The Battery Report 2021

January 08, 2022

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"The battery is the technology of our time." **- The Economist**

In this annual report, we summarize what we consider to be the most significant developments in the battery industry in 2021. 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

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Section 1
Industry

Industry | Overview

Industry players are moving rapidly to pursue higher energy densities and lower costs in order to move carbon emissions to net zero. Technical directions include the development of silicon anodes and solid state battery technologies, increased adoption of LFP chemistries, the emergence of sodium ion, and the continued expansion of stationary storage.

Significant trends include battery and auto manufacturers forming new joint ventures, large quantities of climate venture capital, SPAC exits for early-stage battery startups, and OEMs investing in the future of electric vehicles.

Notable Events	Key Trends	Industry Movement
Innovators	Investment	Manufacturing
Supply Chain Insights	Sustainability	Media

Notable Events | Q1 2021

Selected news pieces each quarter

Jan

Sila Nano raises $590M to fund battery materials factory

EU to invest €3.5B through state aid to Tesla, BMW, and other OEMs

GM declares only zero emission vehicles by 2035

EV battery maker Microvast to go public via SPAC

Feb

Tesla extends partnership with Dalhousie for 5 years

Storedot announces engineering samples for their 5-minute fast charge cells

Enevate raises $81M for Series E silicon anode battery technology

Ford announces commitment of $29B by 2025 to electric and self-driving cars

Mar

VW hosts Power Day event showcasing new technology development plans

Ample opens 5 battery swapping stations for Uber drivers in the Bay Area

Northvolt acquires Li metal battery Stanford-spinout Cuberg

Volvo to go all electric by 2030

Notable Events | Q2 2021

Apr

Farasis Energy reaches 330 Wh/kg with new battery cell

BYD announces the Blade Battery Pack for its pure EV models

Australian mining companies Orocobre and Galaxy complete $4B merger

SK settles IP infringement case with $1.8B settlement to LG Chem

Solid Power completes $130M Series B from Ford, BMW, and Volta Energy Technologies

SK Innovation and Ford form partnership BlueOvalSK to produce 60 GWh of batteries by 2025

May

Murata announces commercialization of solid-state cells in audio equipment, wearables, IoT

Li-S startup Oxis Energy files for bankruptcy

Northvolt and Volvo announce 50 GWh gigafactory, production slated for 2026

Porsche and Custom Cells invest in joint venture to produce specialty batteries for racing

Jun

Renault announces separate collaborations with Envision AESC and Verkor for high-performance batteries

Ascend Elements forms partnership with Honda to recycle old EV batteries in 2022

Notable Events | Q3 2021

Jul

CATL announces new sodium ion battery cells

Daimler and Albermarle partner to directly source future Li supply and recycling

Redwood raises $700M in new funding round

QS announces details of 10-layer cell results in shareholder letter

Form Energy announces iron-air battery for grid scale storage

GM recall for faulty NMC cells at $1.8B in value

Aug

Lilium signs deal to supply Brazilian airline company Azul with eVTOLs

SVOLT reveals NMx prismatic cells with cobalt-free cathodes, production started in July

SK partners with Group14 in joint venture to build manufacturing hub

Ford and SK announce $11B investment under the BlueOvalSK family

Sep

Sila Nano debuts commercial WHOOP smart watch battery

Redwood Materials announces production of copper foil and cathode materials

NIO announces 75 kWh hybrid packs with both NMC and LFP

Notable Events | Q4 2021

Oct

Hertz announces order of 100,000 Teslas for their rental fleet

Stellantis and LG partner to set up 40GWh factory in 2024

Factorial Energy announces strategic investments from Korean OEMs Hyundai and Kia

CATL announces plans for $5B battery recycling facility in Hubei

Nov

Johnson Matthey announces intention to exit cathode materials business

Northvolt invests $750M into R&D campus in Västerås, Sweden

SES unveils 107Ah lithium metal cell prototype at Battery World event

BloombergNEF

Battery pack prices fall 6% to $132/kWh in 2021

Dec

Mitra Chem enters US LFP cathode business with $20M Series A

FREYR Battery is awarded 31 GWh offtake agreement with ESS provider

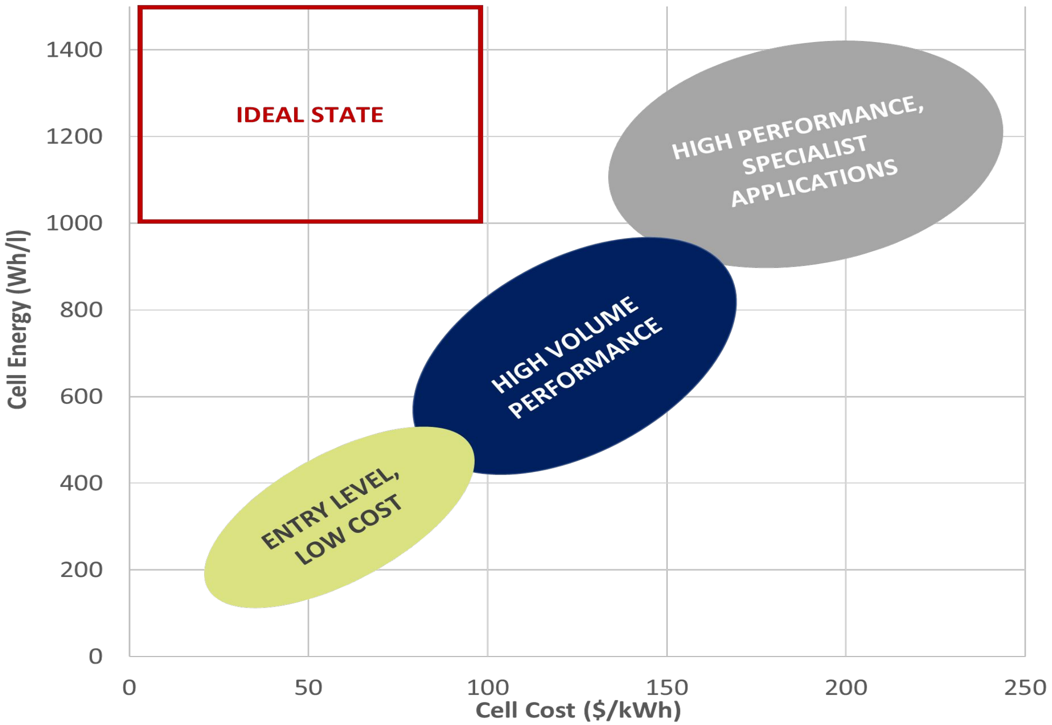
VW announces new partnerships with Umicore (materials), 24M (manufacturing), and Vulcan (lithium supply)

Amita Thailand and Energy Absolute open 50 GWh gigafactory, largest in southeast Asia

Toyota to invest $35B in EV development with plans to sell 3.5 million EVs annually by 2030

Key Trends | Automotive OEM Solutions

The automotive industry is converging around 3 types of battery solutions, but OEMs differ on specific solutions.



ENTRY LEVEL LOW COST				
LFP	Na-ion	Mn-rich	Na-Ni-Cl	NFA

HIGH VOLUME PERFORMANCE					
NCA	NMC	NCMA	eLNO	Gr-Si Blend Anodes	Mn-rich

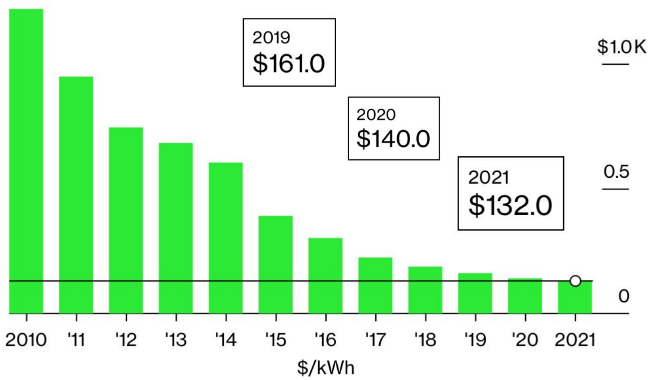
HIGH PERFORMANCE, SPECIALIST APPLCIATION			
Ultra-High Ni Blends	Silicon Anodes	Lithium Metal Anodes	Solid State Electrolyte
Li-S	HV-Spinel Cathodes	Rapid Charge Anodes	Lithium Air

Source: *Bubbles are to visualize overall trends and not intended to completely represent solutions

Key Trends | Costs

Battery price decline slows down due to rising commodity prices. China has lowest pack price globally.

Battery Pack Prices



Source: BloombergNEF

Pack prices fell by only 6% from 2020-2021 compared to 13% from 2019-2020.

Prices were low for the first 6 months of 2021, then started to **increase** in the second half due to supply chain pressures.

Price Increases: Since September, Chinese producers have raised LFP prices by 10-20%. Average pack prices could rise to **$135/kWh in 2022**.

Regional Differences:

- China has the cheapest battery pack prices ($111/kWh)
- U.S. pack price ($155/kWh, 40% higher than China)
- E.U pack price ($177/kWh, 60% higher than China)

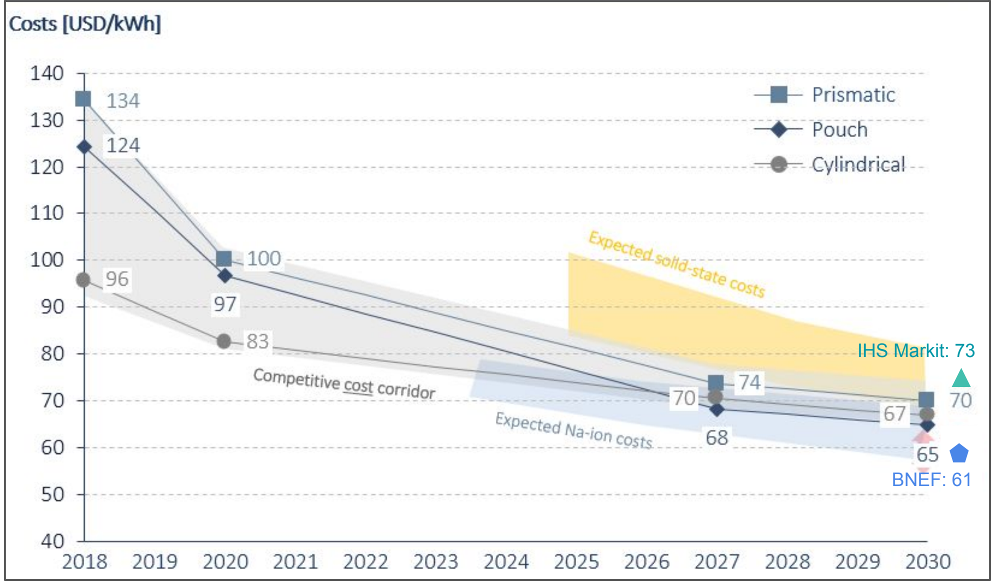
Factors Decreasing Price	Factors Increasing Price
• Adoption of low-cost cathode chemistry LFP (On average, LFP cells are ~30% cheaper than NMC cells in 2021) • Decreased use of Co in Ni-based cathodes	• Rising commodity prices (Li, Co, Ni) • Increased costs for key materials (e.g. electrolytes)

Source: Bloomberg, BNEF Battery Price Survey

Key Trends | Costs

Decreasing cell costs of current Li-ion batteries are making it challenging for next-gen technologies to become competitive.

Cell Cost Developments for Passengers Cars until 2030 [1]



1. High-volume production of >8 GWh/a with dedicated facility

Note: Cost values tabulated by P3 Consulting, unless otherwise specified.

Li-ion technology. Future cell costs of leading prismatic and pouch cell manufacturers (CATL, SDI, LG, SK) will be in a range of **$61-73/kWh** in 2030. The 4680 Tesla cell design is predicted to decrease the costs even further and would set a clear benchmark.

Solid-state technology. Materials are costly and use less established processing methods. Manufacturing costs are strongly dependent on the production of solid electrolyte. Any cost advantages arise from omission of production steps (e.g., formation/aging).

Sodium-ion technology. Significant materials cost reduction identified for Na-ion technology. Lower energy density, however, may limit the overall cost reduction to only 10-30% per kWh.

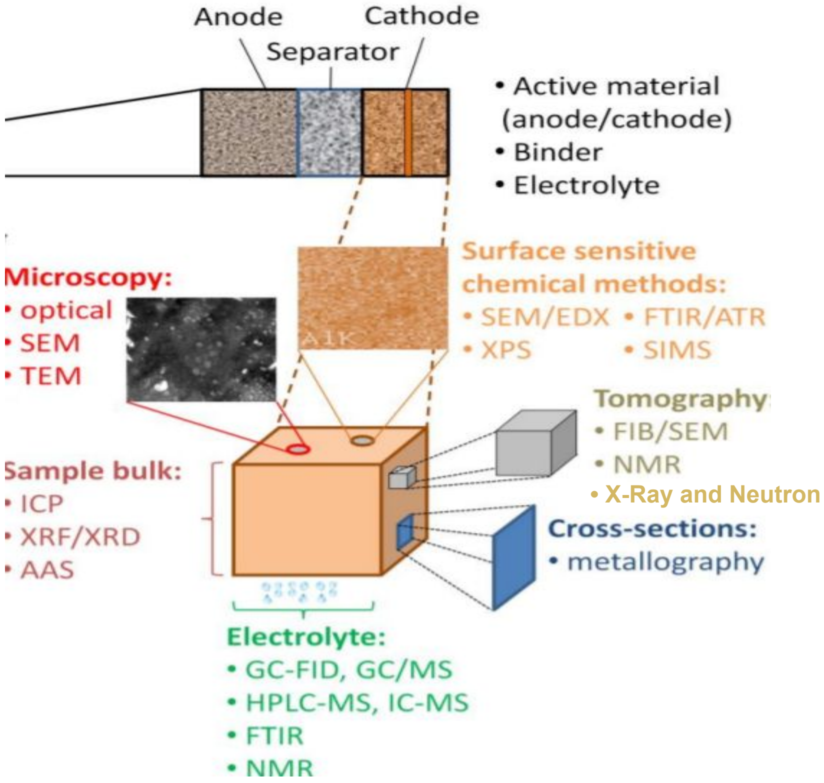
Source: P3 cost assessment & benchmark data, Bloomberg, IHS Markit, Energy Monitor

Key Trends | Characterization

2021 has seen a rise in the prominence of characterization for battery materials and cells.

Companies are driven to fully understand product material characteristics and performance to remain competitive. With a plethora of new technologies, there has been a push for more extensive analytical methods to solve challenges such as understanding the SEI, improving electrolyte additive performance, and testing solid state materials and cells.

Safety issues and recalls necessitate additional factory level QC characterization and analytics to reduce defective cell rates using tools such as x-ray, ultrasound, CT scanning, and predictive testing. Many companies seek to reduce failure rates to the parts-per-billion scale by investing in tools and processes; those that do not risk losing time, money, customers, and reputation.



