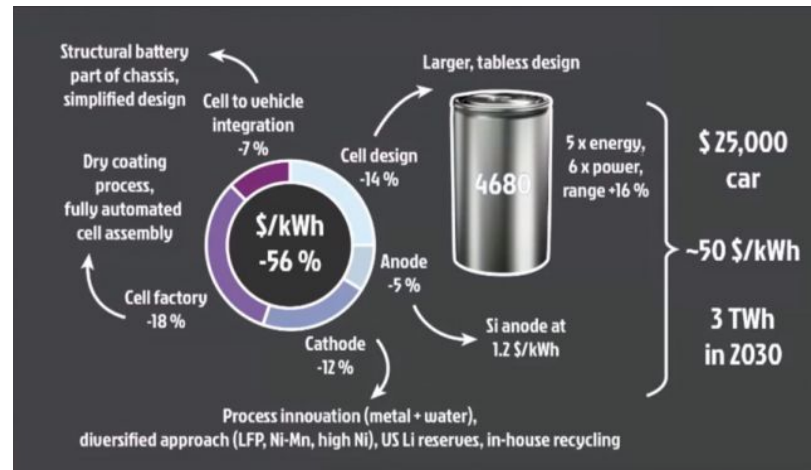
Kyocera & 24M: Introduce SemiSolid lithium-ion residential ESS



Company Spotlight: Tesla's Battery Day (I)



*Source: [Tesla Battery Day](#)

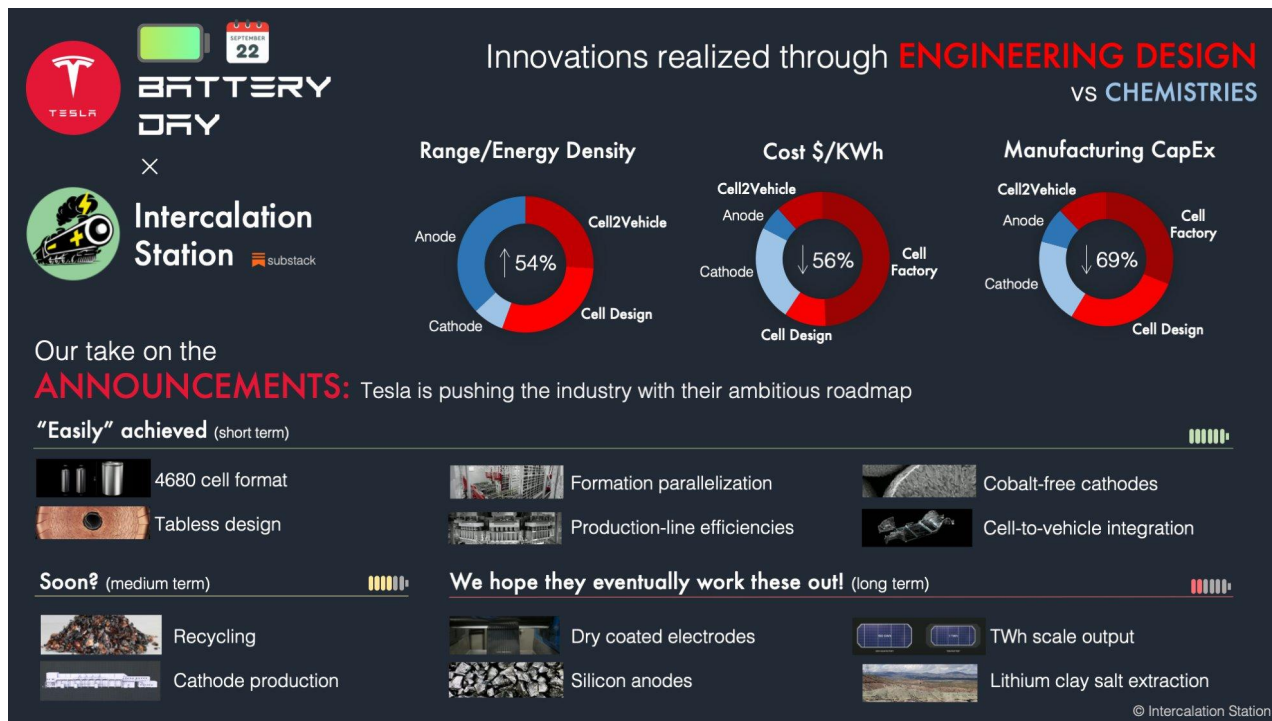


*Source: [Battery Associates](#)

Cost Reduction

Cell design	Tabless, 4680 cylindrical, laser-welded sides, 5x energy, 6x power, range +16%	-14%
Cell factory	Maxwell's dry coating, full automated assembly, formation footprint -75%	-18%
Anode material	Si anode from raw Si, elastic ion-conducting polymer coating, \$1.2/kWh of Si, range +20%	-5%
Cathode material	High-Ni for long range, LFP for entry models, CAM manufacturing, in-house recycling	-12%
Cell vehicle integration	Cell to vehicle, aluminum alloy, single piece Giga casting, mass -10%, range +14%	-7%

Company Spotlight: Tesla's Battery Day (II)



All strategies combined, Tesla could achieve:

- 54% increase in **range**
- 56% decrease on **cost**
- 69% reduction on **investment per GWh**

Short-term:

4680 cell, Tabless design, Formation parallelization, Production efficiency, Co-free (LFP) cathode, Cell-to-vehicle integration

Mid-term:

Recycling, Cathode production

Long-term:

Dry coating, Si anode, TWh scale output, Li clay salt extraction

*Source: [Intercalation Station](https://www.intercalationstation.com/)

Company Spotlight: BYD's Blade Battery



Blade battery design:

- Volumetric energy density +50%
- Cost of battery pack -30%
- Life cycle: 3500 cycles
- Energy density: 140 Wh/kg
- Price: **~\$85/kWh** (lower than CATL's ~\$100/kWh LFP pack for Tesla Model 3's in China)

The egg was blown away by explosion



NCM Lithium Battery:
severely damaged
surface temperature exceeded 500 °C

The egg was charred



Lithium Iron Phosphate Block Battery:
no fire or smoke observed
surface temperature of 200 °C to 400 °C

The egg remained uncooked



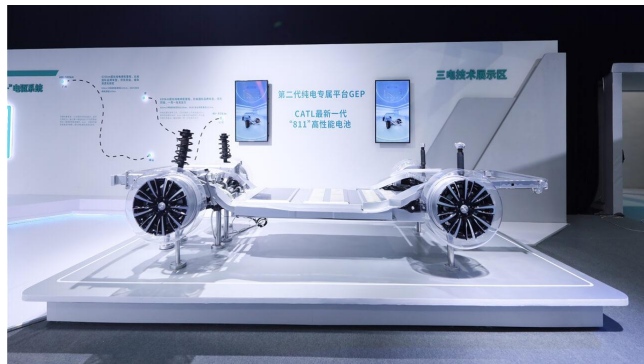
BYD Blade Battery:
no fire or smoke
surface temperature of 30 °C to 60 °C

Safety tests:

- Nail penetration test ✓
- Crush, bend test ✓
- Overcharge by 260% ✓
- Heat to 572F (300C) ✓

*Related reading: [BatteryBits-BYD](#)

Company Spotlight: CATL's CTP/CTC, Co-free, High-Ni

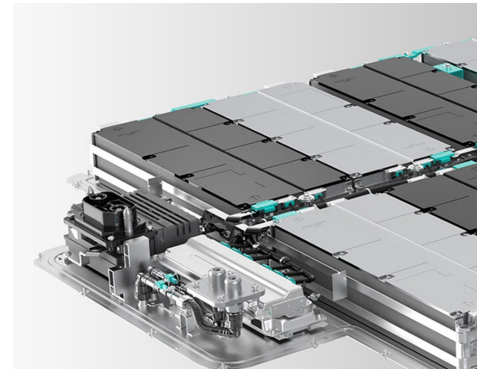


Cell to Pack:

- Volume utilization of pack +15~20%
- Number of parts in pack -40%
- Production efficiency +50%

Cell to Chassis:

- Integration of cells to chassis, for higher energy density and lower cost



Co-Free (LFP)

- Highest energy density: 160 Wh/kg (used in Yutong bus)
- Energy density on Model 3: 125Wh/kg
- Fast Charging: LFP+ EnerSpeed, fast ionic ring technology, 0-80% <20 min
- Cost: \$100/kWh, 43% less expensive per kWh than NCM 811



High-Ni and Beyond

- Single-crystal Ni55 cathode
- Anti-oxidation electrolytes
- 4.5um ultra thin substrate
- FIC coating technology
- Bionic self-repairing electrolyte

*Related reading: [BatteryBits-CATL](#)

Company Spotlight: NIO Day and BaaS



Battery as a Service

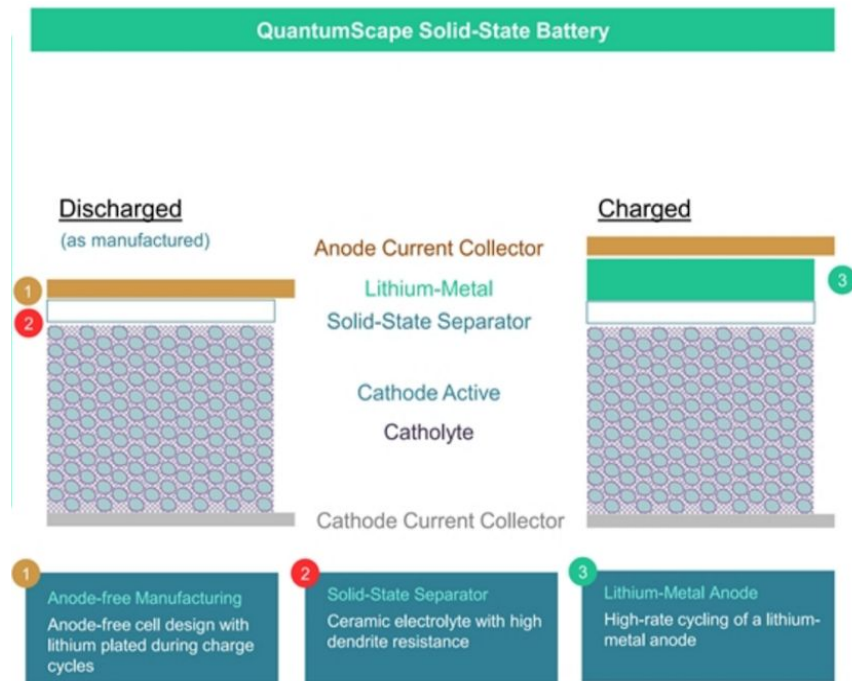
- Vehicle battery separation
- Battery swap in 3 minutes
- Chargeable, swappable, and upgradable batteries
- On-demand battery subscription for flexible capacity
- Power Swap Station 2.0: up to 312 swaps/day/station

From 100 kWh to 150 kWh Battery Pack

- CTP manufacturing speed +40%, energy density +37%
- 150 kWh, **360 Wh/kg solid state battery**
- Nano-coating nickel-ultra rich cathode
- Inorganic pre-lithiated Si/C composite anode
- In-situ solidification hybrid electrolyte
- All-climate thermal management

Company Spotlight: QuantumScape's Solid-State Battery

Anode-free Li-metal ceramic-style single-layer pouch cell



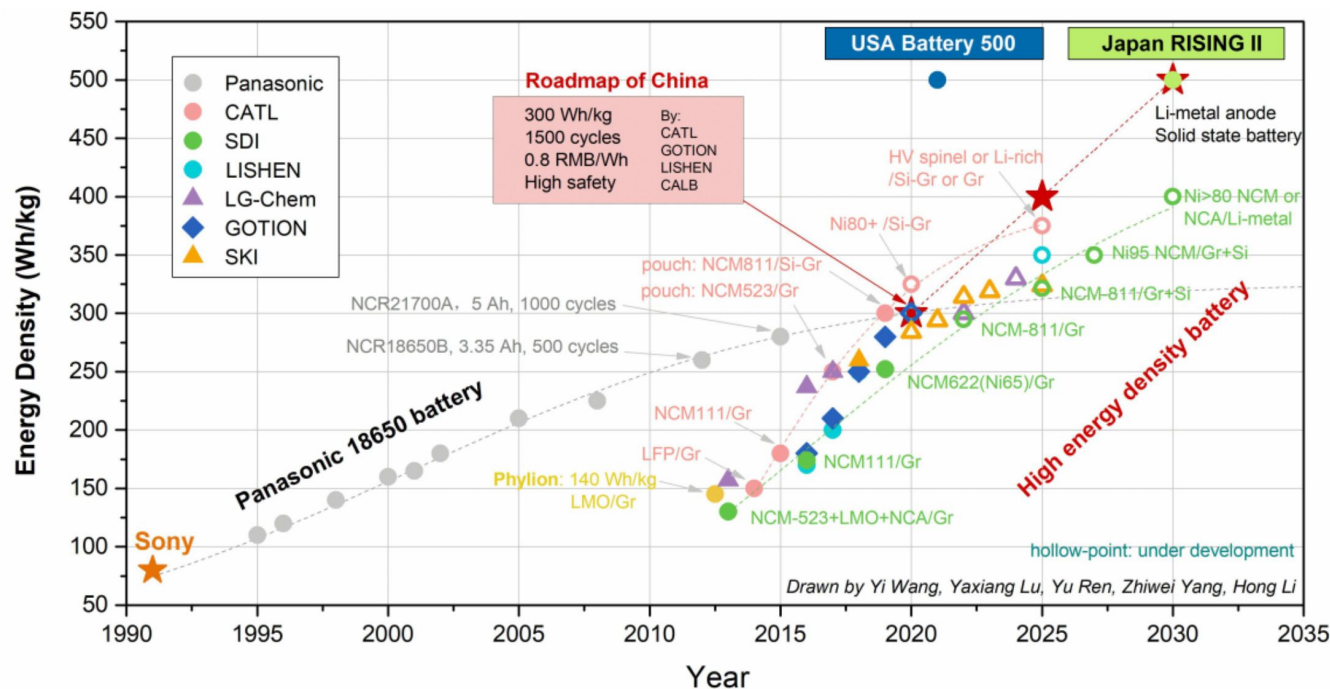
- **Energy density:** >400Wh/Kg
- **Separator:** Solid-state ceramic, high dendritic resistance.
- **Lithium metal anode:** Anode-less cell design with lithium plated directly on current collector during charge cycles.
- **Cycling:** 800 cycles to 80% capacity at 1C
- **Fast charging:** < 15-minute fast charge from 0 to 80%
- **IP:** 200+ patents and 100+ trade secrets
- **Cost:** 17% lower manufacturing costs with established manufacturing processes
- **Market:** The only Li-metal solid state battery with automotive OEM validation
- **Manufacturing:** 2025 production at 20 GWh scale for factory #1 (QS-1)