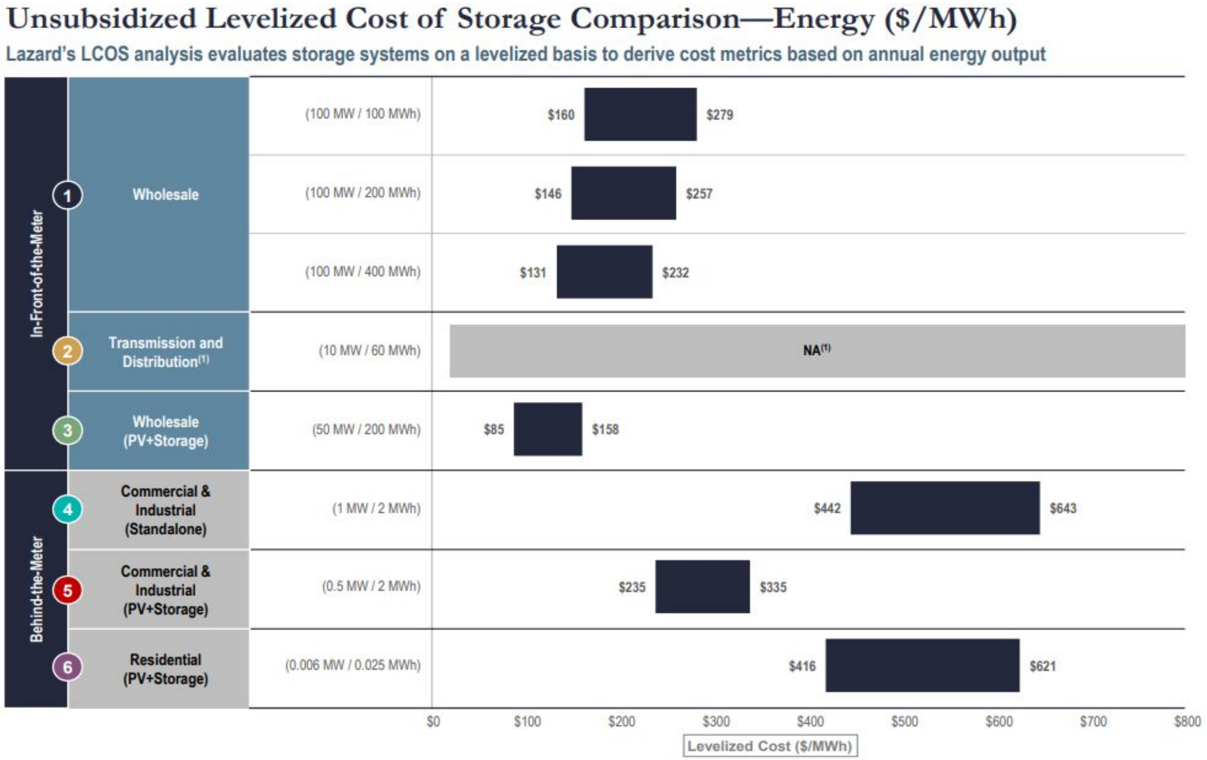
Key Trends | Levelized Cost of Storage

The cost of energy storage continues to decrease from year to year - a race to the bottom.

Levelized cost of storage (LCOS) - the ultimate cost metric for batteries - varies depending on storage application and use case:

- Larger applications (wholesale, grid-connected, scaled to large energy capacities) will continue to provide the **lowest LCOS**.
- Smaller applications (standalone or residential with lower storage capacities) have the **highest LCOS**.

LCOS also varies depending on energy storage technology, but for simplification, this study only looks at LFP, NMC, and Flow technologies.



Source: Lazard's Levelized Cost of Storage 2021

Key Trends | Lithium Iron Phosphate (LFP) Timeline

With LFP patents set to expire in 2022, manufacturers have shifted their focus in the past few years.

1996

Lithium iron phosphate ($LiFePO_4$ or LFP) is identified as a cathode chemistry by A.K. Padhi et al. (Prof. John Goodenough's group at the University of Texas at Austin).

2012-18

A123 (LFP for power tools and EVs) files for IPO. A123 batteries are adopted by Fisker. In 2012, A123 files for bankruptcy and its automotive business are acquired by Wanxiang, a Chinese company. With A123's insolvency, LFP is presumed dead in the US.

2016

China's New Energy subsidies shift focus towards higher energy density. BYD and Gotion face increased competitions from NMC focused players.

2019

China starts to cut subsidies for BEV, HEV, and PHEV.

CATL introduces its cell-to-pack technology to improve volume utilization and to simplify pack design.

2020

BYD introduces its LFP blade battery. CATL and BYD increase LFP's pack level energy density to that of NMC 523. With LFP's additional advantages in cost and safety, there is increased market interest in LFP.

May 2020

In China, production of LFP surpassed NMC for the first time in 3 years.

Mar 2021

At its Power Day event, Volkswagen announces LFP for entry-level BEVs.

Oct 2021

Tesla announces switch to LFP batteries for all standard range vehicles globally.

Daimler to use LFP batteries from 2024 for entry level vehicles, such as EQA and EQB BEVs.

2021 Nov

In China, no new construction of the production lines allowed for EV batteries with cell level energy density less than 180 Wh/kg, a challenge for LFP technologies. (proposal by the China government)

Forecast of LFP global production capacity

770 GWh (2025)

Source: Wikipedia, CNBC, electric.com, S&P global, Deloitte, GG-LB

Key Trends | Lithium Iron Phosphate (LFP)

LFP cathodes are making a comeback. How do they compare to high nickel NMC (nickel > 60%)?

LFP Strength S
- Cost
- Safety
- Lifetime
- Abundance of iron

NMC Strength
- Energy density
- Low temperature performance
- Power

LFP Weakness W
- Weight
- Energy density
- Low temperature performance
- Power

NMC Weakness
- Cost
- Safety
- Ni/Co supply chain
- Lifetime

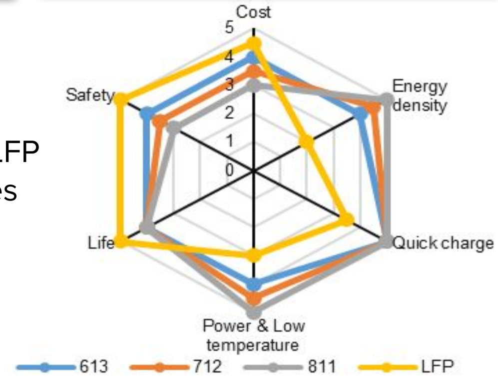
LFP Opportunity O
- Low/mid-range/entry EVs
- e-Bus, e-Bicycle
- Stationary storage
- Cost sensitive applications

NMC Opportunity
- Long range/high-end EVs
- Stationary storage
- e-Bus, e-Bicycle, e-Motor
- Power tools / performance sensitive applications

LFP Threat T
- NMC/high-voltage LNMO
- Na-ion Battery
- Regulations on energy density
- Increasing material cost

NMC Threat
- LFP/high-voltage spinel LNMO
- Regulations on thermal propagation
- Increasing raw material cost

Given the same cell dimensions, cell performance metrics using LFP and high nickel NMC as cathodes



Key Trends | Safety

EV battery safety is a challenge for OEMs. In the race to product launch and production, taking shortcuts on cost, speed, scale, or time can lead to expensive recalls.

At **10 ppm**, **1 out of every 250** electric vehicles are at risk from cell failure, assuming ~400 cells per vehicle (Qnovo). With a projected **120-200 million** EVs by 2030, a 10 ppm defect rate could mean potential failures in up to ~**90,000 EVs in 2030**. The largest and most public battery safety incidents in 2021 involved General Motors recalling ~142,000 Chevrolet Bolt EVs, totaling $1.8B in damages.

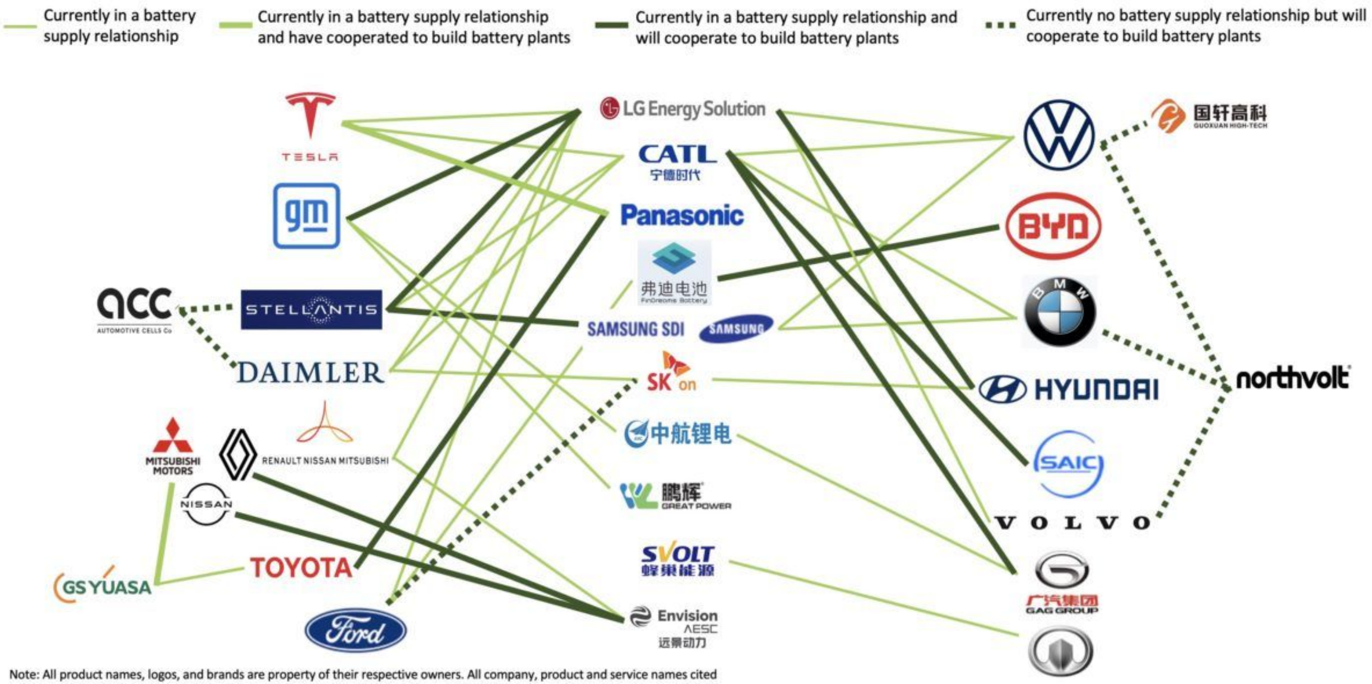
A few potential solutions (non-exhaustive) are listed below:

Cell/Chemistry Level	Manufacturing	BMS Solutions
Pivoting to safer and lower energy density chemistries, e.g., LFP. Implementing **safer materials** at increased cost. Solid-state electrolytes improve safety by removing flammable liquid electrolyte. Liquid electrolytes can also be made safer with additives, ionic liquids, etc. High temperature and durable separator and current collectors can help prevent, slow, or lower the intensity of thermal runaway	Implementing additional **quality control** testing in factories on materials and production steps from slurry mixing and electrodes coating to cell assembly and final pack production. Factories can also implement improved cell design, form factor, and packaging.	Implementing **advanced BMS** monitoring and software solutions to accurately predict end-of-life, identify faulty cells, provide prognostics, improve battery longevity, support fast charging, etc.

Source: Qnovo

Industry Movement | Joint Ventures and Partnerships

Strategic partnerships between main EV OEMs and battery suppliers



Note: All product names, logos, and brands are property of their respective owners. All company, product and service names cited herein are for identification purposes only. Use of these names, logos, and brands does not imply endorsement.

There are **3** partnership trends:

American OEMs are building relationships with Japanese and South Korean battery manufacturers (GM, Tesla, etc).

European OEMs plan to cultivate local battery supply chains (BMW, Volvo, VW, Stellantis, etc).

Chinese, Japanese and South Korean OEMs are working closely with local battery manufacturers (Toyota, BYD, Hyundai).

Source: Researcher & Research

Industry Movement | OEM Roadmaps

OEMs are investing strategically in various solutions to ensure competitiveness

	Cell manufacturing	Cell design	Pack design	Manufacturing	Cell chemistry
	240GWh in Europe by 2030	Unified prismatic cell, solid-state	Cell-to-pack, then cell-to-vehicle	Dry coating	High-Ni, Mn-rich, LFP
TESLA	3TWh Globally by 2030	4680 cell	Cell-to-vehicle	Dry coating, pre-lithiation	High-Ni, Mn-rich, LFP
gm	Ultium Cells JV 70GWh	Ultium pouch cells	Ultium pack, multiple configurations	'advanced' processes	NMCA
Ford	BlueOvalSK JV, 130GWh	IonBoost pouch cell, solid-state	Flexible BEV architecture	N/A	LFP, Ni-based chemistry
STELLANTIS	ACC JV, 130GWh by 2025	Solid-state	Four platforms, Cell-to-pack	N/A	LFP, Ni-based chemistry
RENAULT	Envision, Verkor	Standardised cell, solid-state	Standardised module, in-house production	N/A	NMC
VOLVO	Northvolt	Standardised cell	Standardised module, in-house production	N/A	NMC

Source: BloombergNEF, Company announcements

Industry Movement | US OEMs

General Motors

- **Investment**
  - **Ultium Battery Cell Manufacturer (JV with LGES)**
    $2.3B for 2nd Ultium battery cell manufacturing plant in US
  - **CAMI plant**
    $800M for EV manufacturer in Canada
  - **Controlled Thermal Resources**
    closed-loop, direct extraction
  - **SES**
    $139M (total round) for Li-metal Battery
- **Partnership**
  - **Posco Chemical**
    North America Factory Cathode Materials
  - **Wabtec**
    Ultium battery and HYDROTEC hydrogen fuel cell
  - **Visteon**
    Ultium wireless battery management system

Ford

- **Investment**
  - **BlueOvalSK**
    $11.4B investment for two mega-sites in Tennessee and Kentucky
  - **Ford Ion Park**
    $185M investment for lithium ion and solid-state battery cells in Michigan
  - **Solid Power**
    $130M (total round) for all solid-state battery
- **Partnership**
  - **Redwood Materials**
    Electric vehicle battery recycling
  - **DTE Energy**
    Roof-top solar and battery energy storage

Tesla

- **Investment**
  - **Shanghai Plant**
    $188M to expand Shanghai plant capacity
  - **Jeff Dahn Group**
    $6M grant for Jeff Dahn's Dalhousie University battery team
- **Partnership**
  - **RelSource Cements**
    Blockchain for tracing cobalt production
  - **Talon Metals**
    75k metric tonnes of nickel purchase agreement
  - **Gangfeng Lithium Co**
    3-year lithium supply agreement

Industry Movement | Asia OEMs

Hyundai

Investment
- **SES** – $100M for investment on Li-metal battery
- **Factorial Energy** – JDA and strategic investment on solid-state battery

Partnership
- **CATL** – CTP (cell to battery pack) technology licensing and partnership agreement
- **UL** – Second life battery energy storage system safety and performance
- **LG Energy Solution** – JV on Indonesian EV battery cell plant
- **SK Innovation** – Pouch-type batteries for hybrid electric vehicle (HEV)
- **KST Mobility** – Electric taxi rental and reuse of EV batteries in energy storage systems
- **Lithion Recycling** – Recovery and recycling of high-voltage batteries
- **Delft IMP** – Gas-phase nano coating technology

Toyota

Investment
- **Battery Manufacturing in US** – $3.4B investment announced on US local battery production for EV
- **Battery Supply and R&D** – $14.3B investment for battery supply system and its R&D by 2030
- **Toyota Research Institute** – $36M for its Accelerated Materials Design and Discovery (AMDD)

Partnership
- **Nexeon** – Through PPES (JV between Panasonic and Toyota) on silicon materials for EV batteries
- **BHP** – Through PPES (JV between Panasonic and Toyota) on nickel sulfate supply

Nissan

Investment
- **Japan EV battery plant** – $460M for building car-battery plant in Japan with Envision AESC
- **Europe Plant Expansion** – Envision AESC to build gigafactory in UK Sunderland

Partnership
- **Repsol** – To promote electric mobility with charging networks

Industry Movement | EU OEMs

VW

Volkswagen

Investment

- **MEB EV plant in China**
  To include supplier park for batteries and components

Partnership

- **Enel X**
  High power charging network in Italy
- **Gotion High-Tech**
  to industrialize production of VW's unified cells in China and EU
- **24M**
  Semi-solid battery technology
- **BASF, Daimler, Fairphone**
  Sustainable lithium mining in Chile
- **BP**
  Ultra fast electric vehicle (EV) charging facilities in Europe
- **Samsung SDI**
  Manufacture portion of the production of VW's Unified Prismatic Cell

Daimler

DAIMLER

Investment

- **Automotive Cells Company**
  Become an equal shareholder together with Stellantis and TotalEnergies on ACC
- **Factorial Energy**
  Investment on solid-state battery technology

Partnership

- **BASF, VW, Fairphone**
  Sustainable lithium mining in Chile
- **Siemens Smart Infrastructure, ENGIE, EVBox Group**
  Charging infrastructure for Mercedes-Benz Trucks
- **CATL**
  Expand global partnership on truck batteries supply
- **BMW, BP**
  Digital Charging Solutions GmbH to grow network of chargers across Europe

BMW

Investment

- **Lilac Solutions**
  Efficient and sustainable lithium extraction
- **Solid Power**
  $130M (total) for all solid-state battery
- **Manz AG**
  Build a battery production line for BMW in Germany

Partnership

- **AMTE Power, Sprint Power, BP**
  ultra-fast charging systems for electric vehicles
- **Daimler, BP**
  Digital Charging Solutions GmbH to grow network of chargers across Europe

Industry Movement | Cell Manufacturers

CATL

Investment

- **NEO Lithium**: Lithium project located in Argentina
- **Jinchuan Group**: Cobalt mining and supply
- **China Molybdenum Co**: $137.5M for copper-cobalt mine in the Democratic Republic of Congo

Partnership

- **ZF**: Aftermarket service in e-Mobility and energy battery storage
- **Fisker**: Cementing battery capacity for the Fisker Ocean SUV
- **Canadian Solar**: supply of lithium-ion battery modules for battery storage projects
- **Hyundai MOBIS**: CTP (cell to pack) technology licensing
- **ELMS**: battery supply for class 1 urban delivery commercial electric vehicle
- **BASF**: battery materials solutions, cathode active materials and battery recycling
- **Daimler**: Expand global partnership on truck batteries supply

LG Energy Solution

Investment

- **Queensland Pacific Metals**: binding offtake agreements for nickel and cobalt
- **LGES Michigan**: $1.36B for EV production in North America

Partnership

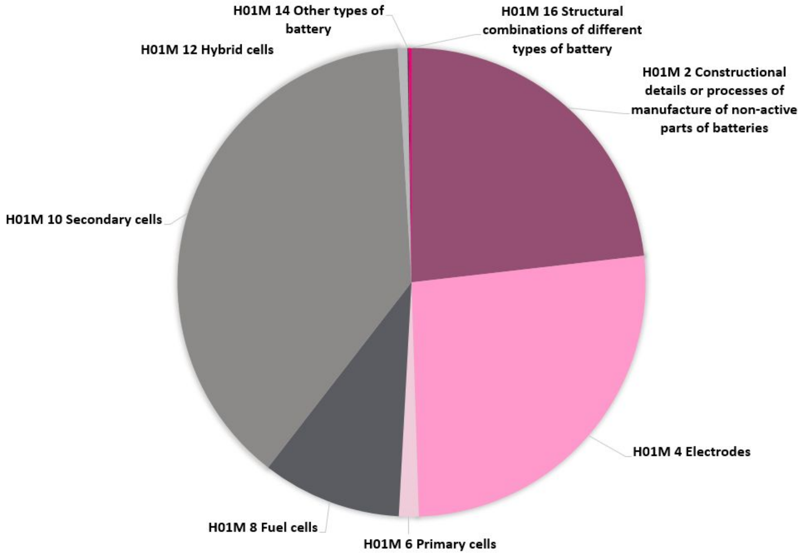
- **Toray**: To establish battery separator film joint venture with LG Chem in Hungary
- **Ultium Battery Cell Manufacturer**: $2.3B for 2nd ultium battery cells manufacturing plant in US (JV with GM)
- **Stellantis**: JV for battery production in North America
- **Sigma Lithium**: Six-year binding term sheet for lithium offtake
- **Romeo Power**: To provide lithium-ion battery cells through 2028
- **Proterra**: Long-term supply agreement for EV battery cells
- **Vulcan Energy**: Supply lithium hydroxide (at least 5 years)
- **Indonesia Battery Corporation**: Battery plant with the capacity of 10 GWh
- **SQM**: To supply LG Chem with ultralight metal lithium
- **Hyundai**: JV on Indonesian EV battery cell plant

Industry Movement | Patent (PCT) Applications

Several companies dominate patent applications

5290 PCT applications (international applications) published between 1 Jan - 21 Oct 2021 in the **IPC code H01M** (“*PROCESSES OR MEANS, e.g. BATTERIES, FOR THE DIRECT CONVERSION OF CHEMICAL ENERGY INTO ELECTRICAL ENERGY*”).

PCT APPLICATIONS BY CLASS IN 2021



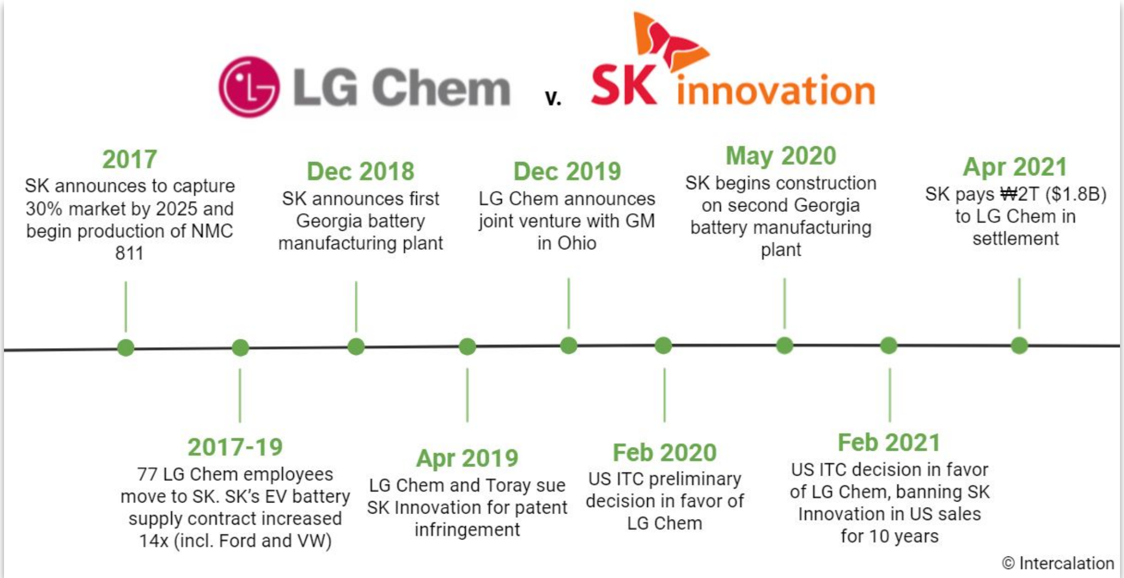
TOP 5 APPLICANTS BY PCT CLASS	
H01M 2 Non-active parts of batteries **312 applications**	LG, CATL, SANYO, Panasonic, muRata (INNOVATOR IN ELECTRONICS)
H01M 4 Electrodes **689 applications**	LG, CATL, SANYO, Panasonic, muRata (INNOVATOR IN ELECTRONICS)
H01M 6 Primary cells **46 applications**	Panasonic, muRata (INNOVATOR IN ELECTRONICS), MITSUI KINZOKU, DAIKIN, 한양대학교 ERICA 산학협력단 (INDUSTRY-UNIVERSITY COOPERATION FOUNDATION HANYANG UNIVERSITY ERICA)
H01M 8 Fuel cells **223 applications**	BOSCH, 潍柴动力 WEICHAI POWER, Panasonic, KOLON INDUSTRIES, AVL
H01M 10 Secondary cells **1050 applications**	LG, Panasonic, muRata (INNOVATOR IN ELECTRONICS), CATL, SANYO
H01M 12 Hybrid cells **27 applications**	한양대학교 ERICA 산학협력단 (INDUSTRY-UNIVERSITY COOPERATION FOUNDATION HANYANG UNIVERSITY ERICA), SHARP, Form energy, NTT, FUJIKURA COMPOSITES

* not listing H01M14 and H01M16 categories since they both had <20 applications

Source: Mewburn Ellis

Industry Movement | Intellectual Property Lawsuits

Case of the year: SK INNOVATION v. LG CHEM



In 2019, a dispute arose after 77 employees moved from LG to SK and allegedly misappropriated trade secrets, which coincided with a 14-fold increase in SK's battery supply contracts.

The dispute, which had initially resulted in the US International Trade Commission imposing a 10-year ban on SK battery imports, was resolved after SK agreed to pay LG Chem a **$1.8B settlement in 2021** plus ongoing royalties, together with a 10-year mutual covenant not to sue.

Growth in the battery industry will continue to lead to more investment and more competition, along with more complex IP litigation, especially between the bigger players. Competition tends to drive further innovation and drive the evolution of effective market regulations and standards.

Source: Mewburn Ellis

Innovators | Battery Value Chain

We share a few innovators to keep tabs on, categorized into broad stages from raw materials to pack design and back. Note: this is *not* a comprehensive list, and just a snippet of the industry (*market size and CAGR data from 2020).

Raw Materials
Extraction, processing

$11b market, 8.3% CAGR*

KoBold Metals, nanoOne, Lilac solutions, EnergySource Minerals, Vulcan Energy Zero Carbon Lithium™, ABTC, Mitra Chem, Standard Lithium, E3 Metals Corp, Kuniko Zero Carbon Battery Metals, Urbix, P+L Pure Lithium, Alpha Lithium, NMG Nouveau Monde Graphite

Cell Components
Electrode, electrolyte, etc

$38b market, 4.9% CAGR*

Sion Power, SES, Nanoramic Laboratories, Echion Technologies, Li-Metal, 24M, LeydenJar Energising Technologies, 6K Energy, nyobolt, EP, volexion, Battrion, Coreshell Technologies, EC Power, Addionics, South 8 Technologies, Cuberg, Ionic Materials, gaussion, Soteria, AM Batteries

Battery Data
AI, BMS, Electronics, etc.

$3.6b market, 19.0% CAGR*

voltaiq, Feasible, BrillPower Revolutionizing Energy Storage, Chemix, GBatteries, TWAICE, Romeo Power, Global Battery Solutions, Aionics, Relectrify Making Energy Storage Affordable, Breathe Battery Technologies, Accure, ReJoule, novo, Wildcat Discovery Technologies, Titan Advanced Energy Solutions

Sustainability
Recycling, reuse, 2nd life

$17.2b market, 6.1% CAGR*

Redwood Materials, Li-Cycle, Ascend Elements, moment energy, Nth Cycle, OnTo Technology LLC, Redivivus, Titan Advanced Energy Solutions, Aceleron, ReCell Advanced Battery Recycling, Elkem, librec Closed-loop Battery Recycling, Sensata Technologies

Innovators | Silicon Anode

Company	Technology	Tot. Funding, Stage	Partnerships / Investments
SILA NANOTECHNOLOGIES	Si nanocomposite	$930M, Series F	DAIMLER, WHOOP, CATL, TDK, SAMSUNG
ENOVIX	3D Si architecture	$254M, SPAC	intel, Qualcomm
ENEVATE	Si porous film	$192M, Series E	RENAULT NISSAN MITSUBISHI, LG Chem, SAMSUNG
StoreDot	Si nanoparticles	$172M, Private	bp, EVE, DAIMLER, VINFAST, SAMSUNG, TDK
nexeon	Si porous columns	£130M, Private	WACKER, SK chemicals
OneD BATTERY SCIENCES	Si nanowires on graphite	$125M, Private	Financial VCs
amprius	Si nanowires	$191M, Series C	AIRBUS, U.S.ARMY
ADVANO	Si nanoparticles	$38.8M, Series A	MITSUI KINZOKU
GROUP14	Si/C nanocomposite	$41.5M, Series B	SK materials, TDK, BASF, FARASIS, StoreDot
LeydenJar ENERGISING TECHNOLOGIES	Si nanopillars	€33.2M, Series A	Financial VCs

* Non exhaustive list of companies

Innovators | Solid State Electrolyte

Company	Technology	Tot. Funding, Stage	Partnerships / Investments
QuantumScape	Anode-free, ceramic SE	$1.2B, SPAC	VW
Solid Power	Si/Li anode, sulfide glass-ceramic SE	$186M, SPAC	Ford, Hyundai, BMW, Samsung
ProLogium	Li/graphite/Si, oxide ceramic SE	$426M, Series E	EVA AIR, NIO, NOVATE
ilika	Si anode, oxidic ceramic SE	$44M, Public	Financial VCs
Sion Power	Li, hybrid ceramic-polymer SE	$50M, Private	BASF We create chemistry, Hyundai CRADLE, A123 Systems, Samsung
IONIC materials	Li/graphite anode, hybrid ceramic-polymer SE	$65M, Series C	Renault, Nissan, Mitsubishi
SES	Li, semi-solid SE	$325M, SPAC	SK innovation, gm, Hyundai
Factorial	Semi-solid SE	$40M, Private	Mercedes-Benz, Stellantis, Hyundai, Kia
北京卫蓝新能源科技有限公司 Beijing WeLion New Energy Technology Co.,LTD	Li, PEO-based SE	$78M, Private	Xiaomi, Tianqi Lithium
StoreDot	Li/Si anode, undisclosed electrolyte	$140M, Series C	bp, EVE, Daimler, VinFast, Samsung, TDK