*Source: [SEC](#)

*Related reading: [BatteryBits-Solid State](#)

Technology Map: Energy Density Target and Progress

Roadmap of energy density goals



Energy Density Achieved:

On the road:

CATL: 279.56 Wh/kg
(Leap Motor T03)

SKI: 269.44 Wh/kg
(Arcfox Alpha-T)

LG-Chem: 257.10 Wh/kg
(Tesla Model 3)

USA Battery 500:

350 Wh/kg, 350 cycles
(Li/NMC 622 Pouch Cell)

*Source: [Battery 2030+ Roadmap](#); Redrawn from Li, et al, cited from Figure 1 in Energy Storage Materials, 23(2019) 144-153

Technology Map: Higher Energy Density Startup Solutions

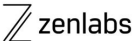
	Company	Main Technology	Energy Density Progress
	Nanoramic Laboratories	Neocarbonix™ electrode processing	30% increase in energy density and 20% cost reduction
	NOHMs	High voltage electrolyte	375Wh/kg for about 1000 cycles at C/5-C/3
	ZenLabs	Novel electrolyte+SiOx anode	315Wh/kg over 1000 cycles and 400Wh/kg over 250 cycles achieved
	Cuberg	Li metal anode+stable electrolyte	369Wh/kg over 370 cycles with specific power 2000W/kg achieved
	Oxis Energy	Li-S battery	400Wh/kg , 200-300 cycles

*Table by BatteryBits

Technology Map: Higher Energy Density - Silicon Anode

Company	Main Technology	Funds Raised	JV/JD/Investment
 Sila	Si nanocomposite	285M	 DAIMLER
 Enovix	3D architecture Si	191.3M	 
 Enevate	Si porous film	111.6M	  LG Chem SAMSUNG
 Nexion	Si porous columns	95M	WACKER
 Amprion	Si nanowire	61.4M	AIRBUS
 Group 14	Si/C composite	35M	  BASF
 Advano	Si nanoparticles	23.8M	 MITSUI KINZOKU
 NanoGraf	Si alloy-graphene	22M	 

*Table by BatteryBits

Related reading: [BatteryBits-Silicon Anode](#)

Technology Map: Higher Energy Density - Solid State

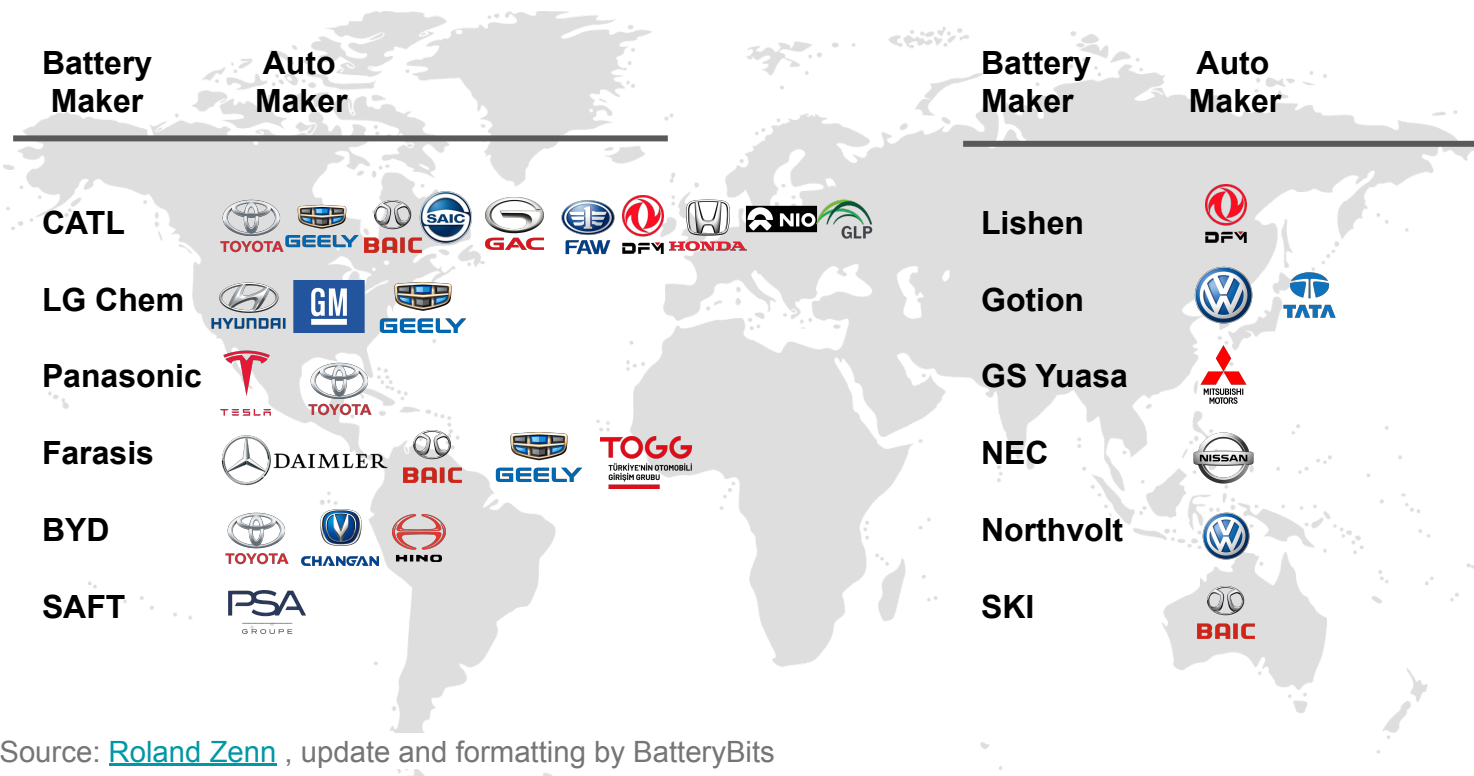
Company	Anode	Electrolyte	Fund Raised	JV/JD/ Investment
 QuantumScape	Anode-free Lithium	Oxidic & Sulfidic Ceramic	\$1B+	
 Prologium	Lithium/Graphite/Si	Oxidic Ceramic	\$100M	 
 Solid Energy	Lithium	Semi-Solid Solvent-in-Salt	\$86M	
 Ionic Materials	Lithium/Graphite	Doped Pi-Conjugated Polymer	\$65M	   
 Sion Power	Lithium	Hybrid Ceramic-Polymer	\$50M	 
 Solid Power	Lithium	Sulfidic Glass-Ceramic	\$23.5M	   
 Bolloré	Lithium	PEO-based Polymer	N/A	
 Hydro Quebec	Lithium	PEO-based Polymer	N/A	

*Source: [Roland Zenn](#) , updated by BatteryBits

Related reading: [BatteryBits-Solid State](#)

Manufacturing Map: JVs between Battery and Auto Manufacturers

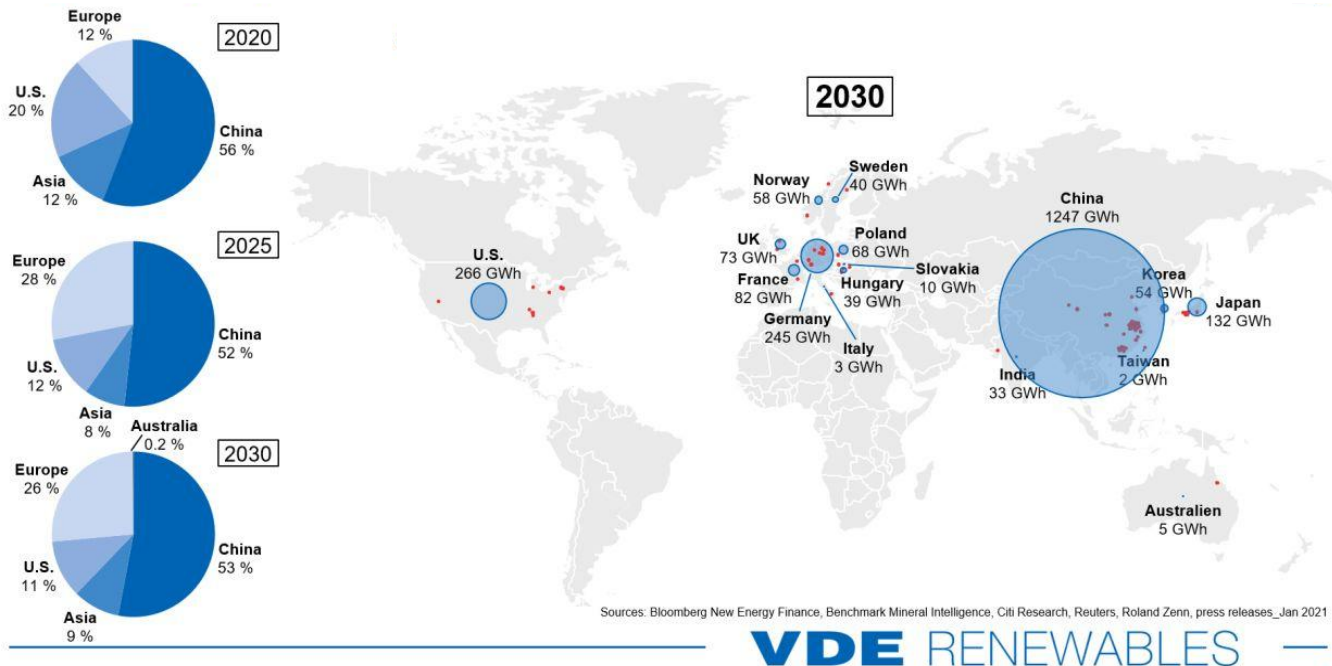
Battery manufacturers and OEMs are partnering up in this new trend



*Source: [Roland Zenn](#), update and formatting by BatteryBits

Manufacturing Map: Global Installed Capacity

China dominates global market in existing and planned production capacity



Capacity GWh	2020	2025	2030
CN	1247	704	1247
NA	65	165	266
EU	39	382	617
AS	41	110	219
Total	328	1360	2353

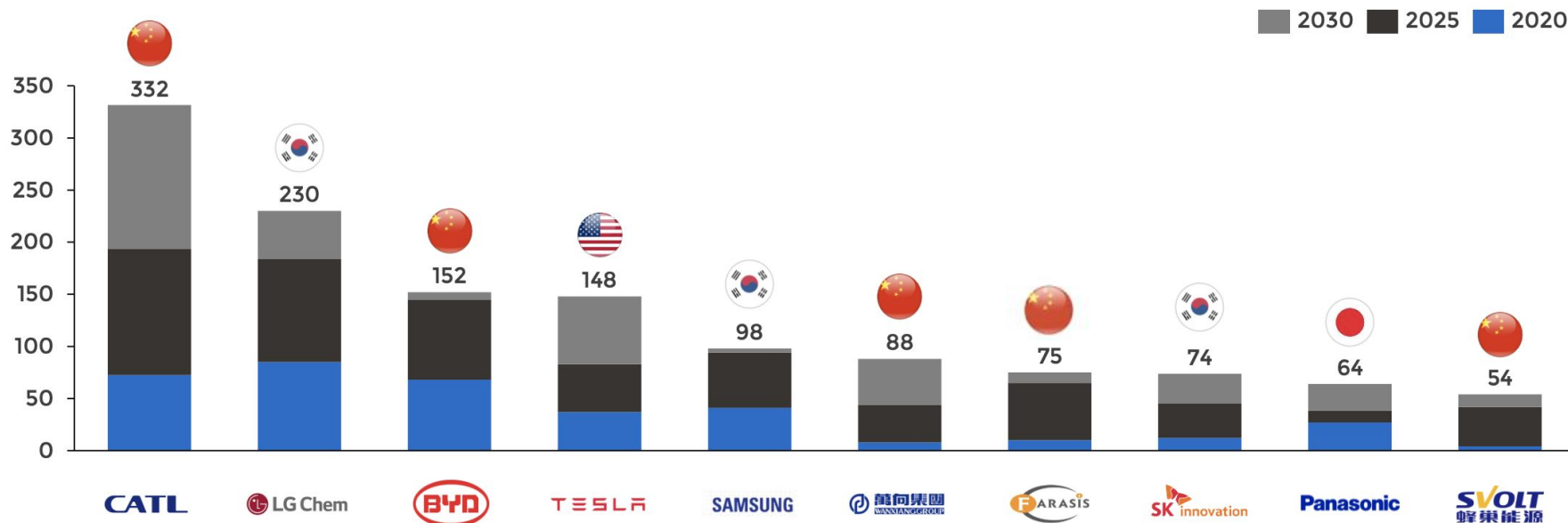
● Existing or planned gigafactory sites in 2030 are marked with a red dot.