* Non exhaustive list of companies

Innovators | Stationary Storage

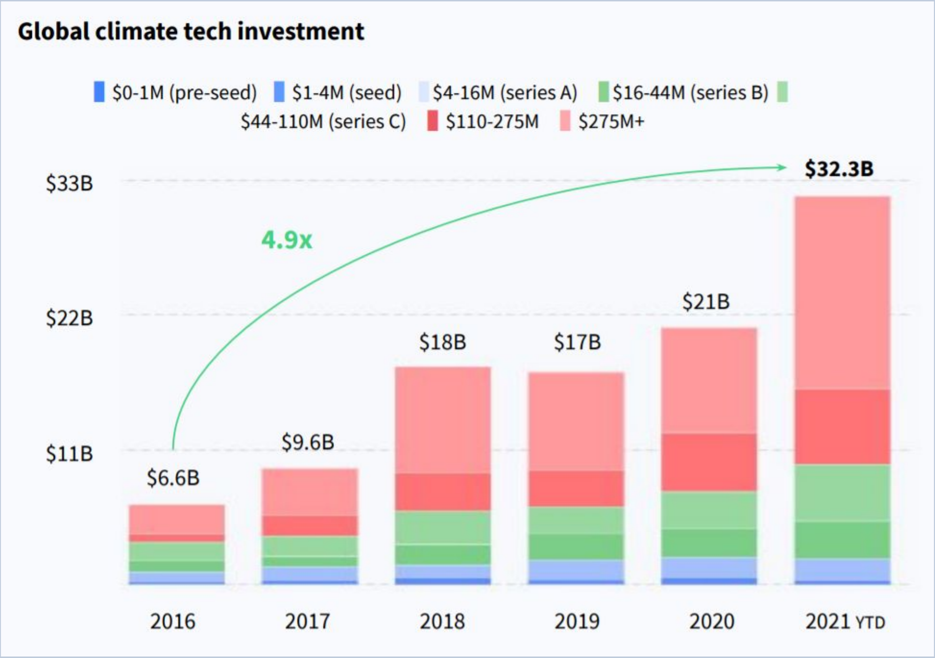
Company	Technology	Tot. Funding, Stage	Major Investors*
ZincFive	Rechargeable Ni-Zn battery for emergency backup power	$36M, Series C	Helios Capital Ventures, Qiming Venture Partners
ENERVENUE	Metal-hydrogen batteries over wide temperature range for 2-12 hrs of storage	$112M, Series A	Schlumberger, Peter Lee
Form energy	Long-duration (100-150 hrs) rechargeable iron-air batteries	$368M, Series D	ArcelorMittal, Energy Impact Partners, Breakthrough Energy Ventures
FREEWIRE	Li-ion fast DC charging for grid infrastructure and EV chargers	$105M, Series C	Riverstone Holdings, BP Ventures
Ambri	Molten-salt batteries for wind and solar power systems	$211M, Series C	Reliance Industries, Khosla Ventures
MALTA	Heat exchanger-based with superheated molten salt	$87M, Series B	Chevron Technology Ventures, Proman, Breakthrough Energy Ventures
RELECTRIFY	Cell-level battery management system and inverter	$4.5M, Series A	Energy Innovation Capital, Clean Energy Finance Corporation
ESS INC	Medium duration (4-12 hrs) iron flow battery	$308M, SPAC	Bill Gates, SoftBank

** Non exhaustive list of companies*

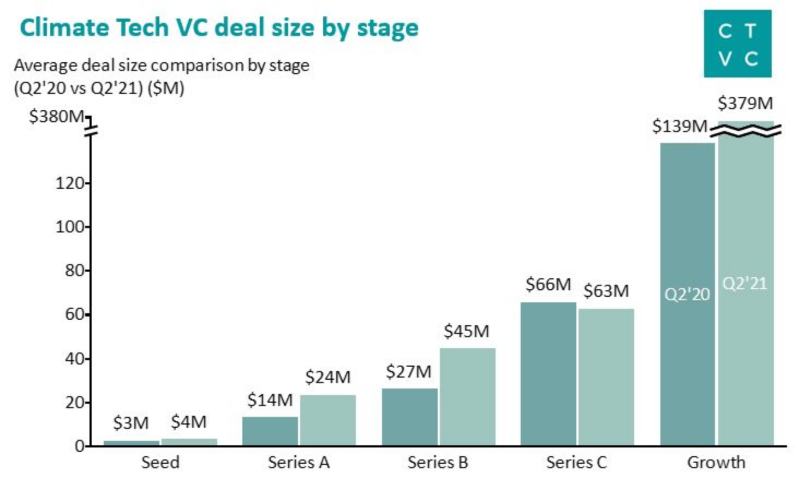
*** Most stationary storage companies are venture-backed as opposed to strategic partnerships, partly due to the higher capex required, longer development time & longer time period for return*

Investment | Climate Tech Venture Capital

In the first 3 quarters of 2021, climate tech startups raised **~$32B**, approximately 5x more than funding in 2016.



Deal sizes have ballooned. The average Series A and B rounds have doubled in size, and the average Growth (post Series C) deals have increased from $139M to $379M. Large amounts of capital are flowing owing to optimism in the industry and a strong push for electrification. Ever present with this excitement is the risk that companies will not be able to live up to investor expectations.

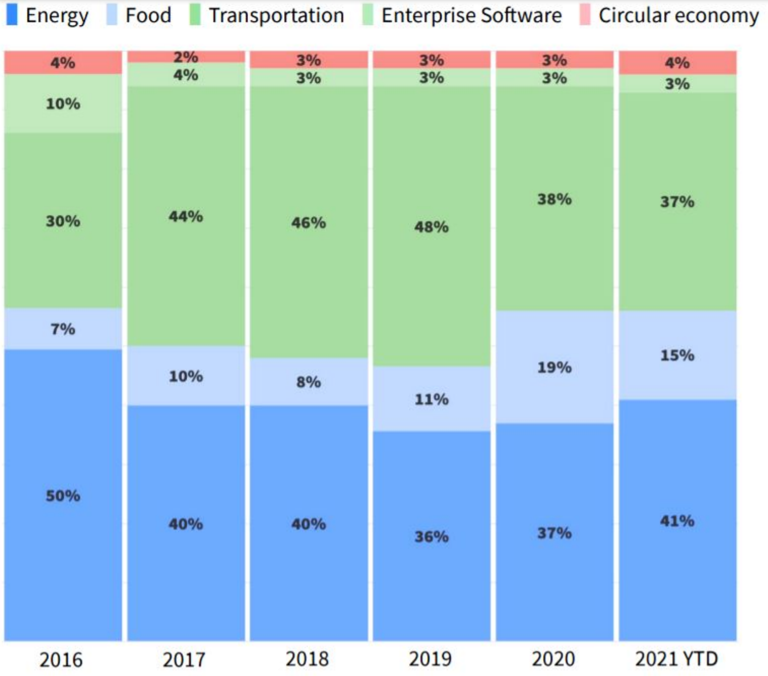


Source: Dealroom, Climate Tech VC

Investment | Climate Tech Venture Capital

Deals in Transportation and Energy make up just under 80% of total deals in climate tech funding.

Climate tech investments by sector



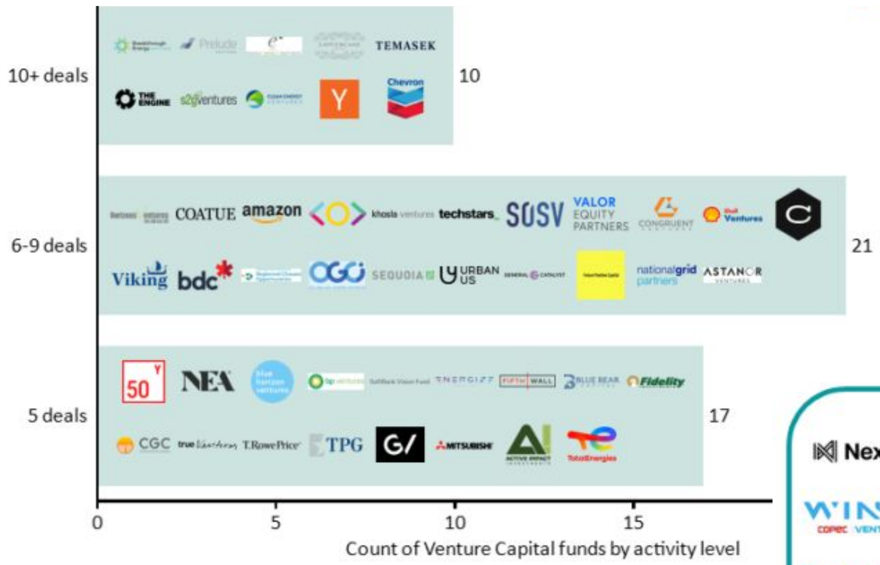
Largest rounds of Q1-Q3 2021 in Transportation and Energy

Company	Transaction	Company	Transaction
SILA NANOTECHNOLOGIES	$590M Series F	Ambri	$144M Venture Round
BETA	$368M Series A	SES Beyond Li-ion™	$139M Series D
ProLogium	$326M Venture Round	Solid Power	$130M Series B
Form energy	$240M Series D	Powin Energy	$100M Venture Round
ample	$160M Series C	OYIKA the way to go	$100M Venture Round
Lilac solutions	$150M Series B	ENERVENUE	$100M Series A

Source: Dealroom, Climate Tech VC

Investment | Climate Tech Venture Capital

Climate tech VC most active investors Q2’20-Q2’21



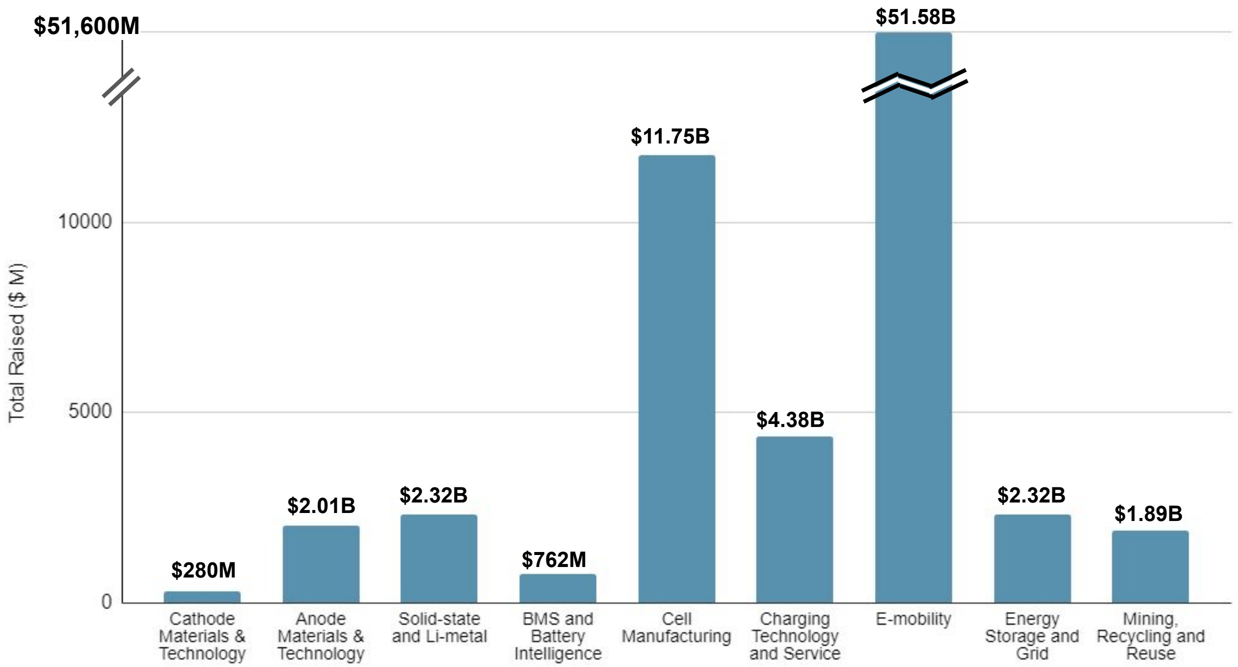
Around **1,000** unique investment firms have participated in at least 1 climate tech deal from Q2’20 to Q2’21. Breakthrough Energy Ventures (backed by Bill Gates) took part in 30 deals.

Corporate VCs announced mandates to invest in new climate technologies. New CVC funds in 2021 include VW ($355M), TDK ($150M), Credit Suisse ($318M), among others. According to CTVC deal tracking, CVCs have participated in 45% of all climate tech deals in the last 15 months.

Source: Climate Tech VC

Investment | Capital Raised by Investment Sector

Battery related investments by sector



E-mobility attracted the most capital in 2021, there are 10 EV startups that raised >$1B USD (5 in US; 1 in EU; 4 in China), with Rivian as top 1 among all, which raised $23B in total and listed in Nasdaq.

Cell Manufacturing and **Charging Infrastructure** are the second and third most popular verticals on capital investing. While EU and Asia countries focused on building more cell manufacturers, US spent more money on building charging infrastructure.

US is leading the investment to startups working on **Anode Materials**, **Solid-state** technologies, **Energy Storage, Mining and Recycling**.

Source: Data from Dealroom, Plot by Volta Foundation

Investment | Capital Raised in Material Innovation

Cathode Material & Technology — Total Raised: $280.59M

[illegible], LYTEN, GREATPOWER, Li-S Energy, MITRA CHEM, Conamix, volexion, ALTRIS

Capital Raised To Date: **Cathode Material & Technology: $280.59M**

Anode Materials & Technology — Total Raised: $2.01B

SILA Nanotechnologies	$933.51M
Enovix	$414.28M
Enevate	$192.36M
Amprius	$191.90M
	$140.99M
Nanoscale Components	$35.07M
Advano	$23.77M
Sionic Energy	$23.19M
Ecellix	$4.00M
LeydenJar	$29.06M
E-magy	$6.05M
Cenate	$5.00M
Sicona Battery Technologies	$3.80M
BSG 佰思格	$1.55M
G Graphite	$1.50M

Capital Raised To Date:
Anode Material & Technology: $2.01B

Solid-state and Li-metal — Total Raised: $2.32B

ProLogium	$823.00M
SES	$520.50M
Solid Power	$358.13M
Sion Power	$290.35M
Cymbet Corporation	$104.50M
卫蓝新能源	$78.13M
Factorial	$53.71M
BrightVolt	$42.50M
Sepion Technologies	$18.75M
Prieto Battery	$18.45M
LionVolt	$6.10M
Solivis	$3.96M
Intecells	$3.00M
Soelect Inc	$2.30M

Capital Raised To Date:
Solid-state and Li-metal: $2.32B

**Companies listed according to Pitchbook with disclosed fundraising deal in year 2021*

Source: Data from Pitchbook, Market Map by BatteryBits

Investment | Capital Raised in BMS and Cell Manufacturing

BMS and Battery Intelligence — Total Raised: $754.81M

Company	Capital Raised
Forsee Power	$327.78M
Wildcat Discovery Technologies	$110.76M
Hyper Strong 海博思创	$95.63M
Titan	$43.19M
TWAICE	$42.18M
BMSer 协能科技	$22.99M
Zitara	$19.88M
eatron Technologies	$13.21M
Voltaiq	$12.05M
Accure Battery Intelligence	$10.73M
Wibotic	$10.26M
AIMP	$9.30M
BrillPower	$5.86M
Relectrify	$5.71M
3ME Technology	$5.00M
ION Energy	$4.64M
Revos	$4.99M
Aviloo	$2.81M
Joulwatt	$2.44M
volytica diagnostics	$2.21M
Breathe Battery Technologies	$2.20M
Fova Energy	$1.00M