*Source: [VDE Renewables](#)

Manufacturing Map: Global Planned Capacity of Top Manufacturers

Planned manufacturing capacity exceeds 2.4 TWh

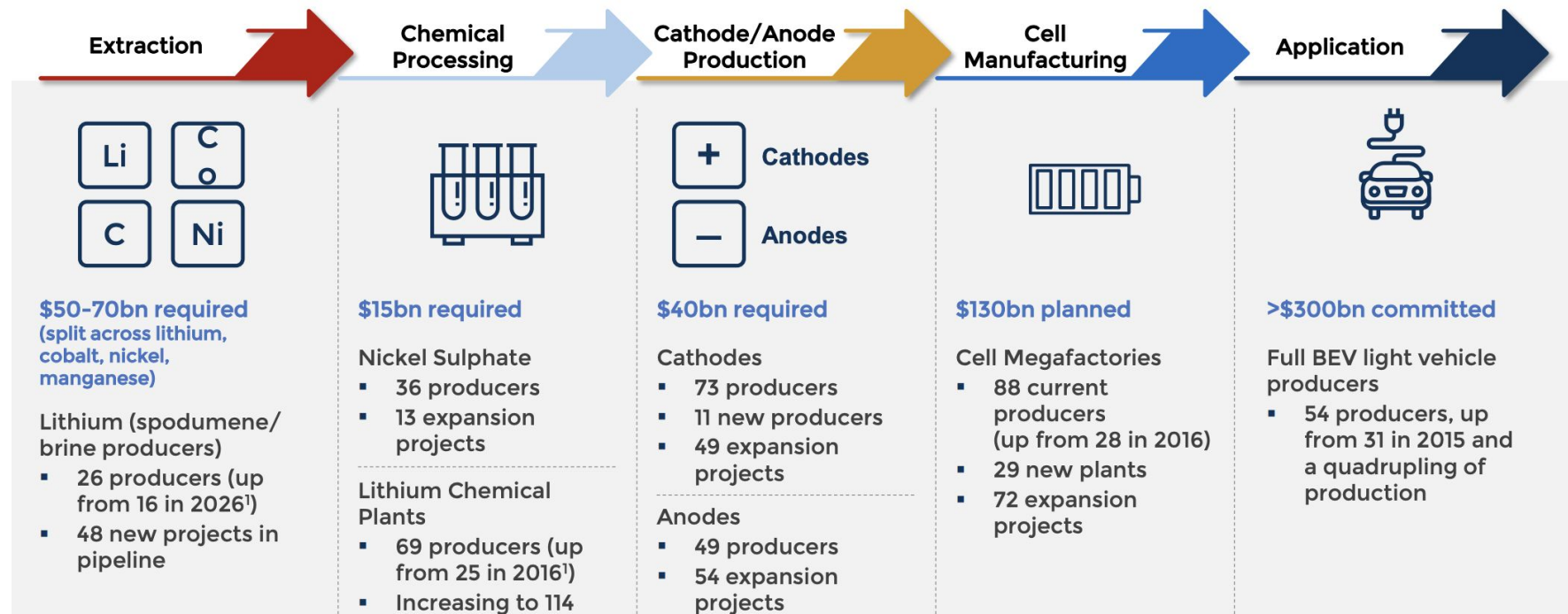
Expected GWh battery cell manufacturing production through 2030 - Top 10 producers



*Source: [BENCHMARK MINERAL INTELLIGENCE](#)

Supply Chain Insights: Building up the EV Supply Chain

EV supply chains are complicated and need \$bn of investment

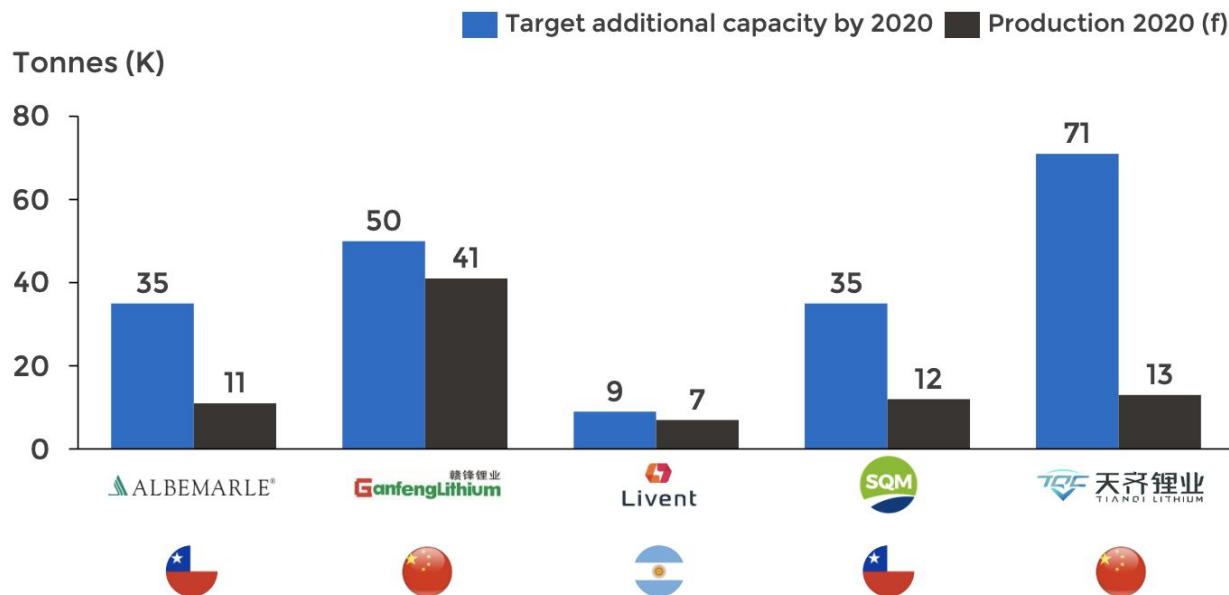


*Source: [BENCHMARK MINERAL INTELLIGENCE](#)

Supply Chain Insights: Upstream Mining

Major lithium suppliers have struggled to meet their targets

2020 target vs. actual production - major lithium production assets ('000 MT LCE)

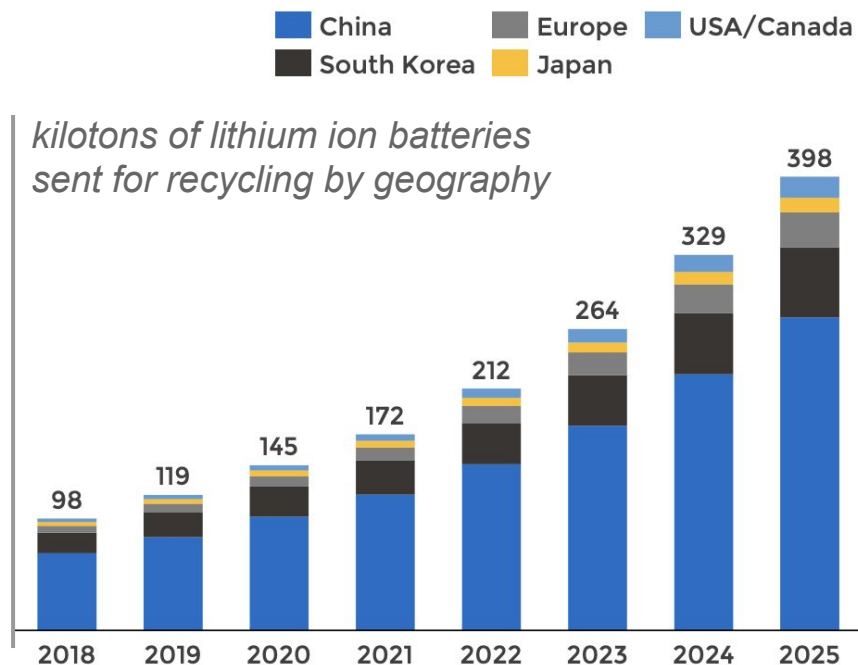


- Lithium supply is highly concentrated geographically
- Innovation on producing **battery grade** lithium is needed
- Lithium supply chain's large **carbon footprint** remains a big problem
- Lithium **shortage** is expected in the next 10 years

*Source: [BENCHMARK MINERAL INTELLIGENCE](#)

Supply Chain Insights: Recycling Raw Materials

Volume of batteries sent to recycling centers expected to grow 4x by 2025



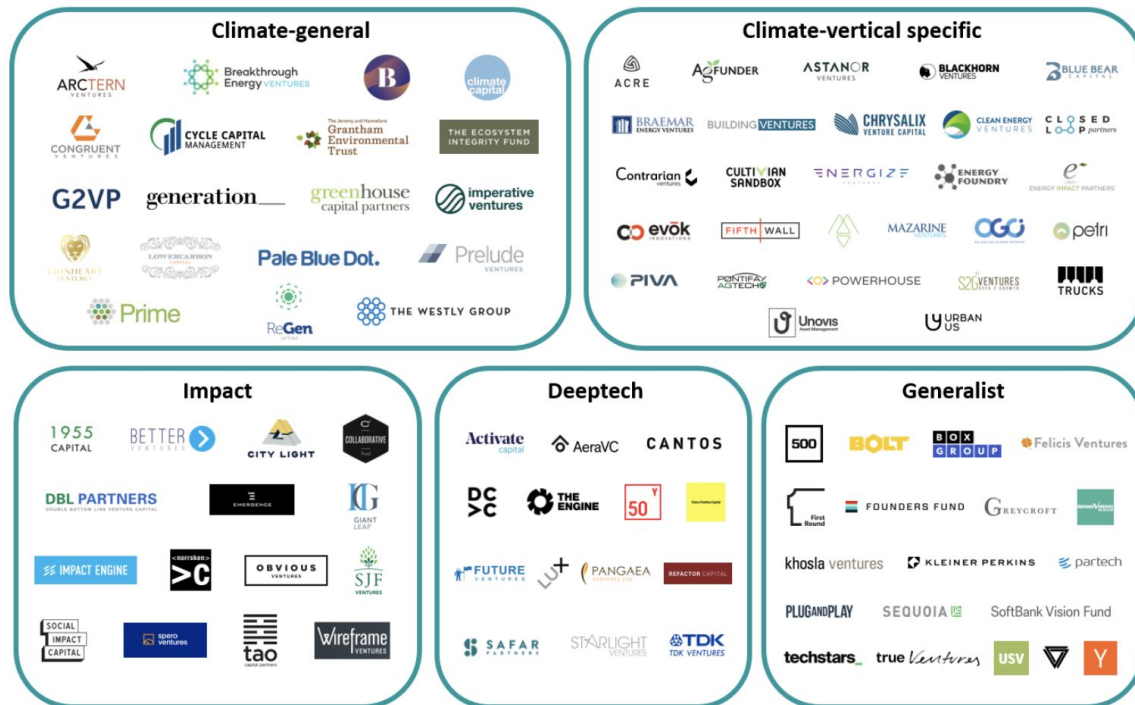
The recycling industry is in its nascent stages, and faces multiple obstacles on its path towards profitability and scale:

- Second life batteries
- Low collection rate from the customer
- Non-differentiated regulation between lead-acid and lithium-ion batteries
- Input feedstock heterogeneity
- Chemical process inefficiency
- Competing priorities with battery life longevity push

*Source: [BENCHMARK MINERAL INTELLIGENCE](#)

Investment: Cleantech VCs On the Rise

The emergence of climate funds: About 95 funds are actively investing



*Source: [Climate Tech VC](#)

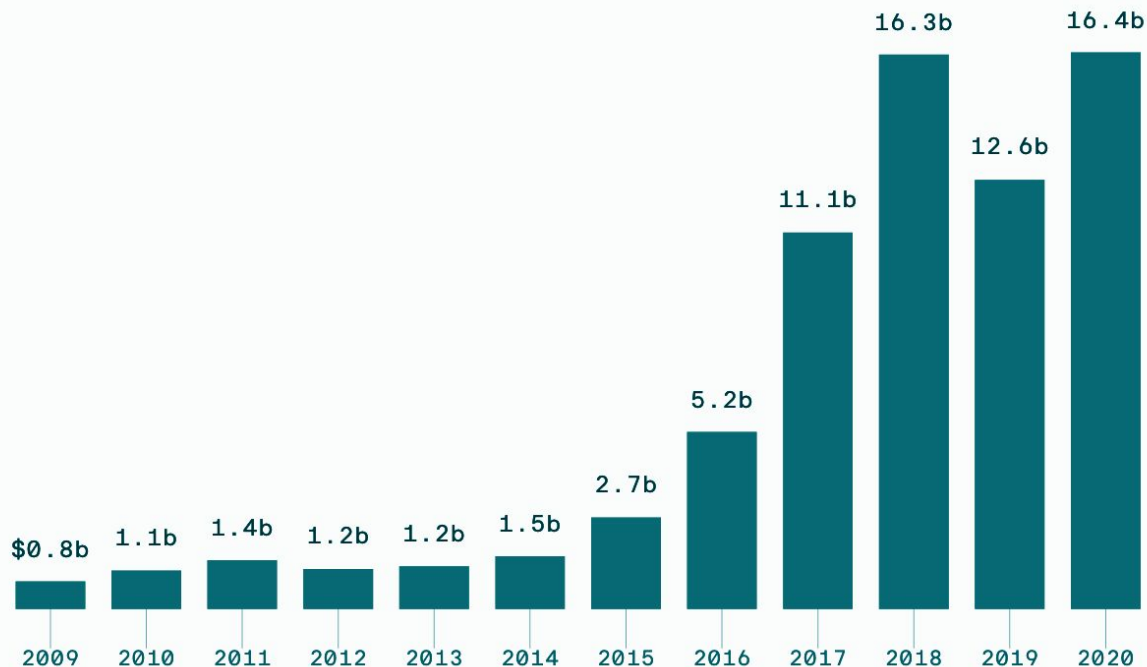
Environmentally conscious VCs are becoming more active in climate and energy storage investments, and climate-specific funds are gaining popularity. Climate venture capital has soared 3750% since 2013 ([PwC](#)).