Capital Raised To Date: **BMS and Battery Intelligence: $754.81M**

Cell Manufacturing — Total Raised: $11.75B

Company	Capital Raised
northvolt	$6.42B
SVOLT 蜂巢能源	$3.21B
microvast	$990.00M
COSMX	$490.29M
24M	$172.68M
Verkor	$120.49M
蔚能	$100.26M
BV	$93.81M
iM3NY	$85.00M
Inobat Auto	$22.60M
Coreshell Technologies	$14.63M
城满电	$12.54M
[illegible]	$5.00M
Electric Era	$3.70M
Soteria	$3.85M
AM Batteries	$2.77M
Blueline	$2.02M
[illegible]	$1.57M

Companies listed according to Pitchbook with disclosed fundraising deal in year 2021

Capital Raised To Date: **Cell Manufacturing: $11.75B**

Source: Data from Pitchbook, Market Map by BatteryBits

Investment | Capital Raised in Energy Storage

Energy Storage and Grid — Total Raised: $2.32B

United States — Total Raised: $1.91B

stem	$570.28M
Form energy	$366.00M
Nanotech Energy	$256.61M
esVOLTA	$140.00M
ZincFive	$113.52M
ENERVENUE	$137.00M
Natron Energy	$92.38M
ESS INC	$61.44M
CABAN SYSTEMS	$42.10M
Cadenza Innovation	$32.73M
IMPRINT ENERGY	$24.17M
ELECTRIQ POWER	$23.24M
ENCELL technology	$24.61M
WeaveGrid	$15.00M
Revolution Power	$7.57M
Æsir Technologies, Inc.	$5.03M
ZELOS	$1.92M

Europe — Total Raised: $124.81M

TESVOLT	$46.26M
neoom	$13.04M
LiNa Energy	$9.48M
ACELERON	$9.46M
CONNECTED ENERGY	$8.32M
ecostor	$8.22M
piclo	$7.53M
otonohm	$5.49M
Cumulus Energy Storage	$4.51M
AquaBattery	$4.00M
GREEN-Y	$3.07M
Caldera	$2.69M

Capital Raised To Date:
Energy Storage and Grid
US: $1.91B; EU: $124.81M

Asia — Total Raised: $199.02M

ECOFLOW	$108.74M
钠创 NATRIUM	$15.55M
STANDARD ENERGY	$69.61M
FLOW TECH	$3.13M
WAAREE ESS	$2.00M

Other — Total Raised: $77.71M

redflow	$65.18M
e-zinc	$6.27M
m	$3.50M
TROES	$1.39M
i-G3N	$1.37M

Capital Raised To Date: **Energy Storage and Grid** **Asia: $199.02M**

Capital Raised To Date: **Energy Storage and Grid** **Other: $77.71M**

**Companies listed according to Pitchbook with disclosed fundraising deal in year 2021*

Source: Data from Pitchbook, Market Map by Volta Foundation

Investment | Capital Raised in Charging Technology

Charging Technology and Service — Total Raised: $4.38B

United States — Total Raised: $2.79B

chargepoin+	volta	EVgo FAST CHARGING	ampLe	WiTricity	FREEWIRE
$955.62M	$631.19M	$400.00M	$275.73M	$139.77M	$90.45M
Momentum Wireless Power	SPAN	FERMATA ENERGY	evconnect	IoTecha	SparkCharge
$70.08M	$45.61M	$28.63M	$25.64M	$24.47M	$16.21M
electrada	HEVO	xeal	emporia	BATTERY STREAK	ampUp
$11.94M	$11.79M	$11.08M	$9.00M	$8.75M	$5.30M
POWER.GLOBAL	RESILIENT POWER	Dynami	CH! ChargerHelp!	MGL Microgrid Labs	GO TO-U
$5.19M	$5.02M	$3.16M	$2.75M	$2.25M	$1.60M
LIBERTY ACCESS TECHNOLOGIES	EV STRUCTURE	OODLES ENERGY			
$1.64M	$1.25M	$1.01M			

Capital Raised To Date:
Charging Technology & Service
US: $2.79B

Europe — Total Raised: $675.65M

allego	wallbox	THE MOBILITY HOUSE	VIRTA	easycharger	EASYGO
$177.42M	$174.67M	$66.23M	$47.54M	$30.35M	$29.61M
Wirelane	ELECTRA	Echion Technologies	serve mobility	CONNECTED KERB	ev.energy
$27.90M	$18.10M	$16.99M	$12.47M	$10.61M	$10.11M
ROCSYS EV Charging Automation	INDRA	JEDLIX	MONTA	TROJAN ENERGY LTD	SPARK HORIZON
$8.86M	$8.13M	$5.80M	$4.74M	$4.68M	$4.00M
ELONROAD	GEYSER BATTERIES	Inbalance	HYPERVOLT	chargetrip	L-CHARGE
$3.17M	$2.85M	$2.78M	$2.25M	$2.21M	$1.50M
AGEVOLT	BONNET				
$1.45M	$1.24M				

Capital Raised To Date:
Charging Technology & Service
EU: $675.65M

**Companies listed according to Pitchbook with disclosed fundraising deal in year 2021*

Source: Data from Pitchbook, Market Map by Volta Foundation

Investment | Capital Raised in Charging, Mining and Recycling

Charging Technology and Service — Total Raised: $4.38B

Asia — Total Raised: $681.80M

TELD 特来电	Aulton 奥动	Gridwiz	LUUP	云快充	XCHARGE
$285.73M	$232.07M	$67.75M	$26.16M	$14.60M	$11.58M
Battery Smart	Gegadyne Energy	OYIKA the way to go	EVAR	ElectricPe	go=go
$11.18M	$9.59M	$7.54M	$4.70M	$3.00M	$2.00M
Xnergy	POWER + WWW 全来电	RACEnergy	LITHION		
$2.00M	$1.54M	$1.31M	$1.06M		

Other — Total Raised: $240.56M

powermat	DANNAR	driivz	HYPERCHARGE	CHARGELAB	greenv
$195.00M	$7.00M	$22.75M	$6.05M	$5.55M	$4.21M

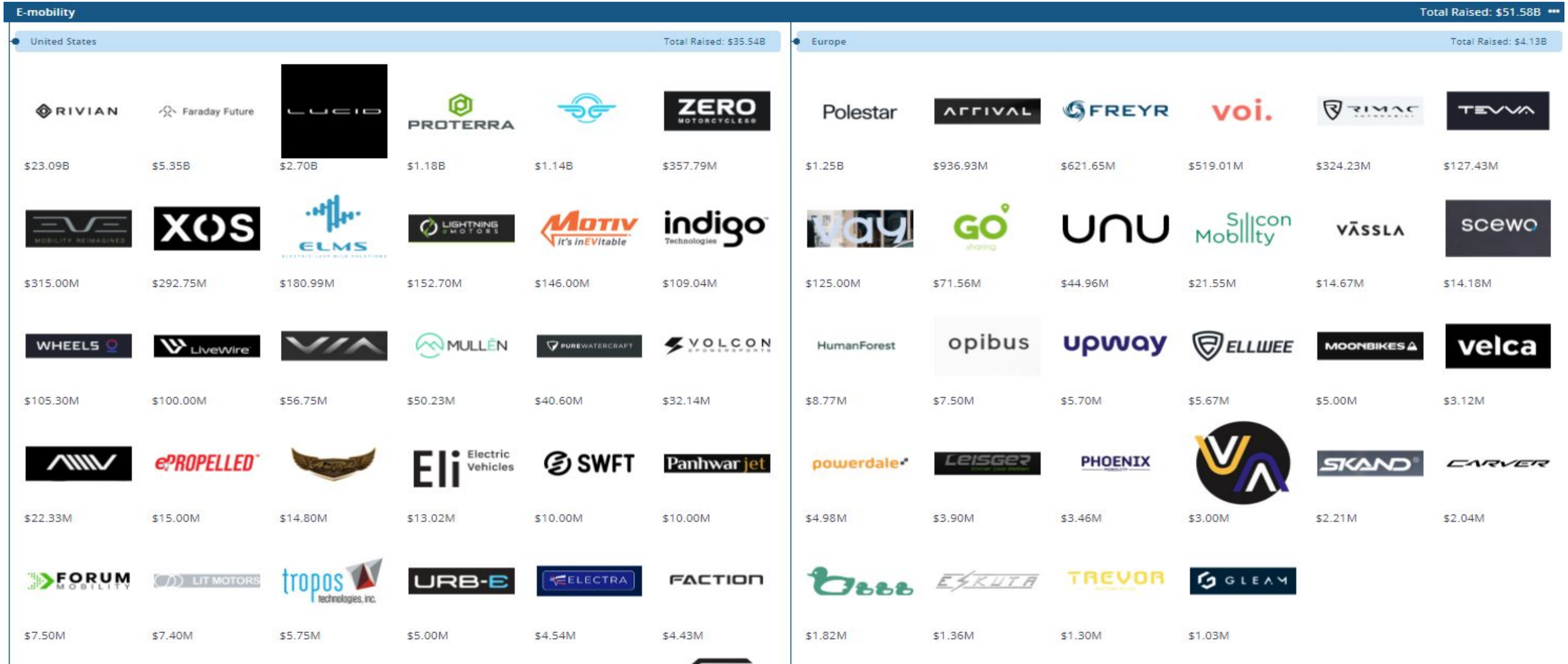
Capital Raised To Date:
Charging Technology & Service
Asia: $681.80M Other: $240.56M

Mining, Recycling and Reuse — Total Raised: $1.89B

REDWOOD MATERIALS	Li-Cycle	Lilac solutions	ASCEND ELEMENTS	CONTROLLED THERMAL RESOURCES	ENERGYX
$824.64M	$579.50M	$173.60M	$132.85M	$37.00M	$34.01M
SUMMIT NANOTECH	NTH CYCLE	Adionics	Cornish Lithium	betteries	GREEN LITHIUM
$17.61M	$16.60M	$15.68M	$49.97M	$2.60M	$2.25M
librec					
$2.19M					

Source: Data from Pitchbook, Market Map by Volta Foundation

Investment | Capital Raised in E-mobility

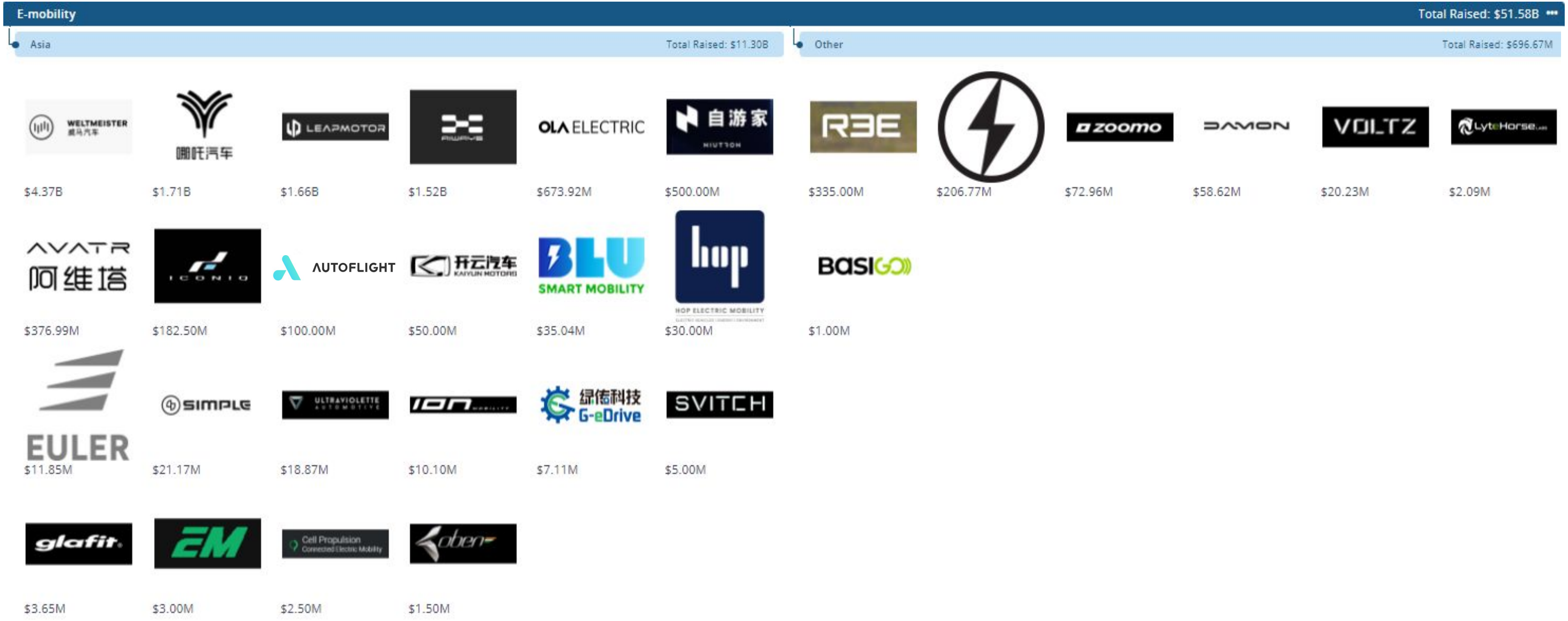


**Companies listed according to Pitchbook with disclosed fundraising deal in year 2021*

Capital Raised To Date:
E-mobility US: $35.54B EU: $4.13B

Source: Data from Pitchbook, Market Map by Volta Foundation

Investment | Capital Raised in E-mobility



Source: Data from Pitchbook, Market Map by Volta Foundation

Investment | Investor Landscape

Top active investors (VC, CVC, Corp) by vertical in 2021

Cathode Materials & Technology

- Fontinalis Partners
- Earthshot Ventures
- LG Energy Solution
- Social Capital

Anode Materials & Technology

- 8VC
- Shift
- Aravaipa Ventures
- Mission Ventures
- Seed Group
- Astralabs
- artesian

Solid-state and Li-metal

- GM Ventures
- LG Technology Ventures
- Volta Energy Technologies
- motus ventures
- 丹莘资本 dGav Capital
- 春華 Primavera
- equinor
- SAIC
- Stanley Ventures
- FM Capital
- Caterpillar
- SBCVC 软银中国资本
- New Science Ventures
- Pilatus Capital
- Applied Materials
- Solvay
- Eden Rock Group
- ACVC Partners
- Creative Ventures
- Calm Ventures
- Xiaomi Ventures
- Gaingels
- Dolby Family Ventures
- Impact Science Ventures
- BMW i Ventures
- Alumni Ventures
- Fine Structure Ventures

BMS and Battery Intelligence

- UVC Partners
- Speedinvest
- NIO
- Energize Ventures
- Chery
- GS Futures
- Lightspeed
- Thin Line Capital
- SBVP Santa Barbara Venture Partners
- Doral
- 云和资本 Yun He Capital
- BYD
- Aves Capital Management
- HG Ventures
- SE Ventures
- Fortistar
- SVTech Ventures
- WRF Capital
- MMC ventures
- Aster
- W Fund
- 清控银杏 THG Ventures
- USV
- Blue Bear Capital
- 42CAP
- EDP Ventures
- Capnamic
- FTTF
- Atlantic Labs
- longcapital 長石資本
- Hella Ventures
- Fontinalis Partners
- Ajax Strategies LLC
- climate capital
- Your Nest Venture Capital
- Energy Innovation Capital
- Prime Venture Partners
- 8VC
- Samyakth Capital
- Riso Capital
- Dholakia Ventures
- amazon

Cell Manufacturing

- ABB Technology Ventures
- norrsken VC
- Siemens
- VW
- Bridford Group
- Oshkosh
- Xiaomi Ventures
- Cathay Innovation
- Midea
- Fujifilm
- Itochu
- 海通开元 HT Capital
- CATL
- oppo
- 国创中鼎
- SAIC
- NIO
- Oceanpine
- Magnis Energy Technologies
- TDK Ventures
- Doral
- foothill ventures
- 盘石资本 Sun Rock Capital
- 金庫資本 KYMCO Capital
- Keiretsu Capital
- EQT Ventures
- Arkema
- Creative Ventures
- Waterstar
- North Bridge Venture Partners
- Kyocera
- 德载厚资本 Virtue Capital
- 建业投资
- VinFast

*Investors listed VC, CVC or Corporate investors for top deals in each sector according to Pitchbook with disclosed fundraising deal in year 2021

Investment | Investor Landscape

Top active investors (VC, CVC, Corp) by vertical in 2021

Energy Storage and Grid

Breakthrough Energy, Capricorn Investment Group, e~, Prelude Ventures, The Engine, Vamos Ventures, ArcelorMittal, helios Capital Ventures, Qiming Venture Partners, Schlumberger, IDG Capital, Saudi Aramco Energy Ventures, BASF Venture Capital GmbH, Koch, SB Energy, GC International, Pangaea Ventures Ltd., Hillhouse, Sequoia, Greensoil PropTech Ventures, capricorn, ibg Beteiligungsgesellschaft Sachsen-Anhalt mbH, connecticut innovations, S&R 安丰创投, Grok Ventures, Huaihai, KNI KNET Investment Partners LLC, CHI Impact Capital, Scout Fund, Nixdorf Kapital AG, The Westly Group, SCG, SoftBank Ventures Asia, 미래과학기술지주(주) Mirae Holdings, Ltd, buzzard energy Business by Nature

E-mobility

amazon, Third Point Ventures, Palantir, Daimler Truck, bp ventures, FM Capital, PBJ Capital, Lucky Tree, 412 Venture Fund, Abdul Latif Jameel, Proof, Lane VC, Trousdale Ventures, Gaingels, Quiet, Koch, ICT capital, Kreos Capital, 360, NordicNinja by JB Nordic Ventures, UNU Global, SK, Inbox Capital, TDK Ventures, Trucks, Soma Capital, autoX, nineyards Equity, Porsche Ventures, 广发信德 GF Xinde Investment, PCCW, CATL, SoftBank Vision Fund, 信德集團 Shun Tak Holdings, 涌铧投资 Yonghua Capital, 合肥产投集团 Hefei Industry Investment Group, 50 Fifty Years, DiDi, Alpha Wave, 两江产业 Liangjiang Industry

Charging Technology and Service

Energize Ventures, Brighter Capital, Shell Ventures, ptt Group, ENEOS Innovation Partners, Rose Park Advisors, momentum, Moore Strategic Ventures, Foxconn, prefix, TransformVC, KAAJ Ventures, VAS Ventures, High-Tech Gründerfonds, Energy Environment Investment, Mitsubishi Corporation, ULU Ventures, Congruent Ventures, GIC, Stage 1 Ventures, SIP, SharesPost, 春阳资本 CY Capital, Lahti Energia, Sinopec, Fisker, Landis+Gyr manage energy better, Incite, climate capital, Cathay Innovation, Seaya Ventures, Korea Investment Partners Co., Ltd., bp ventures, SK gas, Abacon Capital, CathayCapital 凯辉基金, Energy Innovation Capital, Perseo, Blue Bear Capital, Alumni Ventures, Capricorn Investment Group, Orillion, Iberdrola ventures, HCVC, TDK Ventures, phoenix Global Resources, Arctern Ventures, alexa fund, 1/0 One Zero Capital, meritz 메리츠증권, a/o proptech, Munich RE, Helen Ventures, Collaborative Fund, Energy Foundry, Rubicon Venture Capital, Wireframe Ventures, Nobunaga キャピタルビレッジ, Spiral Capital, vertex Growth, future energy ventures, TBS Innovation Partners, Sparx, Digital Garage, anri

Mining and Recycling

amazon, Capricorn Investment Group, Ford, Lowercarbon Capital, Earthshot Ventures, Breakthrough Energy, BMW i Ventures, The Engine, Presidio Ventures, orbia, Trumpf, Doral, TDK Ventures, At One Ventures, foothill ventures, Hitachi Inspire the Next, Moore Strategic Ventures

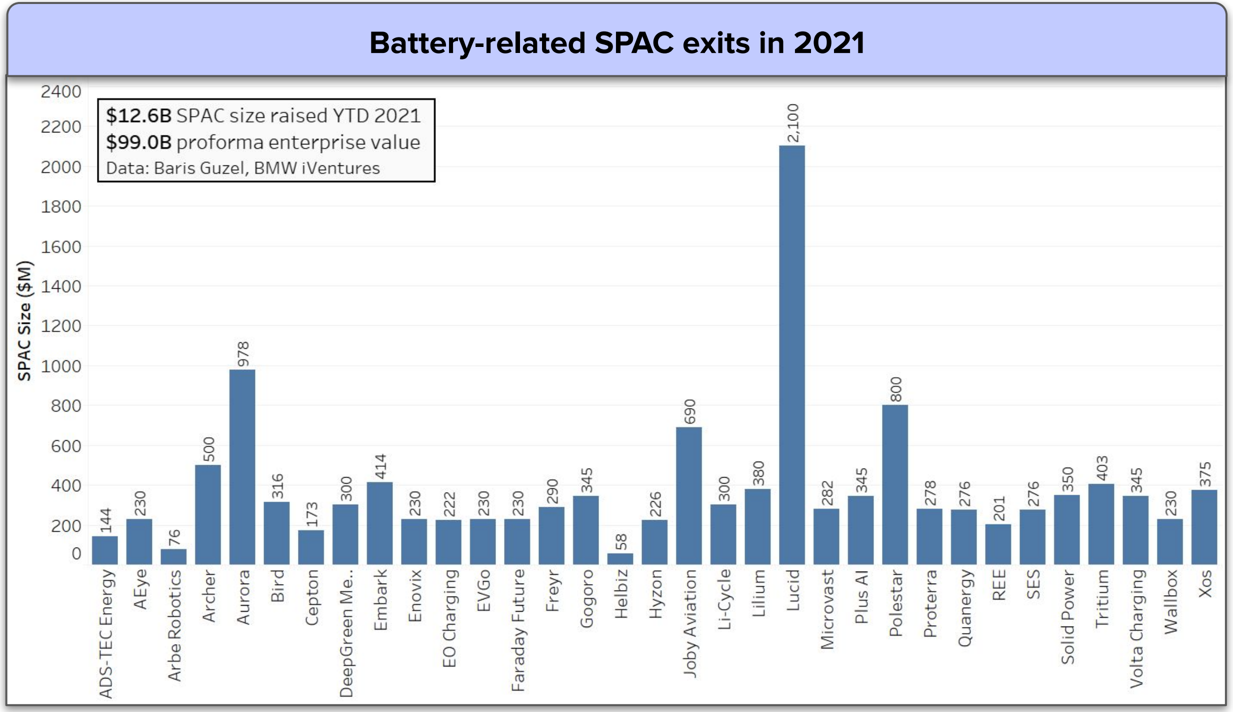
**Investors listed VC, CVC or Corporate investors for top deals in each sector according to Pitchbook with disclosed fundraising deal in year 2021*

Investment | SPACs

More companies went public via SPAC in 2021 compared to 2020.

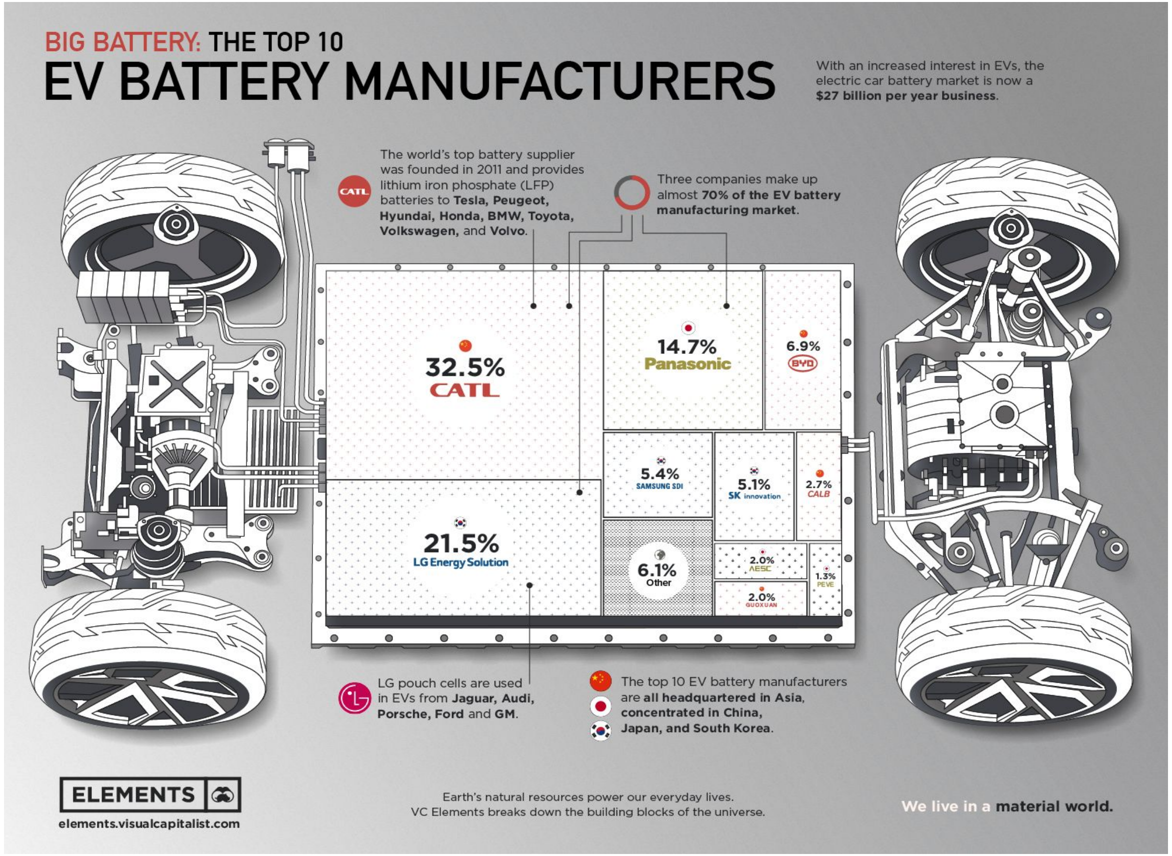
Special purpose acquisition companies (SPAC) made a splash with companies opting to raise capital quicker and easier than through private capital/IPO. SPACs may be a better fit for deep/climate tech companies that need significant capital and time, and this method for going public has continued to dominate in 2021.

In 2021, we counted 32 company exits via SPACs (focusing on EV specific sectors: EV manufacturers, batteries, sensors, autonomous vehicles, eVTOLs, FCEVs, infrastructure) of **$11.8B** total raised with a total enterprise value of **$79B** (compared to $5.9B raised across 23 companies with a total enterprise value of $37.5B in 2020).



Source: Mobility-related SPAC Deals, Baris Guzel, BMW i Ventures

Manufacturing | Global Overview

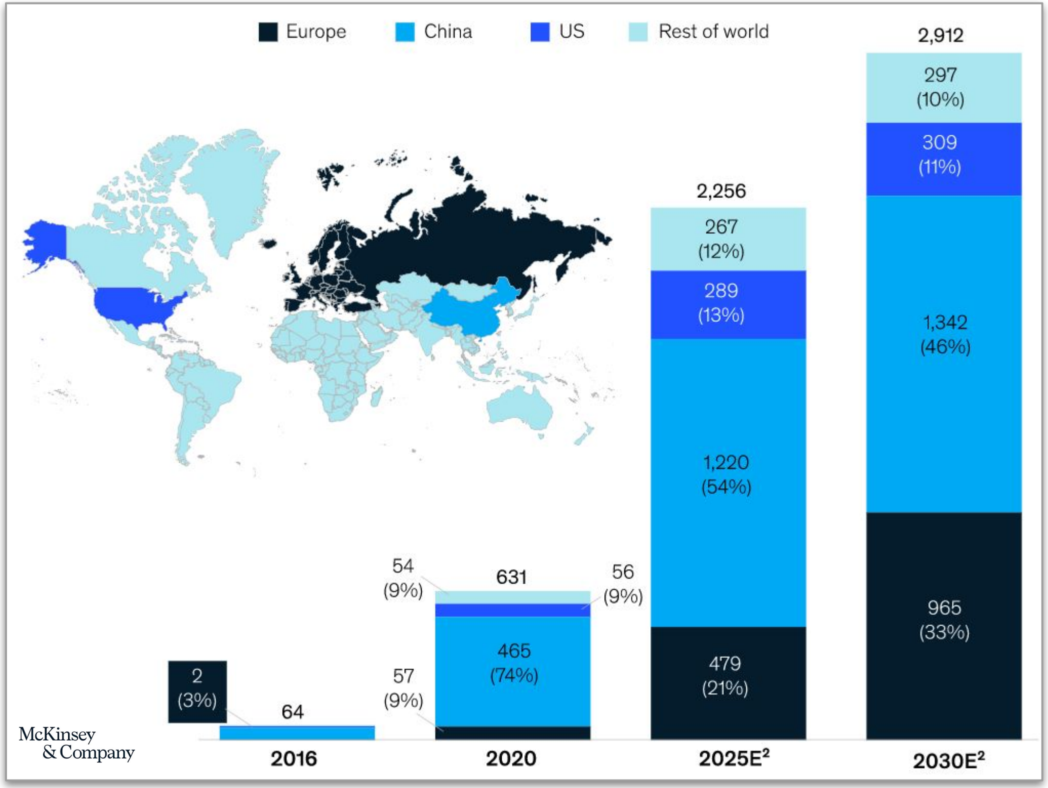


Asia has and continues to dominate battery manufacturing with the top 10 (by market share) all located in China, South Korea, and Japan, the largest 3 being CATL (32.5%), LG Energy Solutions (21.5%), and Panasonic (14.7%).

European and **North American** manufacturers are looking to reduce reliance on Chinese suppliers, with a whole host of new factories and technologies.