Number of VC firms:

- Climate-general: 19
- Climate-vertical specific: 28
- Impact: 15
- Deeptech: 14
- Generalist: 19

Investment: Record High Cleantech Investment

VC investments into cleantech reached an all-time high of \$16.4 billion in 2020



*Source: [Data-pitch book](#), [Chart-Axios Visuals](#)

- The climate technology market amounts to around **\$2.5 trillion**
- Venture capital investments started increasing significantly in 2016 and 2017
- Clean-energy technologies are expected to grow substantially in the next 30 years

Investment: 2020 VC Portfolio in Energy Storage

More than \$500 million allocated to battery related startups

Energy storage

Form Energy: \$76M

Highview Power: \$55.5M

Quidnet Energy: \$10M

Orison: \$8.5M

Voltstorage: \$7.4M



Natron



ENERVENUE

Battery management, software, microgrids, EV chargers and more

Demand Power: \$71M

Skeleton: \$49M

FreeWire: \$25M

PowerUp: \$6M



FREEWIRE

Batteries

QuantumScape (solid-state battery): SPAC IPO

Eos Energy Storage (Zinc-based battery): SPAC IPO

Redwood Materials (battery recycling): \$40M

Natron (Na-ion battery): \$35M

EnerVenue (Ni-H battery): \$12M

*Source: [pv-magazine](https://www.pv-magazine.com)

Investment: The Rise of SPACs

A fastpass for cleantech companies to IPO

Electric Vehicle													Electric Vehicle (Chinese)									
																						
TSLA	FSR	RIDE	HYLN	XL	GOEV	WKHS	SOLO	IDEX	FUV	AYRO	GP	NKLA	NIO	XPEV	LI	KNDI	BYDDY	NIU				
Electric Vehicle (SPAC - Pre-Merger)				Lidar			(SPAC - Pre-M)															
																						
CIIC*	NGA*	GIK*	FIII	LAZR	VLDR	MVIS	CGRO*	IPV*	THBR	CLA												
Battery				(SPAC - Pre-M)			Charging			(SPAC - Pre-M)												
																						
RMO	QS	CBAT	THCB	BLNK	BEEM	SBE*	TPGY*	NBAC														
Energy Res. & Storage				(SPAC - Pre-M)			Natural Resources (Lithium, etc)			EV ETFs												
																						
CLSK	EOSE	STPK*	MP	WWR	ALB	LTHM	LAC	VALE	PLL	SOL	DRIV	HAIL	IDRV	PBW	EKAR	LIT						
Solar																	(SPAC - PM)					
																						
SEDG	ENPH	FSLR	NEE	RUN	JKS	DQ	MAXN	CSIQ	NOVA	SPWR	SOL	SPI	SUNW	JE	POLA	PPSI	ALAC					
Hydrogen Fuel Cell							(SPAC - Pre-M)															
																						
FCEL	PLUG	BE	BLDP	HTOO	AMCI																	

**ELECTRIC VEHICLE, SOLAR,
HYDROGEN FUEL CELL SECTORS**

NYSE & NASDAQ Listed Only
UPDATED: December 31, 2020 - v3.0

TL Designed by @Joeyzunn

* SPAC Options Available

* SPAC Options Available

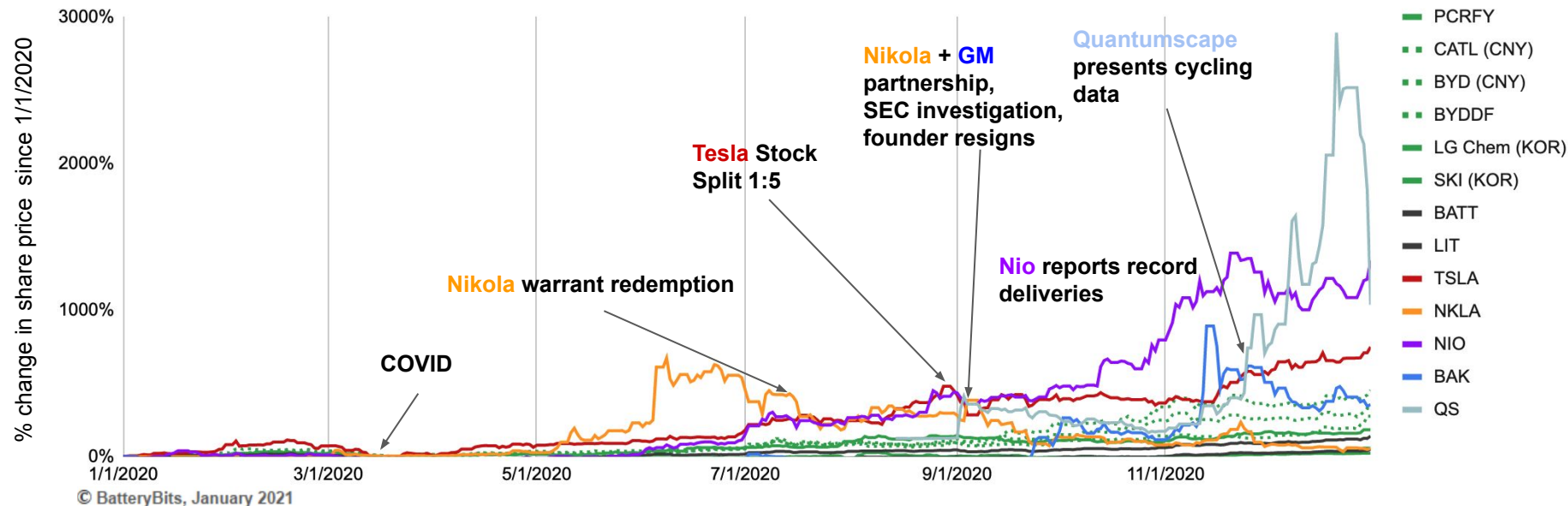
*Source: [Joeyzunn](#)

SPAC: special purpose acquisition company. A financial vehicle for mid-late stage, often pre-revenue cleantech companies to gain access to public markets

EV and battery companies are relying on SPACs as a new funding mechanism to satisfy their large capital needs without meeting the traditional metrics for an IPO

Investment: A Year of Surprises, Successes, and Scandals

Eventful year as investors seek to uncover the “next Tesla”

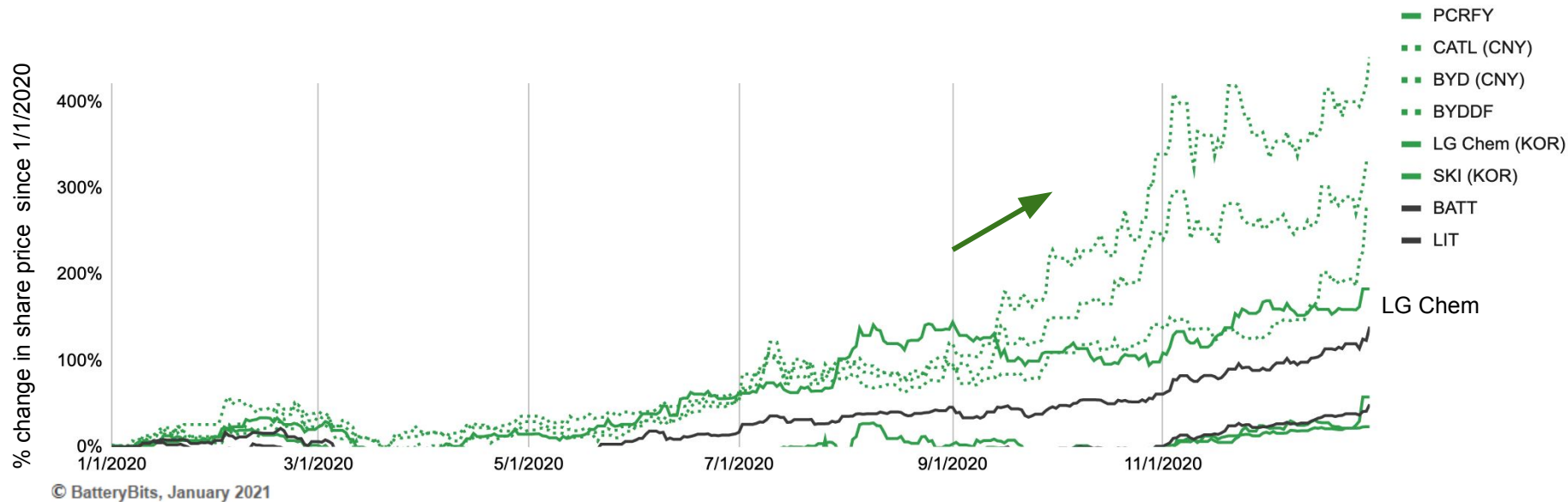


* Related reading: [BatteryBits - Preventing Fraud](#)

Investment: A Year of Strong Growth Despite the Global Pandemic

ETF funds BATT and LIT saw 50% and 140% growth in 2020 respectively

With the exception of LG Chem, the market performance of Chinese manufacturers was 2x better than their Korean and Japanese counterparts.



EV safety concerns made headlines

GM recalls 68,000 electric Chevy Bolts over battery fire concerns

There have been at least five incidents of Bolt batteries catching fire

By [Andrew J. Hawkins](#) | [@andyjayhawk](#) | Nov 13, 2020, 2:03pm EST

[News Analysis] EV fires draw attention to separator tech of LG Chem, Samsung SDI, SK Innovation

Korean battery giants apply different technologies to make batteries safer

By Kim Byung-wook

Published : Nov 2, 2020 - 16:31 Updated : Nov 2, 2020 - 18:39

Chinese EV battery maker CATL faces criticism after three GAC electric cars ignite fires

A Tesla Model S erupted 'like a flamethrower.' It renewed old safety concerns about the trailblazing sedans.

By [Faiz Siddiqui](#)

Dec. 28, 2020 at 5:00 a.m. PST

ELECTRIC CARS IN CHINA

China EV startup WM Motor issues recall after battery fires

Tencent-backed producer blames supplier and offers free replacements

NIKKI SUN, Nikkei staff writer

October 28, 2020 21:25 JST • Updated on October 28, 2020 22:15 JST

LG Chem Recalls Home Battery Systems After Reports of Fires

By [Mark Chediak](#) and [Brian Eckhouse](#)

December 3, 2020, 11:12 AM PST Updated on December 4, 2020, 10:00 AM PST

*Sources: [Bloomberg](#), [Washington Post](#), [The Korea Herald](#), [The Verge](#), [Asia Nikkei](#), [MorningTick](#)

Section 2: Research

Research Highlights

There was a wealth of research knowledge generated in the battery field in 2020.

We identified some of the **most interesting research papers** we've seen this year from the following fields:

Cathode

Anode

Fast Charging

Degradation

Lithium Metal

Solid-State

Electrolyte

Recycling

Diagnosis

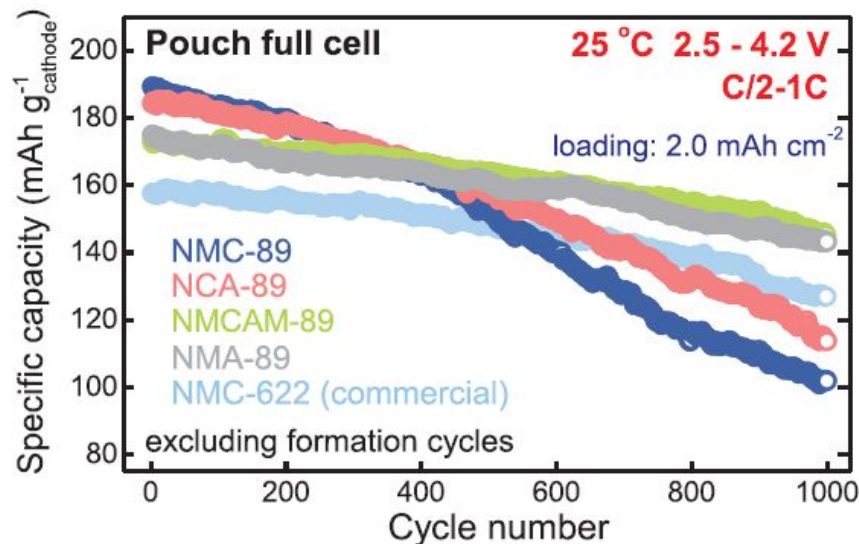
Machine
Learning

1. Cathode: Cobalt-free for a sustainable future

A novel cobalt-free high-nickel NMA cathode outperforms NMC and NCA in capacity retention rate after 1000 cycles.

- NMA is composed of Ni (89 mol%), Mn, Al
- Operates at 40 mV higher voltage
- Superior thermal stability
- Slightly lower specific capacity

NMA's cobalt free chemistry and the similarity of its synthesis process to NCA and NMC make it a strong contender for next generation high energy Li-ion batteries.



*Source: [Advanced Materials](#)

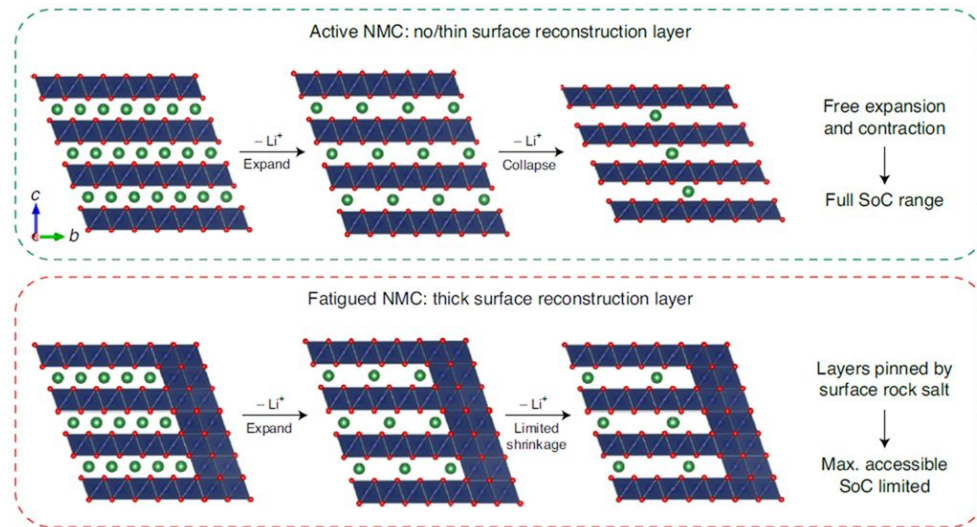
Research Group: Dr. Arumugam Manthiram, UT Austin

2. Cathode: Discovering new degradation mechanisms

Ni-rich layered cathodes degrade due to structure driven fatigue.