Manufacturing | Global Overview

Global manufacturing is projected to balloon this decade

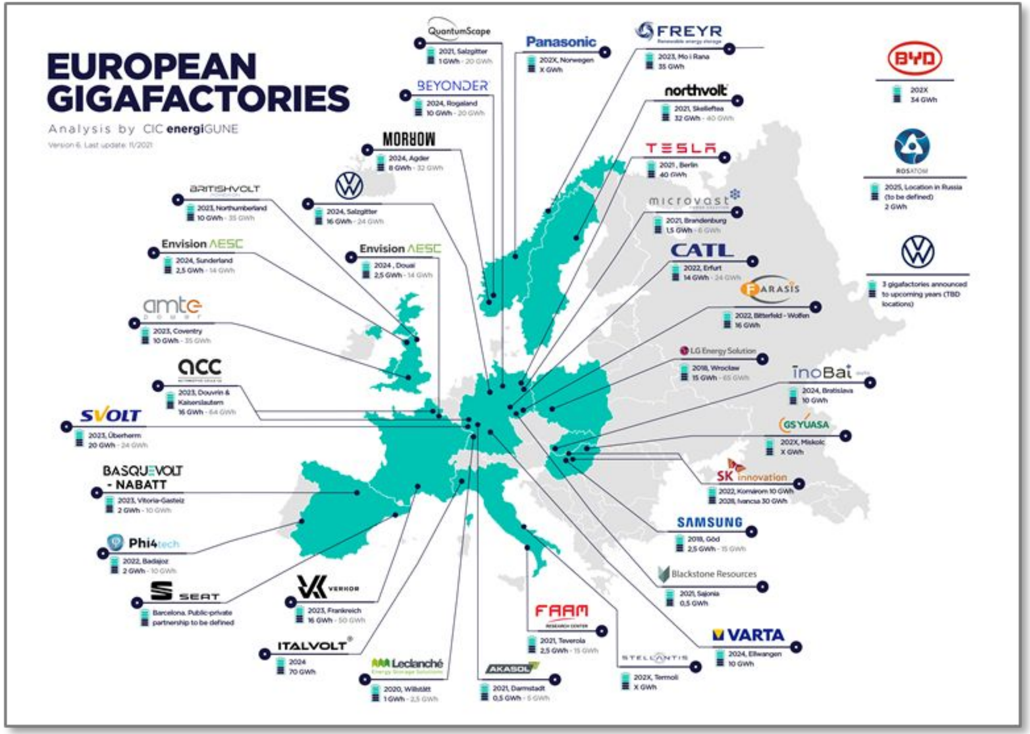


In 2020, China had a production capacity of **465 GWh** (74% world total), the USA had **56 GWh** (9% world total), Europe had **57 GWh** (4% world total).

Battery cell companies and start-ups have announced plans to build production capacity of up to **2256 GWh** by 2025. China is projected to lead the market with **1220 GWh** (54% world total), Europe with **479 GWh** (15% world total), and the USA with **289 GWh** (13% world total).

Manufacturing | Europe

Europe is taking positions in recent years to catch up with Asia in the battery industry



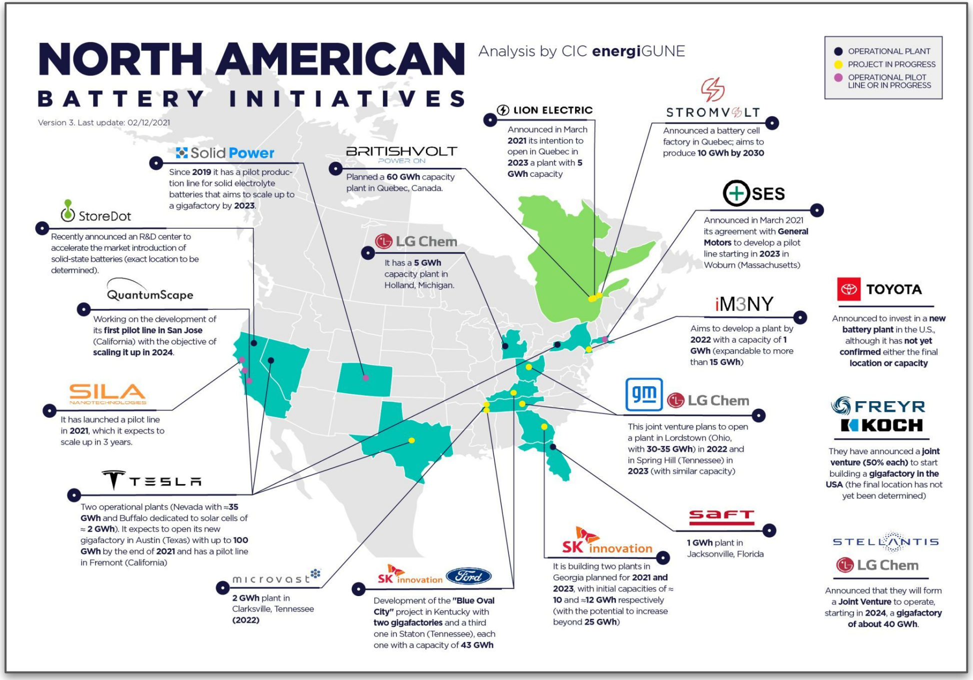
In Europe, 35+ projects have been announced and are expected to be in production by 2030.

OEMs such as Volkswagen, Renault and Daimler are among the main drivers of these projects, by collaborating with and promoting companies and projects, such as Northvolt, Verkor or ACC. Volkswagen stands out from the rest at this moment, projecting at least 240 GWh of annual capacity by the end of the decade.

Public support and funding such as European Funds are helping to increase the number of projects. Some of these projects are early stage and it will be necessary to keep an eye on them over the coming years.

Manufacturing | North America

Similarly, North America (especially the US) has also started to develop its own industry



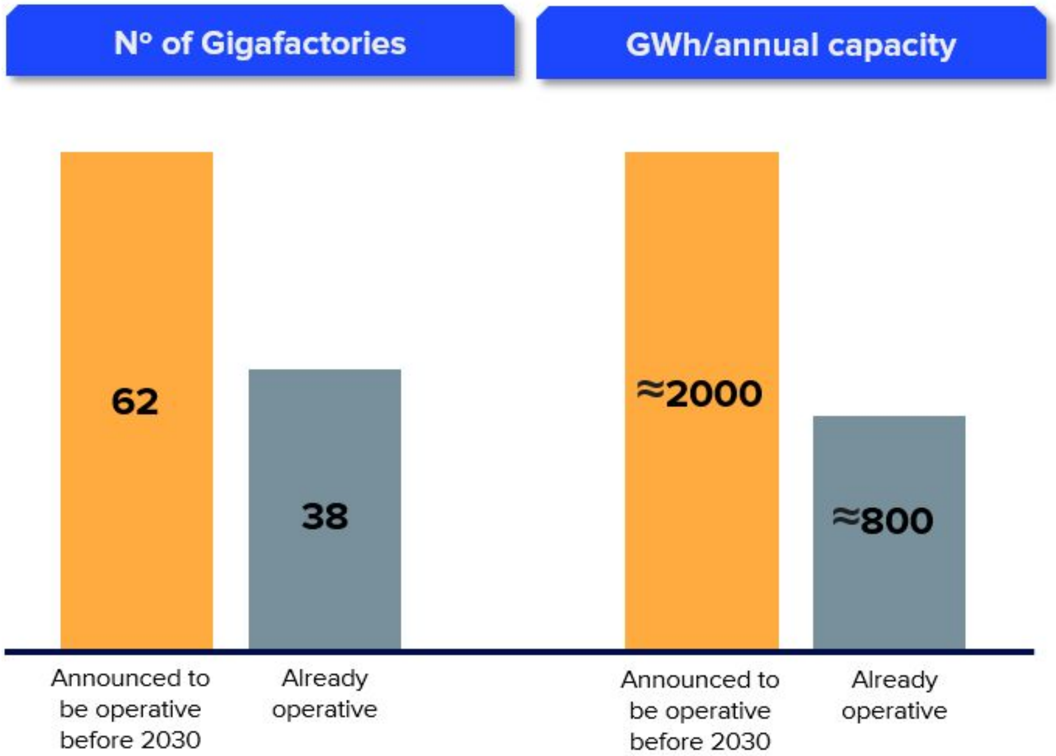
Companies have announced gigafactory projects in North America, which up until recently have been practically devoid of initiatives except for those already developed or underway by Tesla. This map is dominated by the US, which, thanks to its large OEM manufacturers, is also seeking to become a leader in the energy storage and electric vehicle industry.

In addition to large manufacturing projects, the initiatives of smaller startups, such as SolidPower, Quantumscape, Sila and Solid Energy stand out, seeking to revolutionize the market through their technological innovations.

Canada has already begun to take the first steps to develop this industry nationally, and it is expected that Mexico will soon be seeking to do the same.

Manufacturing | Asia

Despite these efforts, Asia will likely continue to lead the industry in the coming years



Asia remains the region of reference in the battery industry, due both to the number of plants and GWh of capacity and to the major players in the sector (BYD, CATL, SK Innovation, Envision, etc).

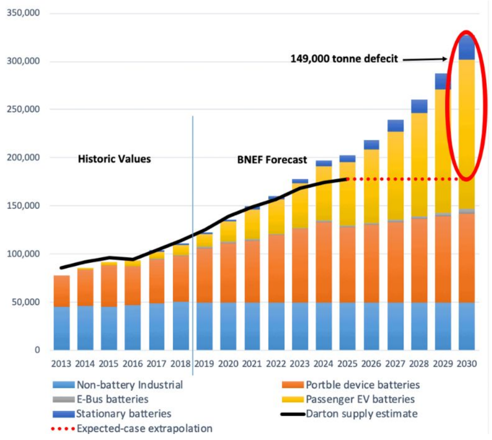
By 2030, the number of gigafactories is expected to increase by >50%, growing in productive capacity to more than double the current level.

China stands out from the rest, with more than half of the continent's plants by 2030 and 60% of the capacity.

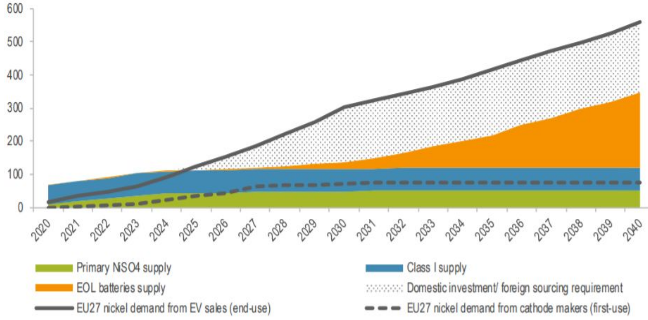
Supply Chain Insights | Raw Materials Shortage

Three major battery materials are experiencing a supply crunch.

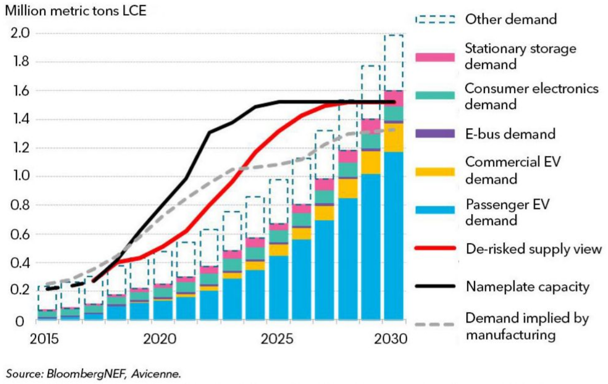
Cobalt: Projected deficit of 149 kton by 2030	Nickel: Demand 6X by 2030, outweighs supply	Lithium: Demand 5X by 2030, outweighs supply



Cobalt supply and demand projections (tons)
Source: Investor Intel



Refined nickel supply and battery demand projections (kton)
Source: Roskill



Global lithium supply and demand projections
Source: Bloomberg

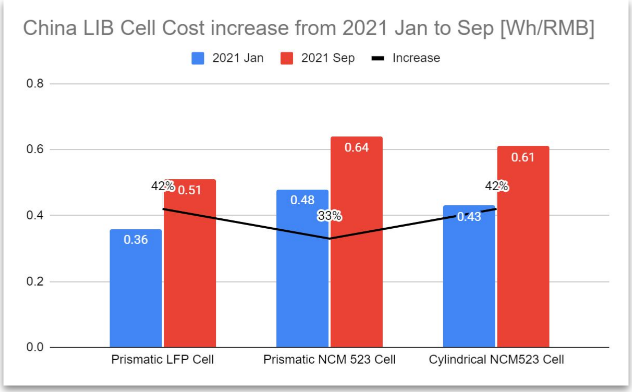
With battery prices falling year on year in the last decade on route to $100/kWh, battery prices have reversed direction abruptly due to material shortages with BYD reporting +20% in their battery prices starting November 2021. Automakers (e.g. Tesla, VW, Daimler) are switching to iron-based cathodes due to the abundance of material and fewer supply shortages.

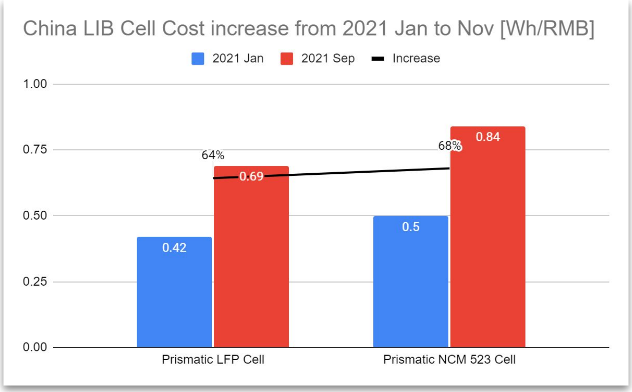
Source: Investor Intel, Roskill, Bloomberg

Supply Chain Insights | Raw Materials and Battery Prices

Raw material and cell costs in China from Jan to Sep 2021

Materials	Jan 2021	Sep 2021	% Increase (average)
LFP [10k RMB/t]	3.5-4	6-6.5	+67%
Single Crystal NCM 523 [10k RMB/t]	11-13	18-20	+58%
Electrolyte [10k RMB/t]	3.5-5	9-11	+135%
Synthetic Graphite [10k RMB/t]	3.2-4.5	4.0-6.0	+30%
Wet Process Separator (9+3um) [RMB/m2]	1.6-2	1.8-2.6	+22%
8um Copper Foil [10k RMB/t]	8-8.5	10.7-11	+32%
12um Aluminum Foil [10k RMB/t]	2.6-3	3.4-3.8	+29%
Conductive agent SP [10k RMB/t]	3.3-3.8	4.2-4.8	+27%
PVDF [10k RMB/t]	10.5-13	28-32	+155%





Source: GGII, SMM

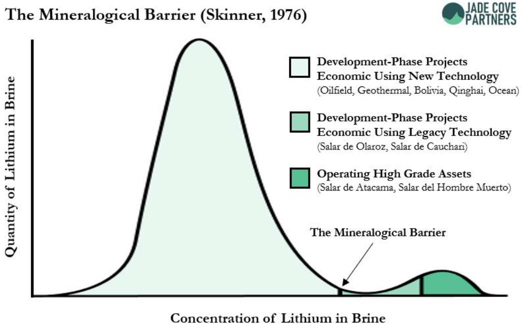
Supply Chain Insights | Lithium Extraction Technology

With the rapid growth in demand for lithium carbonate and lithium hydroxide, the lithium industry is kicking into high gear to supply new battery customers and reduce its environmental impact.

Both junior mining project developers and major producers have raised significant capital and advanced a variety of different lithium natural resource projects around the world. There are two major themes in this growth story.

1) The need to expand production to lower grade, less pure natural resources like sedimentary clays, oilfield brines, and geothermal brines.
2) Implementation of more sophisticated technologies in extraction and processing to reduce carbon emissions and other environmental impacts.