- Fatigued phase limits the accessible state of charge
- Authors propose that the fatigued phase is caused by high lattice mismatch between the cathode bulk layered structure and the rock-salt surface reconstruction layer above 75% SOC

This understanding serves as a stepping stone for future Ni-rich cathode research, and may inspire the development of additives, doping agents, and coating methods.



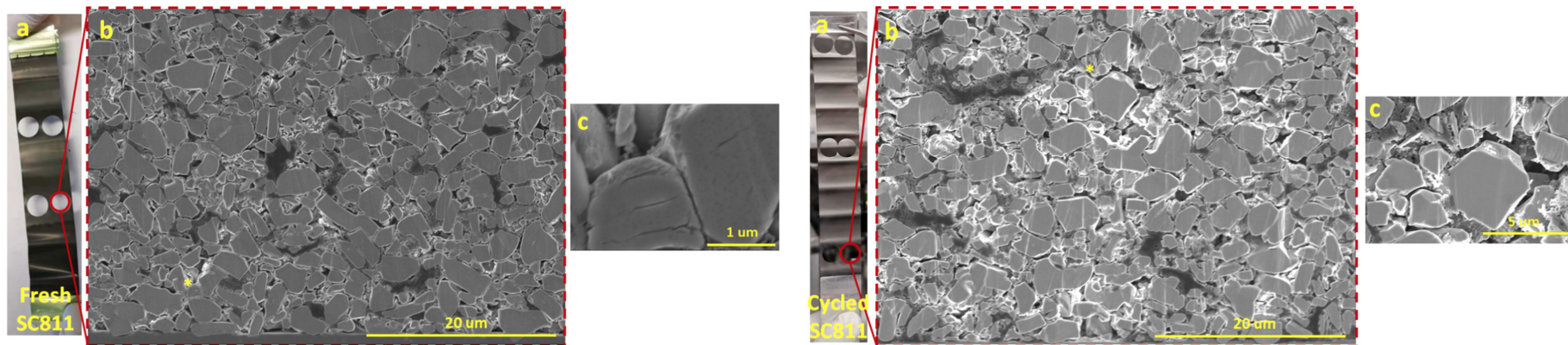
*Source: [Nature Materials](#)

Research Group: Dr. Clare P. Grey, Cambridge University

3. Cathode: Single crystal materials

Single crystal cathodes are robust against microcracking.

- No visual difference between fresh and cycled (1100 cycles) materials
- Single crystal materials can be promising materials for high energy density and long cycle life Li-ion cells



*Source: [Journal of Electrochemical Society](#)

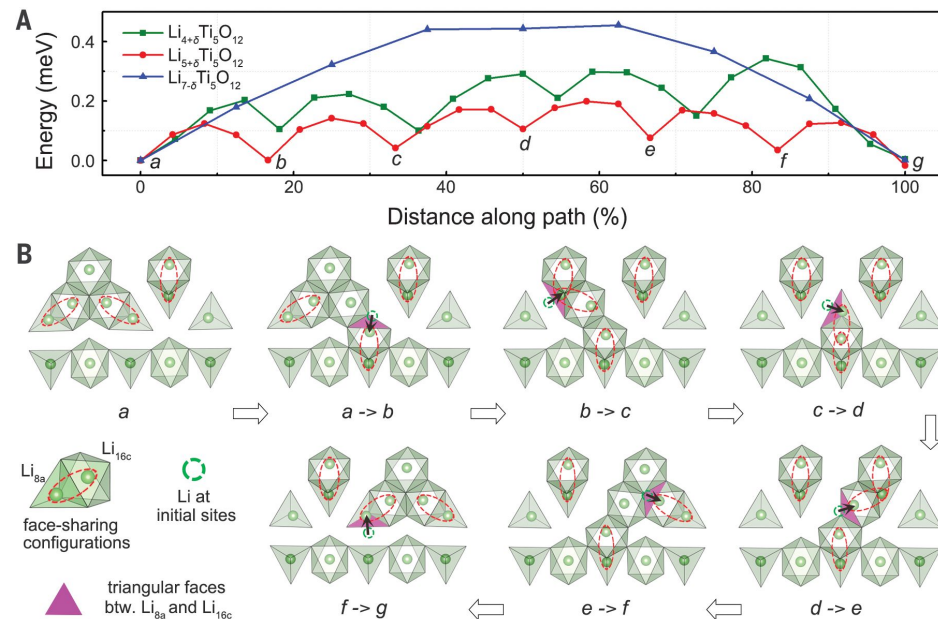
Research Group: Yulong Liu, Western University; Jessie Harlow, Dalhousie University; Jeff Dahn, Dalhousie University.

4. Anode: Real-time tracking of Li^+ migration

LTO facilitates fast Li^+ transport via the kinetic pathways in its metastable intermediates.

- The energy landscape above the ground-state enables fast Li^+ transport in LTO
- This study was performed by combining in-situ TEM with computational modeling

This research provides a framework for real-time in-situ study of Li^+ transport within the electrode, and serves as a foundation for future work on the design of electrodes.



*Source: [Science](#)

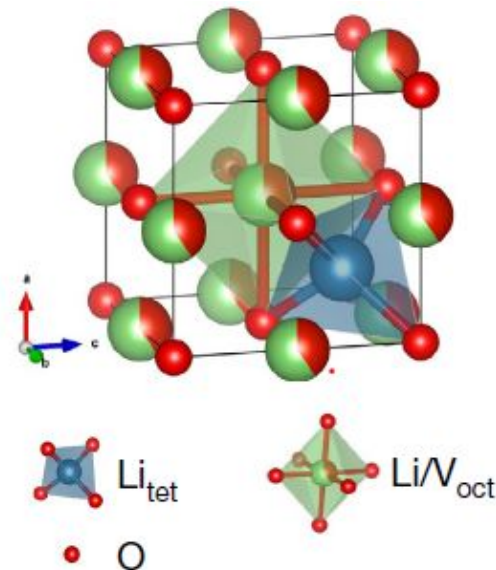
Research Group: Dr. Feng Wang, BNL; Prof. Gerbrand Ceder, UC Berkeley and LBNL

5. Anode: Novel materials for ultra-fast batteries

A newly-invented rock salt anode $\text{Li}_3\text{V}_2\text{O}_5$ exhibited both high capacity and charging rate.

- New rock salt anode lithium-vanadium oxide ($\text{Li}_3\text{V}_2\text{O}_5$) demonstrates reversible cycling at 0.6 V, capacity of 260 mAh g^{-1} , fast charging up to 40% of capacity in 20 seconds, and over 6000 cycles of stable cycling
- The startup Tyfast was spun out to commercialize this technology, with a focus on electric buses and power tools

A promising material to realize ultra-fast charging batteries for broad commercial applications.



*Source: [Nature](#)

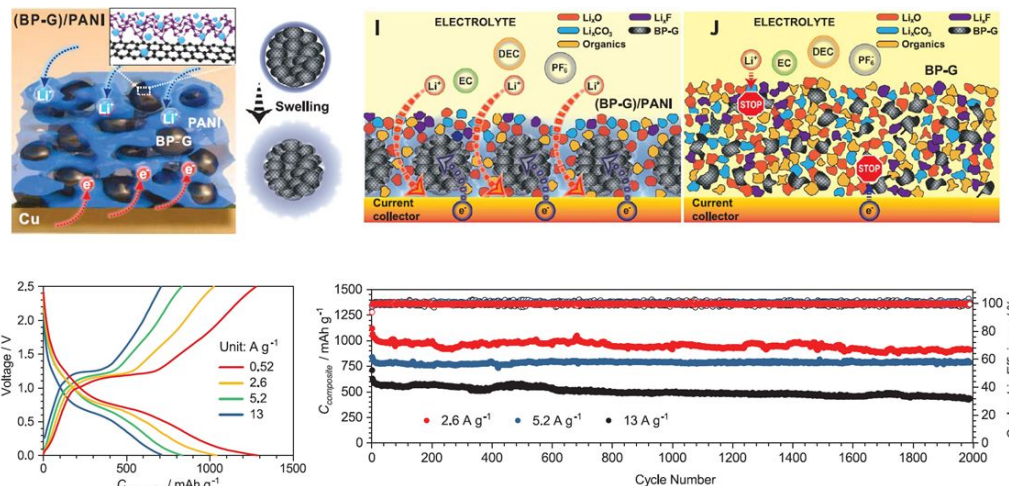
Research Group: Dr. Ping Liu, Dr. Shyue Ping Ong, UC San Diego; Dr. Huolin L. Xin, UC Irvine; Dr. Jun Lu, ANL

6. Anode: Improving graphite anode rate capability

Black phosphorus-graphite composite anode with thin polyaniline polymer gel coating forms a stable SEI and demonstrates excellent capacity, rate, and cycle life.

- The covalently bonded black phosphorus graphite interface prevents edge reconstruction and ensures fast Li^+ entry/exit
- Thin polyaniline polymer gel coating prevents continued formation and inhibits buildup of less conductive Li fluorides and carbonates

The electrode design is a major benefit to current Li-ion chemistry and we expect to see it on the manufacturing line soon.



*Source: [Science](#)

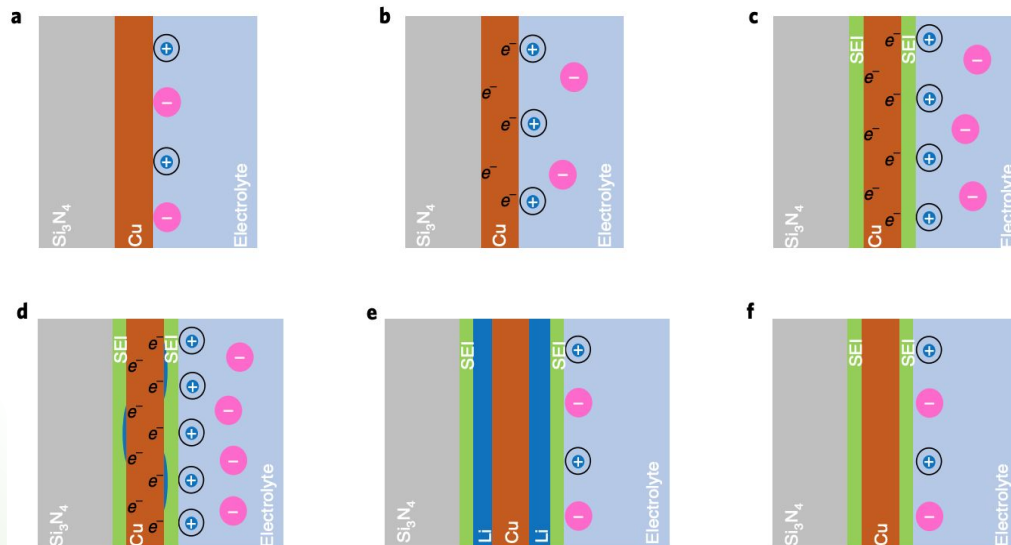
Research Group: Dr. Xiangfeng Duan, UCLA; Dr. Hengxing Ji, University of Science and Technology of China

7. Anode: Real-time mapping of solid electrolyte interphase (SEI)

Characterization of SEI with in-situ liquid secondary ion mass spectrometry (SIMS)

- During initial charging, an electric double layer forms at the electrode/electrolyte interface
- This double layer structure predicts the eventual SEI chemistry
- Inner SEI layer is thin, dense, and inorganic while the outer SEI layer is porous and organic-rich

Real-time nanoscale observations offer a molecular understanding of SEI and pave the way for the engineering of better interphases in the future.



*Source: [Nature Nanotechnology](#)

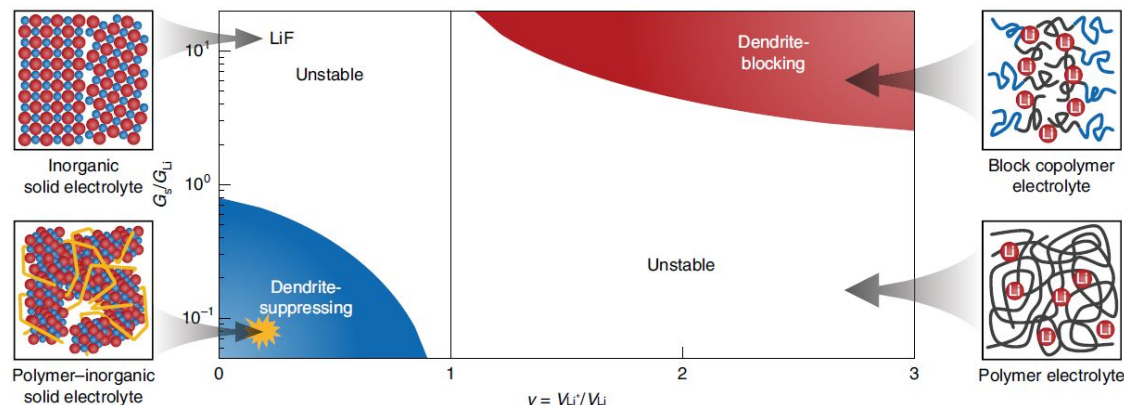
Research Group: Dr. Zihua Zhu, Dr. Chongmin Wang, Dr. Zhijie Xu, PNAL; Dr. Kang Xu, US Army Research Laboratory

8. Solid State: Model for solid electrolyte design

A universal chemomechanical model for designing solid-ion conductors enables exploration of “soft” dendrite-suppressing regimes

- Mechanisms of pressure-driven dendrite blocking and density-driven dendrite suppression, explained by the competing influence of shear modulus and partial molar volume of Li^+ , are mutually exclusive

This study is a step forward from the Monroe-Newman model. It justifies previous research conducted on dendrite suppression by soft materials and lays the foundational design principles for future solid electrolytes.



*Source: [Nature Materials](#)

Research Group: Dr. Brett A. Helms, LBNL, Prof Venkat Viswanathan, Carnegie Mellon University.

9. Solid State: Setting benchmarks

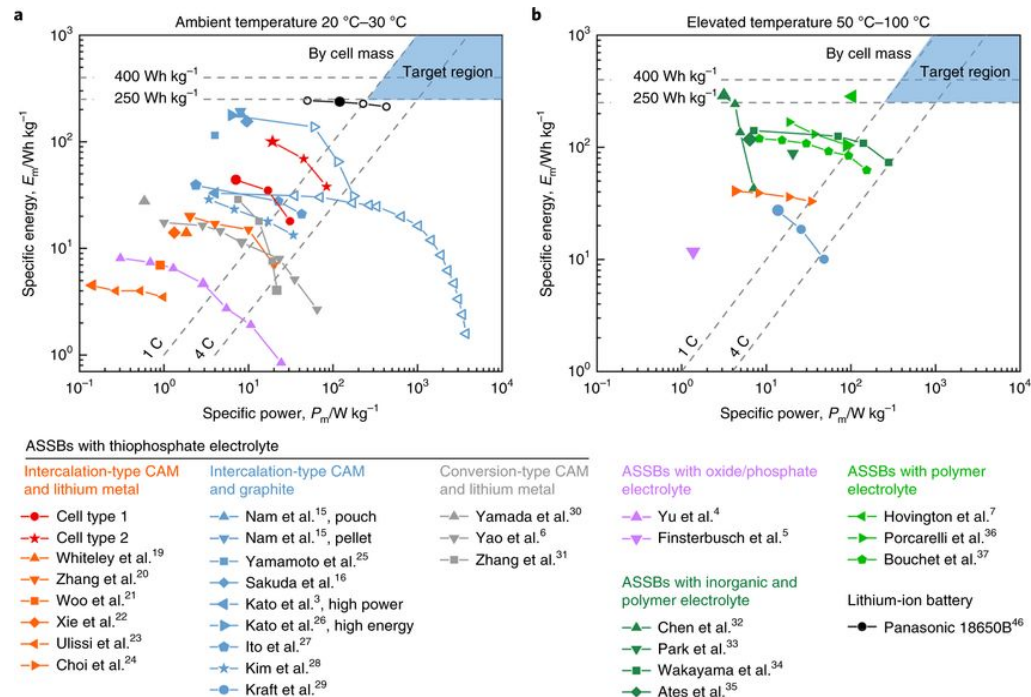
Referencing solid-state batteries against a standard benchmark

- Solid-state batteries are benchmarked against a reference system consisting of a Li metal anode, β - Li_3PS_4 solid electrolyte, and NMC-622 cathode
- New research targets identified for solid-state systems

With the rapid pace of development in solid-state battery technology and commercialization, these standard metrics enable an apples-to-apples comparison across the field.

*Source: [Nature Energy](#)

Research Group: Dr. Jürgen Janek, Dr. Felix H. Richter, Justus-Liebig-University Giessen

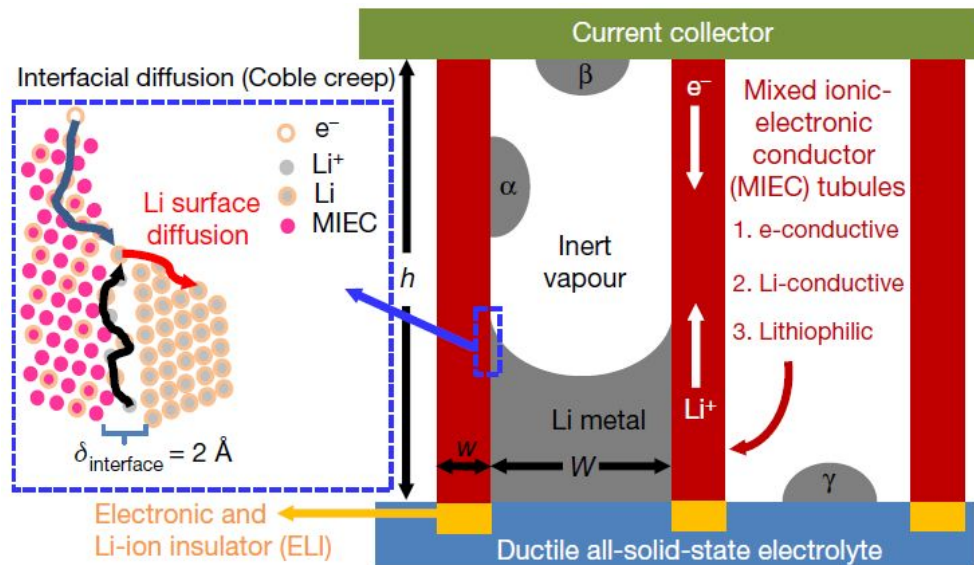


10. Li metal: Novel 3D anode architecture

Parallel hollow tubules guide stable plating and stripping of metallic Li via Cobel creep.

- Hollow tubules of mixed ionic-electronic conductors (MIEC) at the anode allow for metallic Li to be plated reversibly in a solid-state battery
- Coble creep mechanism of interfacial diffusion provides stress relief that enables reversible plating

The race is on for higher energy density and anode engineering with novel materials and structures offers a path forward for Li metal anodes.

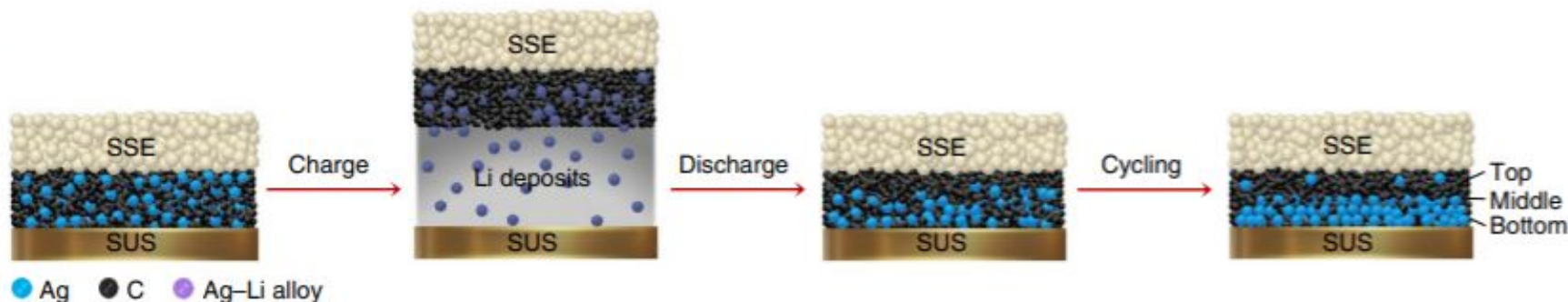


*Source: [Nature](#)

Research Group: Dr. Ju Li, MIT

11. Li metal: Anode free solutions

Solid-state Li metal battery exhibits high energy density (900 Wh/L) and long cycle life (1000 cycles) with Ag-C composite interlayer.



Composite anode electrode has long been one of the holy grails of battery research to enable Li-metal battery. This paper demonstrates a promising new interlayer material towards realizing a commercial Li-metal battery.

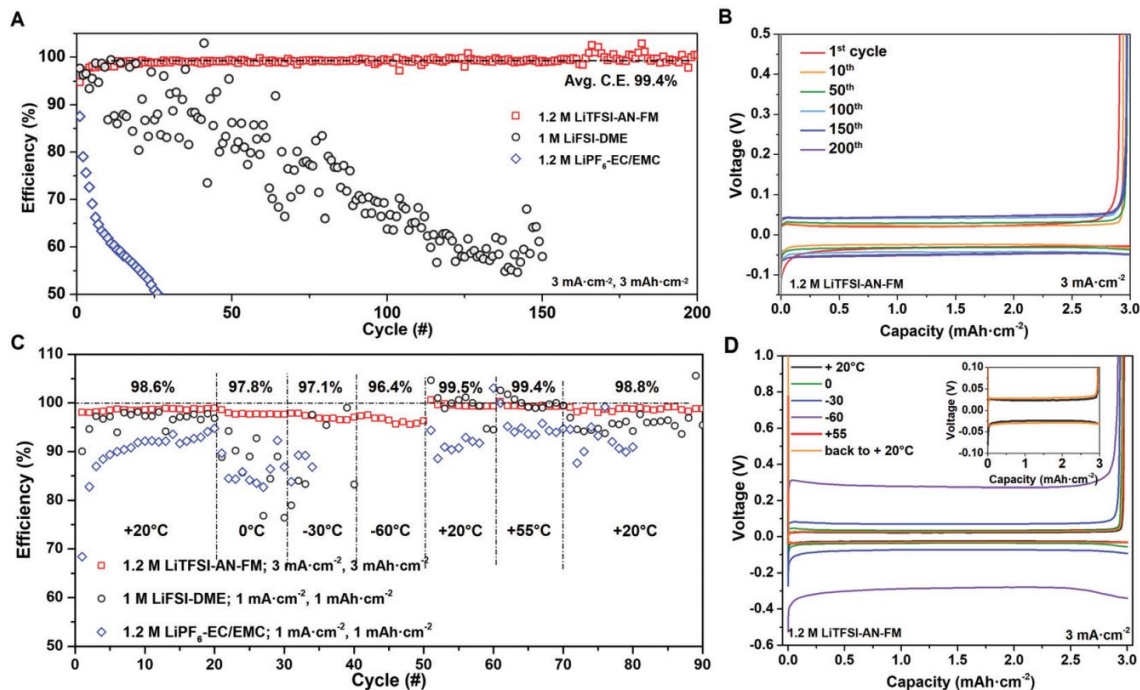
*Source: [Nature Energy](#)

Research Group: Dr. Yong-Gun Lee, Dr. Yuichi Aihara, Dr. Dongmin Im, Samsung Advanced Institute of Technology

12. Li metal: Fluoromethane-based liquified gas electrolyte

Enabling high energy density Li-metal battery operation in wide temperature range (-60 to 55°C).

- Acetonitrile selected as a cosolvent to complement fluoromethane-based (FM) liquified gas electrolyte
- Extended above FM's critical temperature range 44°C for the first time
- Conductivity: $>4 \text{ mS cm}^{-1}$
- Coulombic efficiency: 99.4% over 200 cycles at 3 mA cm^{-2}

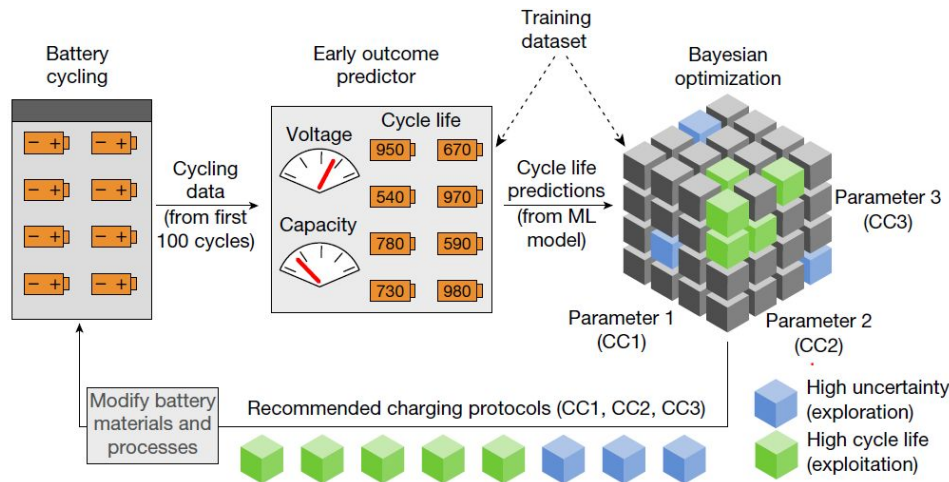


*Source: [Energy & Environmental Science](#)

Research Group: Dr. Shirley Meng, UC San Diego; Dr. Oleg Borodin, US Army Research Laboratory

13. Machine learning-aided battery development

A closed-loop approach combining an early-prediction model and Bayesian regression algorithm reduces time required to optimize battery fast charge protocols from 500 to 16 days.



Battery cycling and validation is expensive and time-consuming. We are excited to see the impact of AI on battery research and development.

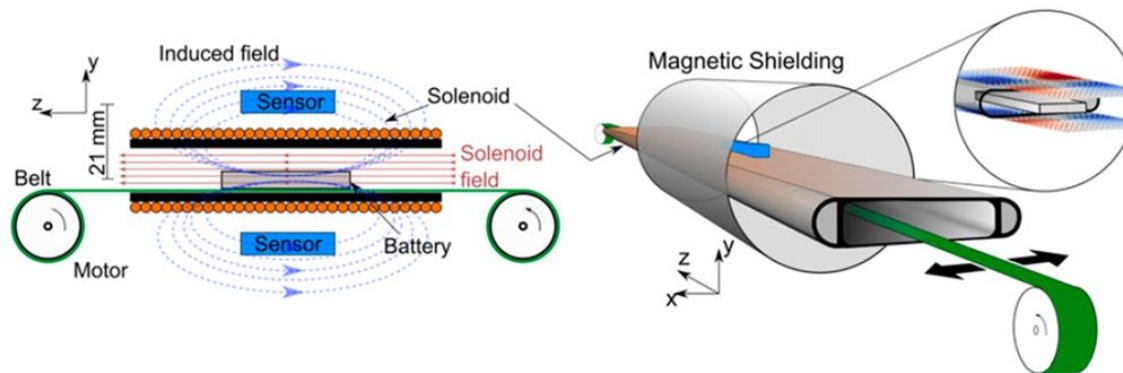
*Source: [Nature](#)

Research Group: Dr. William C. Chueh, Dr. Stefano Ermon, Stanford University; Dr. Richard D. Braatz, MIT

14. Contactless battery diagnostics

A simple, high-throughput, and nondestructive diagnosis on the state of charge (SoC) and defect detection using atomic magnetometers.

- This novel diagnostic method identifies hot spots of charge storage
- Weak transient internal currents (μA) are measured to infer state of charge



This research offers a low-cost, non-destructive technique for quickly screening batteries for local defects.

*Source: [PNAS](#)

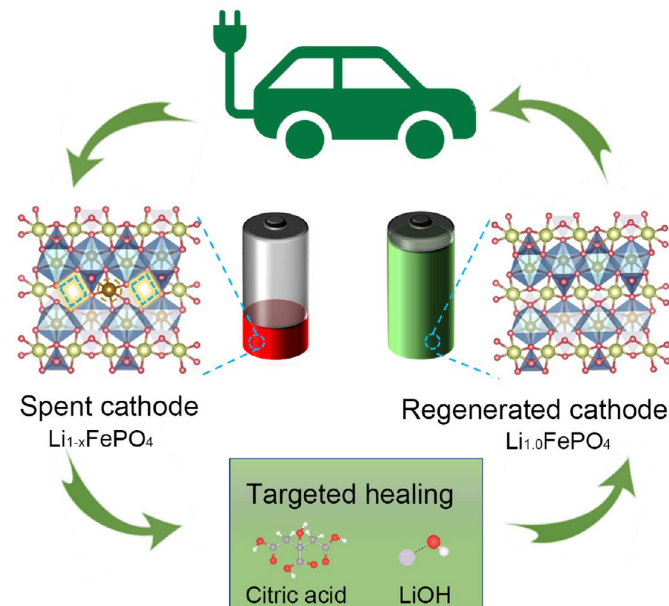
Research Group: Geoffrey Z. Iwata, Johannes Gutenberg-Universität Mainz; Alexej Jerschow, New York University

15. Recycling: Novel LFP recycling methods

LFP cathode recycling using a targeted healing strategy reduces energy usage and greenhouse gas (GHG) emissions.

- Recycled lithium iron phosphate (LFP) matches pristine LFP in performance
- LFP is regenerated via low temperature aqueous solution relithiation and rapid post-annealing

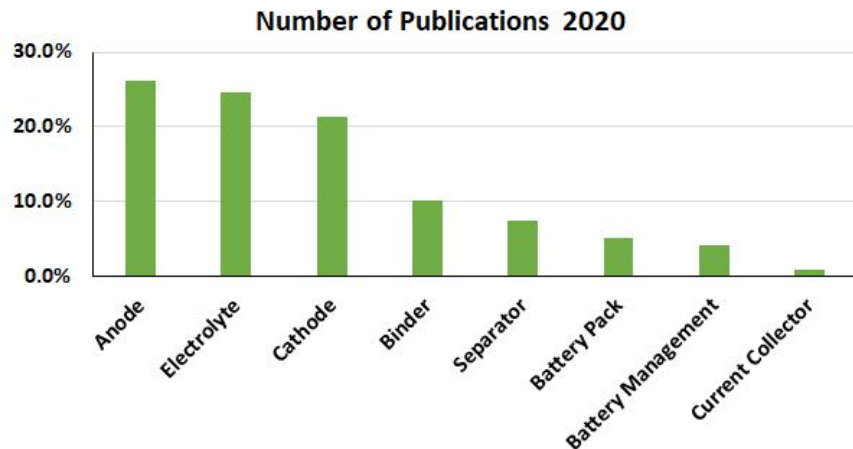
A well-designed battery recycling process is essential to minimizing the environmental impact of Li batteries throughout their lifecycle.



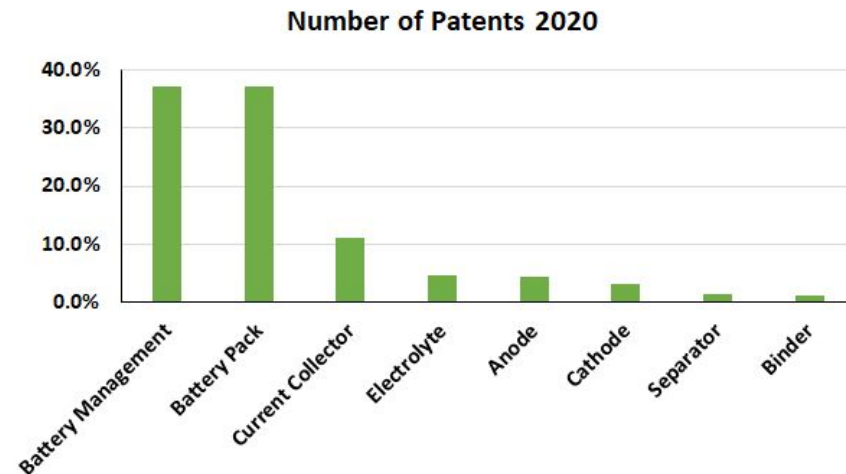
*Source: [Joule](#)

Research Group: Dr. Zheng Chen, UC San Diego

Ranked Research and Patent Popularity by Battery Components



Materials level innovations occur primarily in academia. Research interests are dominated by **cathode**, **anode**, and **electrolyte** materials, comprising almost 90% of all publications.



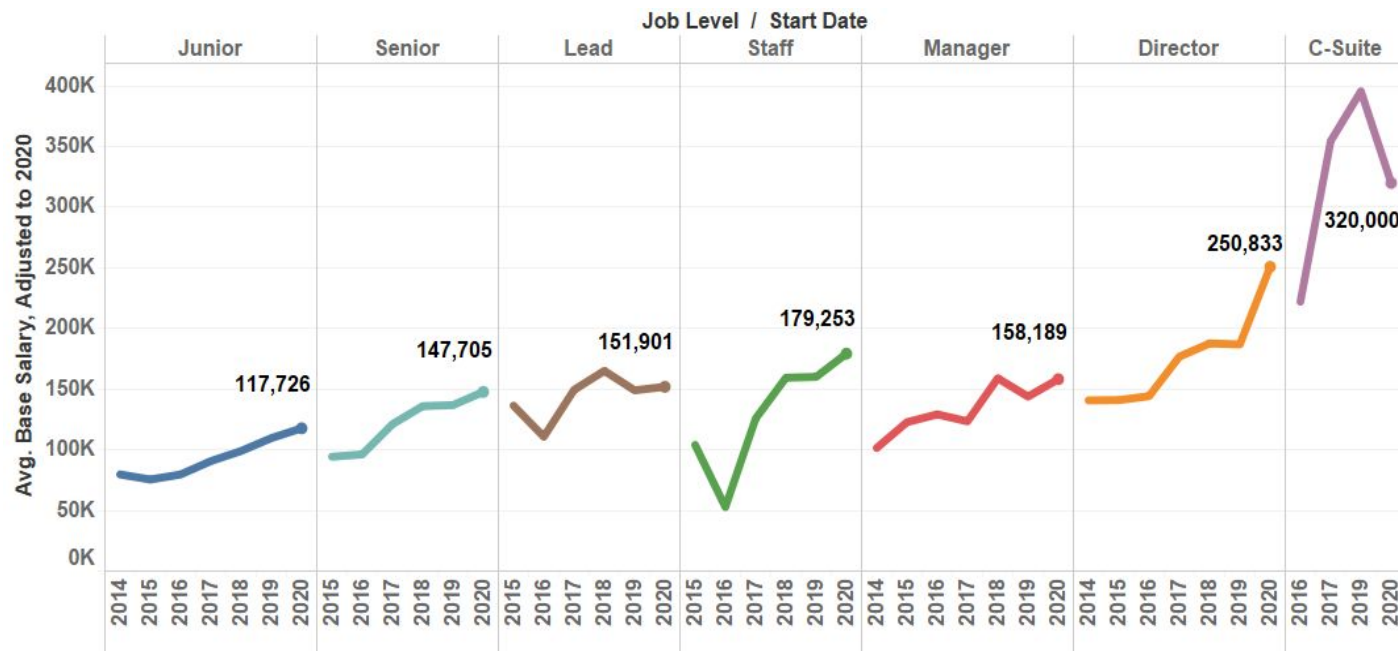
Industry is working hard on pack and system level optimization. The leading areas of invention are **battery management**, **battery packs**, and **current collector**.

*Source: [Google Scholar](#)

Section 3: Talent

Salaries soaring as companies compete for battery talent

US reported salaries (H1B) for battery industry roles surged 40% in the past 5 years.



© BatteryBits, January 2021

Sources: www.h1bdata.info (n = 1675)

Note: Salaries have been adjusted for inflation, set to 2020. Actual earnings may be higher as stock compensation is not included. Data for certain job levels may not be representative due to insufficient data sources (e.g. C-Suite, Director).

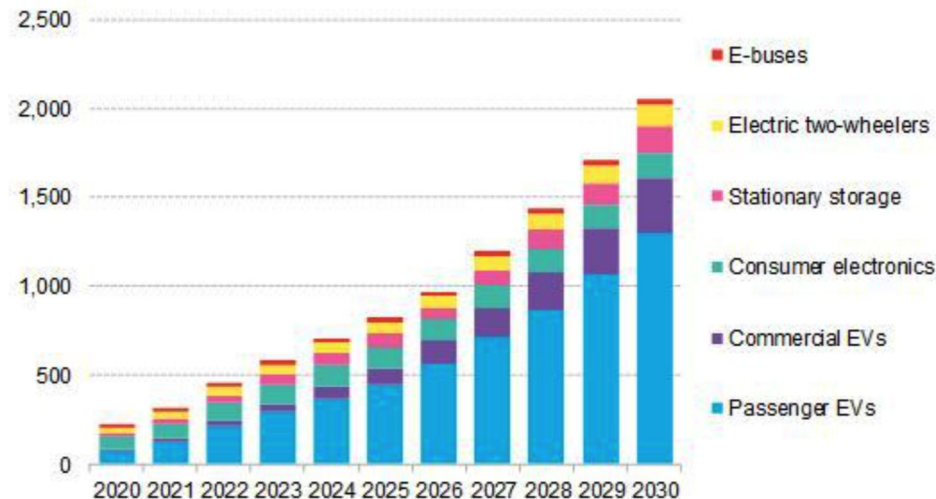
Li-ion manufacturing creates new job market

423,000 - 813,000 new jobs will be created globally in the battery industry by 2030.

- Predicted battery production capacity in 2030:
 - 1.4TWh ([Wood Mackenzie](#))
 - 2.5TWh ([Benchmark Minerals](#))
- Each GWh of battery capacity creates 40 jobs in direct production, and 200 indirect jobs in the upstream value chain, such as materials, R&D, and equipment manufacturers.
- At the beginning of mass production, the employment ratio is likely higher, at an estimated 125 employees / GWh, due to lack of economies of scale. ([Fraunhofer ISI](#))

Figure 25: Lithium-ion battery demand outlook

GWh/year



Source: BNEF. Note: See respective section for details.

Source: [BNEF](#)

Companies scramble for talent to meet aggressive product timelines

GM to hire 3,000 engineers, designers, IT workers to speed up electric vehicle production

Jamie L. LaReau Detroit Free Press

Published 1:47 p.m. ET Nov. 9, 2020 | Updated 4:36 p.m. ET Nov. 9, 2020

SK Innovation Accelerates Hiring At Its EV Battery Site In Georgia

How Panasonic Is Closing a Lithium-Ion Engineer Skills Gap

The battery industry is just one of many industries that can benefit from broadening the talent pool by looking at different skill sets to fill open positions.

Posted: June 18, 2020

B Bloomberg

Tesla Pitches 5,000 'Middle-Skill' Factory Jobs to Texas County

Executives from Tesla Inc. will use an unassuming job-type description in their pitch to a Texas county on the merits of the carmaker's ...

Jun 23, 2020

Britishvolt Gigaplant to create 5,000 supply chain jobs



By **CHRISTOPHER WALTON** — 14th December 2020

GM CEO: Lordstown battery plant hiring, construction ahead of schedule

According to Ultium's website, the jobs will offer immediate health benefits, holiday pay, GM vehicle discounts, and \$20,000 in annual educational support.

Thursday, November 5th 2020, 4:34 PM EST by Mike Gauntner

*Sources: [Bloomberg](#), [Detroit Free Press](#), [InsideEVs](#), [LogisticsManager](#), [TrainingMag](#), [WFMJ](#)

Production facilities create job opportunities for local communities



Wroclaw,
Poland

“More than **1800 jobs** will be created at the Wroclaw site, taking the total workforce up to more than **6000 full-time employees** by end-2022.” ([EIB](#))



Berlin,
Germany

“Tesla has strong support from local political leaders thrilled at the prospect of **10,000 new jobs** and the presence of a company that is worth far more on the stock market than all of the German carmakers combined.” ([NYTimes](#))



Bitterfeld-Wolfen,
Germany

“Farasis is building a plant for battery cells in Bitterfeld-Wolfen and is expected to create up to **2,000 new jobs**.” ([Electrive](#))



Commerce, GA,
USA

“Already **60 employees** joined SK Innovation and by the end of this year, the number is expected to increase to 150, and then to **more than 1,000** by the end of 2021....The number of direct jobs by 2024 should increase to **over 2,600**.” ([InsideEVs](#))



Kaiserslautern,
Germany

“Around **2,000 jobs** are to be created in the resulting plant that should have a production capacity of 32 GWh.” ([Electrive](#))



Saarland,&
Heusweiler,
Germany

“Around **400 jobs** will be created by the start of production at the end of 2023 (Saarland) Around **150 jobs** are to be created at the Heusweiler location by the start of production in mid-2022.” ([LinkedIn](#))

Building the talent supply

Global competition to attract and retain top talent to meet supply chain demands.

- “China attempts to steal workers from LG, SK” ([KoreaTimes](#)), offering talented engineers salaries 3-4 times their typical salary in Korea ([CBCU](#)).
- Long-standing efforts to recruit overseas scientists continues ([Foreign Policy](#))
- China continues its 2nd year of vocational training program for “Battery Production Engineer” ([Source](#)) as part of the State Council’s National Medium- and Long-term Talent Development Plan (2010–2020). Program goals include building a comprehensive talent evaluation system, defining the battery manufacturing role standards, and overall improving the battery manufacturing workforce skill set.



Where does battery talent congregate?

Despite the global pandemic, communities and organizations have been created to share content and connect the battery community.

Community Events

[Battery Brunch](#)

Online Battery Symposiums

[Battery Modeling Webinar Series](#)

[Stanford Storage X International Symposium](#)

[Oxford Battery Modeling Symposium](#)

Newsletters & Blogs

[Intercalation Station](#)

[BatteryBits](#)

[The Mobilist](#)

Social Media

YouTube: [The Limiting Factor](#)

Twitter:

[@electrochemical](#) [@YingShirleyMen1](#)

[@BatteryPapers](#) [@SteveLevine](#)

[@MjLacey](#) [@JamesTFrith](#)

[@VenkVis](#) [@mart_di_be](#)

[@KristinaEdstrm2](#)

*Source: [ACS](#)

Section 4: Policy

Policy for an environmentally sustainable future

Killing two birds with one stone: a post-pandemic stimulus to create jobs and help the climate ([McKinsey](#)).

- After the 2008-09 crisis, the economic meltdown caused a steep decrease in emissions, but rebounded to an all-time high in 2010 with the implementation of stimulus packages that did not focus on environmental impact. **How can stimulus packages in 2020 be improved?**
- The COVID-19 economic crisis coincides with a pivotal time in the fight against climate change. Stimulus programs that prioritize low-carbon initiatives can provide socioeconomic and climate benefits and usher in a new era towards reaching the Paris Agreement goals of keeping global warming under 1.5 °C and 2 °C.
- The next slides highlight major policy movements from the United States, Europe, and China with a focus on energy storage.

A warm welcome to CleanTech 2.0...

... and how to avoid a repeat of CleanTech 1.0 ([PwC](#)).

- With a raft of global policies to support the pandemic and green stimulus packages, investments and government policies need to be aligned to avoid the pitfalls of the first cleantech boom in 2006-11 when \$25b was invested and an est. 90% of funded companies failed to return any capital.
- **The original CleanTech boom failed for several reasons:** a global recession emerged, falling silicon prices from China crushed solar startups, falling oil prices hammered biofuel startups, and venture funding was a very poor match for R&D startups.
- **Today is different.** More people than ever are [increasingly concerned about climate change](#). Clean technologies (including batteries) have had an additional decade of R&D and are now lower cost, technically sound, and directly competitive with incumbent fossil fuel technologies. Funding from government agencies and climate-specific venture capital, which understand the long development times and high capital requirements, eliminates risk along the spectrum of technology readiness levels and is better able to support the new cleantech market.

US policy under the Biden administration

US President Elect Joe Biden plans to implement green investments as a method for tackling the coronavirus economic crisis.

- \$2T in federal funding to spend over four years to “build back better”: decarbonize transportation, electricity, and building sectors, the plan including a highlight in battery storage innovation and domestic production ([Joe Biden](#)).
- President Biden’s target of net zero carbon emissions by 2050 requires the reduction of US emissions by 75 gigatons and would be sufficient to shave the temperature rise by 0.1 degrees C in 2100 ([Climate Action Tracker](#)).
- President Biden plans to establish ARPA-C focused on climate technologies including battery storage ([Wall Street Journal](#)).



Europe catalyzes support for energy storage



Major countries in Europe stay on track for the European Green Deal.

- The UK revealed a green industrial revolution plan to support 220k jobs over the decade, including £1.3B for EV charging infrastructure and £1B for electrification of vehicles including the mass production of batteries ([UK energy white paper](#), [10 point plan](#)).
- Increased financial support for the EU: €1B for battery projects in 2020 and €10B of grants over the next decade. Europe has goals to be climate neutral by 2050 ([European Commission](#)).
- Brexit free trade agreements discriminate against trade in lower-carbon electric vehicles due to “rules of origin”, as the bulk of electric car parts come from Asian countries. UK policy will build local supply chains for batteries manufactured in the UK or EU ([The Times](#)).
- Batteries from the EU need to be sustainable, high-performing, and safe over their entire life cycle to promote competitive sustainability and to minimize the environmental impact of batteries. A new mechanism of "battery passports" will be introduced to ensure responsible mineral sourcing along the supply chain ([European Commission](#)).

China's plan for a green future at risk



China moves towards carbon neutrality, but remains a large stakeholder in “dirty” investments.

- China's \$2.9T coronavirus stimulus package fails to prioritize clean energy, and turns instead to dirty industries (high carbon energy and infrastructure) like coal to kickstart the economy ([CarbonBrief](#)).
- China reveals fiscal subsidies to promote new energy vehicles including BEVs, PHEVs, and FCVs, effectively extending vehicle subsidies through 2022 ([ICCT](#)).
- Chinese President Xi Jinping publicly pledges at the UN General Assembly to be carbon neutral by 2060. The announcement is significant as China is currently the world's largest emitter of CO₂, but the high-carbon stimulus package puts the UN pledge in question.
- China hosts some of the biggest battery manufacturers: CATL, BYD, and Guoxuan High-Tech. Greenpeace is actively pushing Beijing to implement policies around end-of-life, recycling, and ethical raw materials ([Greenpeace](#)).

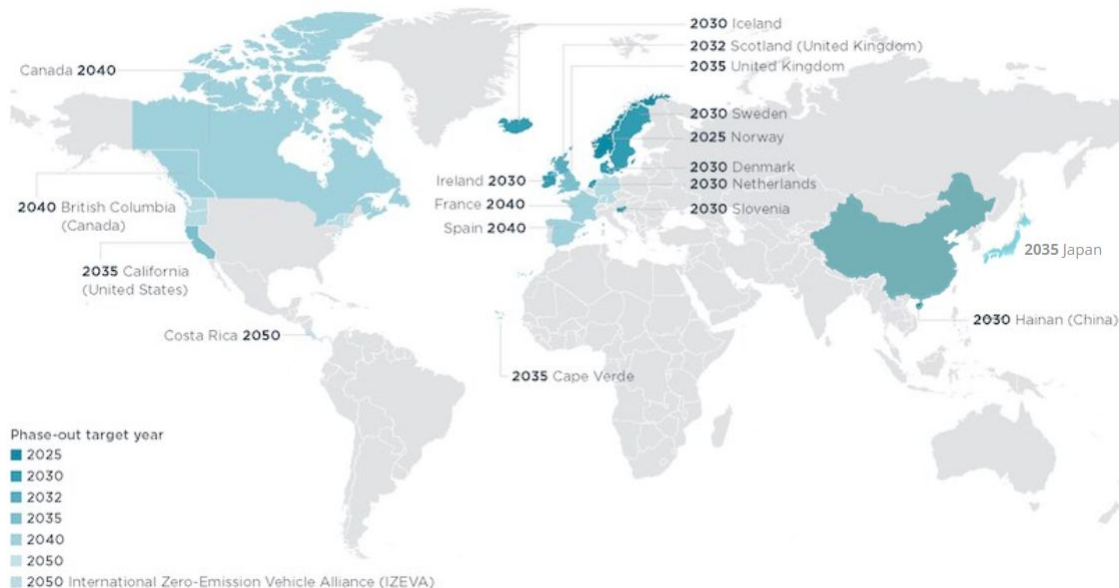


Fossil fuel vehicle bans around the world 🌍

Electric vehicles are the largest market for batteries today. To date, 23 countries and states have publicly announced plans to phase out fossil fuel vehicles.

- Austria, 2035
- Belgium, 2026
- **California, 2035***
- Canada, 2040
- China, 2035
- Costa Rica, 2050
- Denmark, 2030
- Egypt, 2040
- France, 2040
- Iceland, 2030
- India, 2030
- Israel, 2030
- **Japan, 2035***
- **Massachusetts, 2035***
- Netherlands, 2030
- Norway, 2025
- **Singapore, 2040***
- Slovenia, 2030
- Spain, 2040
- Sri Lanka, 2040
- Sweden, 2030
- Taiwan, 2040
- **United Kingdom, 2030***

* announced in 2020



Source: modified from [The Driven](https://www.the-driven.com/)

Section 5: Predictions

Predictions for the next 12 months

1. SPACs continue to gain prominence and legitimacy as an accepted avenue for privately held cleantech companies to go public. Cleantech SPACs will raise >\$3B USD in 2021.
2. BEV battery cell-level cost (volume-weighted average) will drop below \$95/kWh.
3. Following the successful listing of QuantumScape, at least 3 new startups will be formed to commercialize “Beyond-NMC” chemistries such as Co-free, solid-state, Si-anode, Li-sulfur, etc.
4. Hybrid-state (solid+liquid) batteries will achieve 80Ah in industry.
5. Electric vehicles with 150 kWh packs will be announced.
6. AI/ML-first companies will enter the industry, at least 3 new (AI + Energy) startups will be formed.
7. Demand for skilled workers will continue to outpace supply. Average starting base salary for battery engineers in the US will be >\$125k.
8. The Biden administration will announce a series of policies supporting cleantech, including new funding for research, EV subsidies, and support for the development of clean energy infrastructure.
9. EV market penetration to accelerate - global EV sales will top 3 million vehicles for the 1st time.
10. Municipal buses to electrify faster than any other segment of wheeled transport, accounting for >30% of global new bus sales.

Conclusions

Thank you for reading the inaugural State of Batteries Report!

In this report, we reviewed and highlighted key developments in the battery industry in 2020. This report is meant to be a comprehensive and accessible guide to battery research, industry, talent, and policy, and to help foster conversations on the state of batteries and its trajectory for the future.

We look forward to receiving your feedback on how we can improve this presentation, as well as suggestions for next year's edition. Please reach out to us at sponsorship@volta.foundation.

Thank you!

BatteryBits Editorial Board

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Disclaimer

The views expressed herein are solely those of the authors, and have not been reviewed or approved by any other organization, agency, employer or company. The primary purpose of this work is to educate and inform.

Acknowledgments

We would like to thank the following individuals for their contributions to the article:

- [Vivas Kumar](#), Principal, Benchmark Minerals
- [Hong Li](#), Professor, Institute of Physics, Chinese Academy of Sciences
- [Dr. Jochen Mähliß](#), Head of Batteries and Energy Storage Systems, VDE Renewables GmbH
- [Roland Zenn](#), Procurement & Purchasing Senior Manager, Farasis Europe
- [Andrew Wang](#), PhD Candidate at Oxford University, Co-Founder at Intercalation Station
- [Nathan Benaich](#) and [Ian Hogarth](#), AI investors and State of AI authors

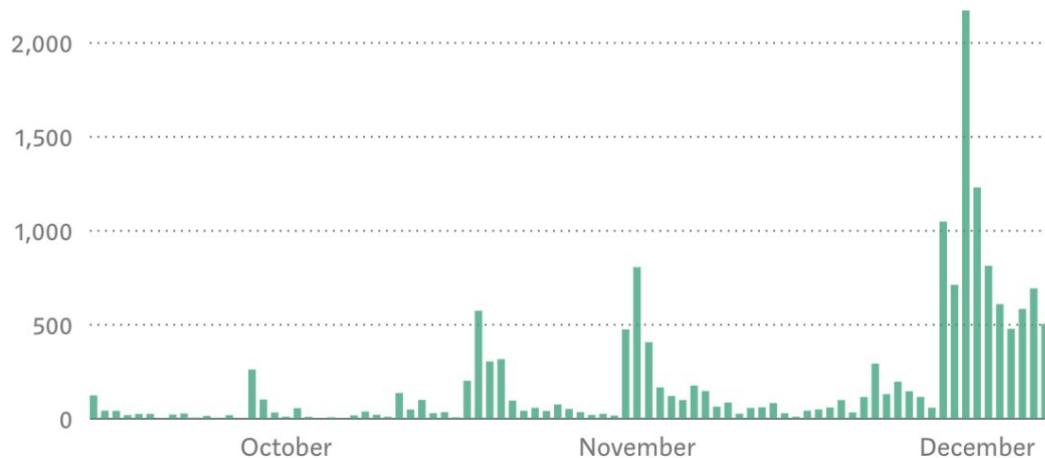
We would like to thank the following individuals for their ideas and suggestions:

- [Darren Lim](#)
- [Zhiwen Huang](#)
- [Crystal Jain](#)
- [Eli Leland](#)
- [Steve He](#)
- [Raymond Smith](#)
- [Tim Suen](#)
- [Gabe Hege](#)

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How to cite this work

Yiu, Nicholas. Jing, Linda. Yeh, Yen. He, Katherine. Zheng, Eric. “State of Batteries Report 2020.” *BatteryBits*, 16 January 2021. Web. Date accessed.

Please remember to acknowledge the BatteryBits team and cite the report appropriately.

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January 16, 2021