Lithium brine projects leveraging direct lithium extraction technologies raised over $0.5B in 2021 for process scale-up. Rio Tinto even acquired a DLE brine project in Argentina. Pegmatite mineral projects have also enhanced their focus on renewable energy integration to reduce their carbon emissions.



Families of Lithium Natural Resources

Brine Resources	Minerals in Pegmatite Resources	Minerals in Volcanic & Sedimentary Resources
Salar Oilfield Geothermal Ocean Waste Streams	Spodumene Petalite Amblygonite Eucryptite Lepidolite Zinnwaldite	Smectites Illites Jadarite Zabuyelite Zeolites Amorphous Silicas

Standard Lithium Announces US$100 Million Direct Investment From Koch Strategic Platforms

Strategic Investors Join Final Closing of Lilac Solutions' $150 Million Series B for Lithium Extraction Technology

VULCAN ENERGY ZERO CARBON LITHIUM™
Vulcan successfully completes A$200 million Placement to accelerate and expand its dual renewable energy and lithium development strategy

Pilbara Minerals locks in Pilgangoora solar power
October 20, 2021 News Henry Ballard

Sigma Lithium Will Be Powered by Clean Energy and The Company Will Use State-of-the-Art Water Recirculation Circuits in its Processing Combined with Dry Stacking Tailings Management.

Rio Tinto Buys $825 Million Lithium Project in Battery Push RioTinto

Source: JADE COVE PARTNERS

Sustainability | Overview

Recycling and sustainability are becoming a growing concern from a supply chain perspective.

There is fierce competition for the primary materials for batteries and the tremendous growth in gigafactories will exacerbate existing supply chain issues. This section covers below list of topics for generating a sustainable ecosystem to accompany the rapid growth of the industry:

1. **Life cycle analysis (LCA) of batteries**
2. **Greenhouse gas emissions from EV production vs ICE production**
3. **Critical materials commentary**
4. **Current recycling methods**
5. **OEM investing in recycling**
6. **Regulations by country**
7. **Regulation example: EU Battery Directive Proposal**

Sustainability | Life Cycle Assessment

As of December 2021, every major lithium producer outside of China has made a net zero commitment.

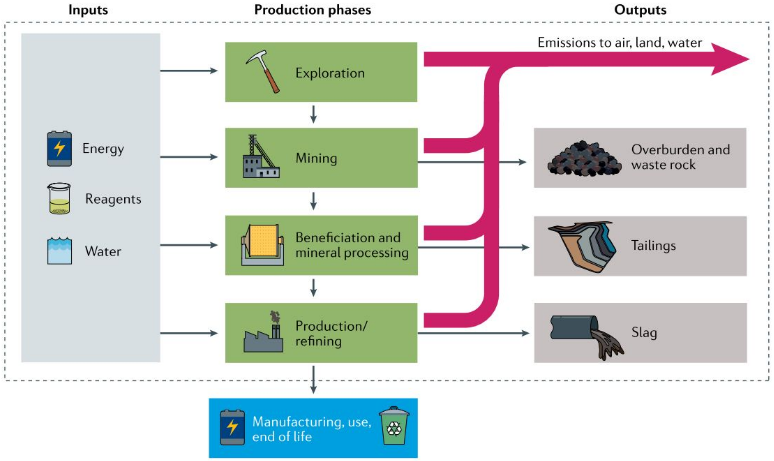
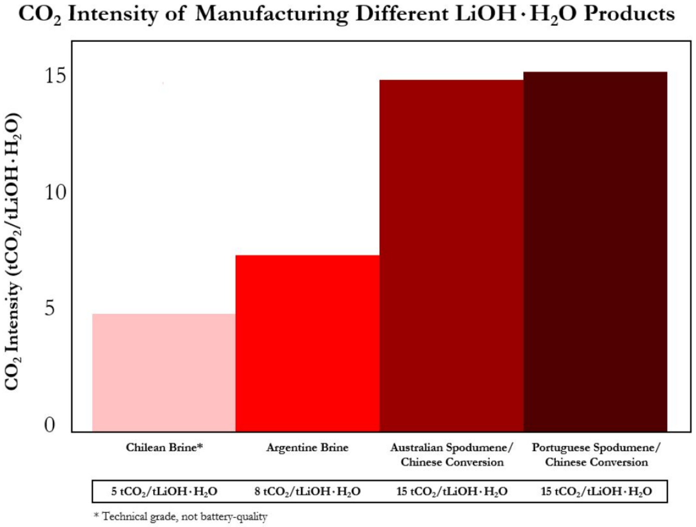


Fig. 2 | **The production phases for technology materials.** The flow diagram gives an overview of the inputs, production phases and outputs related to electric vehicle production. Emissions could include greenhouse gas emissions, pollutants and toxic substances[174]. Figure adapted with permission from REF.[174], Elsevier.



Decarbonization strategies align the battery raw materials sector with the priorities of their customers. Life Cycle Assessment (LCA) is the scientific methodology used for quantifying the environmental impacts of mining on climate, water, and land. Minviro published the first LCA of a lithium-ion cell using modern LCA data on energy and raw materials, which demonstrated that selecting materials suppliers with low emissions is the industry's most important lever for mitigating the embodied emissions of energy storage.

Source: Pell, R., Tijsseling, L., Goodenough, K. et al.

MINVIRO

Sustainability | Life Cycle Assessment

Decarbonizing all battery raw materials is critical as both the cathode and anode drive mining impacts

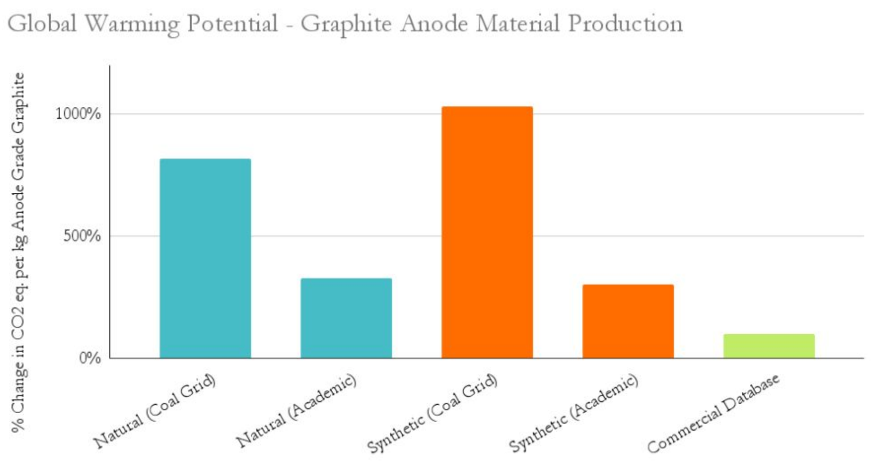
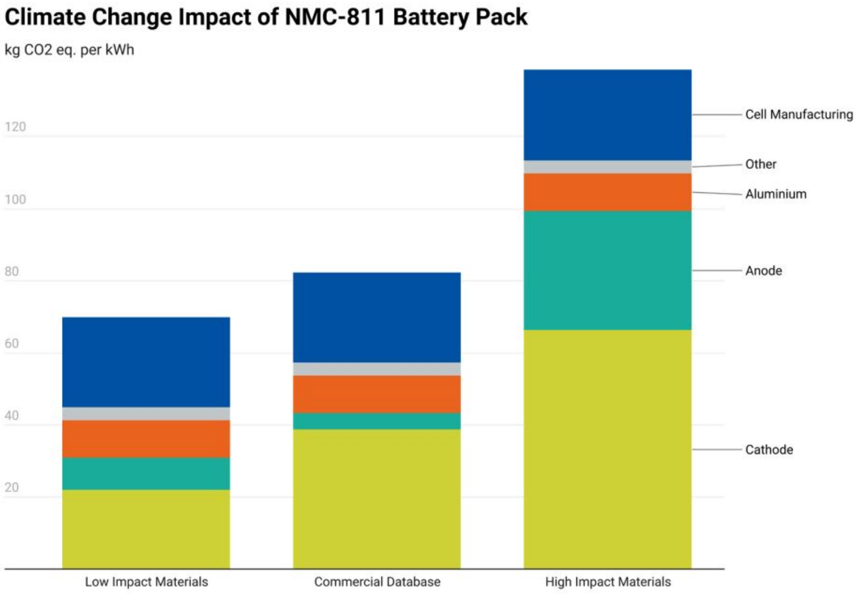


Figure 2. Percentage change in Global Warming Potential (GWP) for various battery-grade graphite LCA data points, normalised to a database value. Includes the two new calculations conducted for this study (natural and synthetic routes for coal-based grid mixes), natural academic data, synthetic academic data and a battery-grade graphite entry in a commercial LCA database.



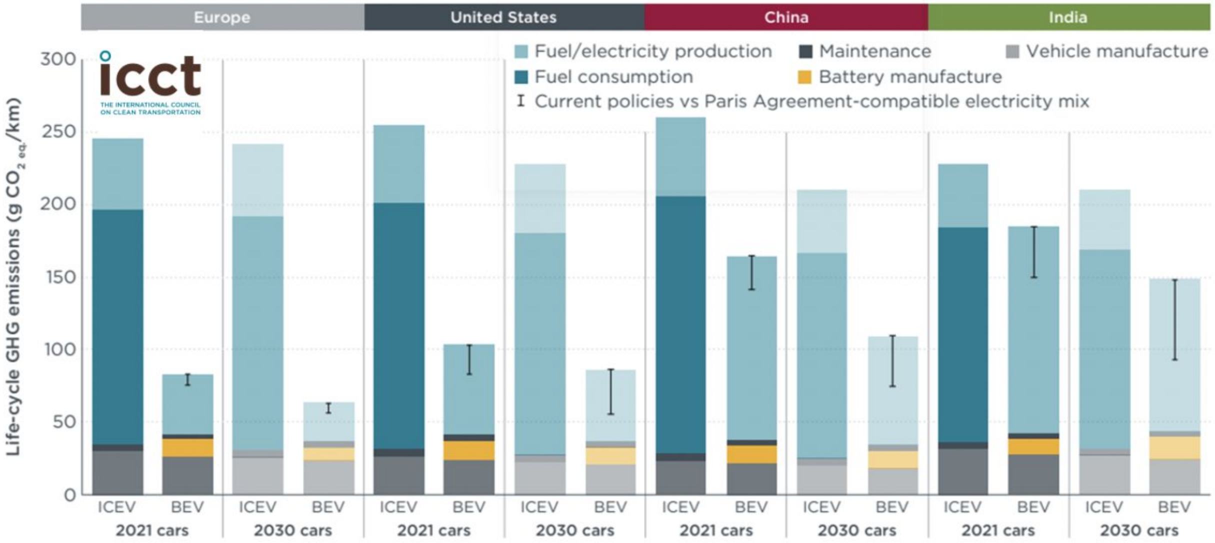
Decarbonization strategies apply to all battery materials. New innovators and incumbent producers innovate and explore novel methods for low-impact manufacturing across all raw materials. This includes the integration of renewable electricity and heat into chemical and mining processes and, in some cases, the complete overhaul of process technologies.

Source: Pell, R., Tijsseling, L., Goodenough, K. et al.

MINVIRO

Sustainability | GHG Emissions

Greenhouse gas (GHG) emissions from EV vs ICE production



Raw material refining and battery production are carbon intensive processes, in addition to producing other pollutants. Carbon emissions from battery production have decreased in recent years.

EVs contribute no tailpipe GHG emissions, but they initially have a higher carbon footprint after production than ICE vehicles due to battery pack manufacturing (they may also continue polluting depending on the energy grid used to charge them). This initial carbon deficit from manufacturing takes several thousand vehicle-miles/year of ownership to overcome. The good news: GHG emissions from battery production have decreased over the past decade due to efficiencies from producing at larger scales and the introduction of more renewable energy sources on global energy grids.

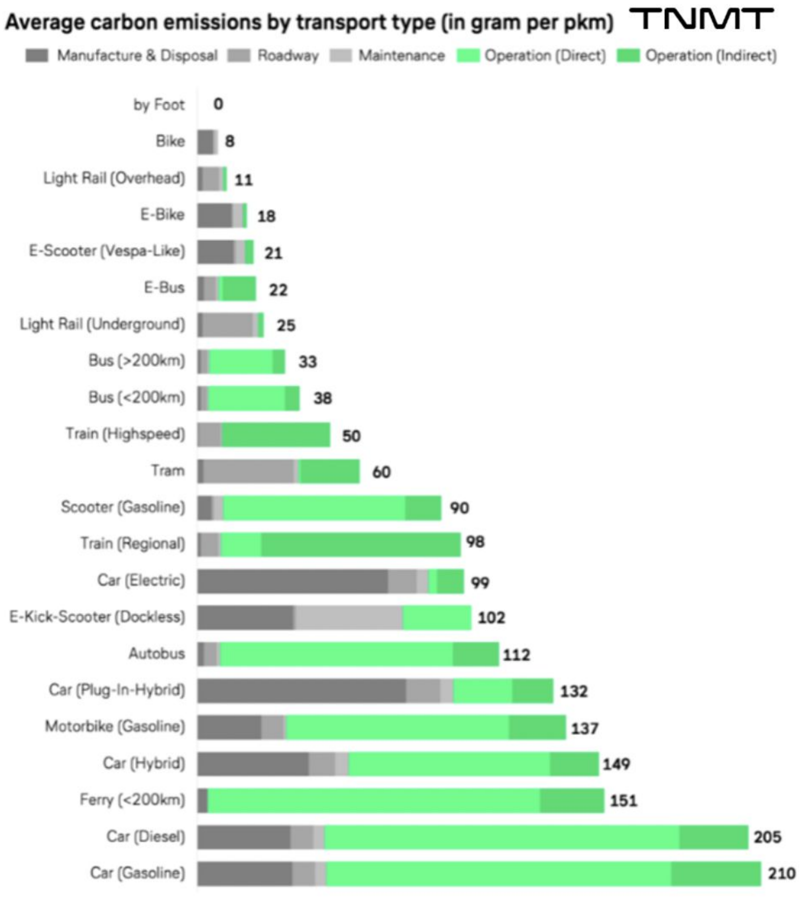
Sustainability | GHG Emissions

Alternatives to single occupant EVs

Luxury EVs helped usher in the current EV boom. However, they have non-negligible GHG emissions which are directly correlated to the size their battery packs. In addition, there is not enough nickel, cobalt, or lithium in the world for every car-owner to drive a high-range luxury EV.

It may be worth considering adopting alternative modes of transportation which are less carbon intensive and more efficient than EVs, such as "micro EVs", electric buses, e-bikes and e-scooters.

EVs are not the only application of lithium-ion batteries. The electrification of buses and bicycles can have a greater impact on reducing GHG emissions while using fewer valuable materials.



Sources: Lufthansa Innovation Hub Analysis, TNMT.com, press and various research studies — see extra Airtable

Sustainability | Ethics

Critical metals: The human cost

Labor abuses in the Democratic Republic of the Congo – where over half the world's supply of cobalt is mined – are well-documented and widely reported (see Amnesty International's landmark 2016 report). While many industry-led initiatives have formed in recent years to tackle the issue, human rights groups are skeptical of their impact. Additionally, the dangers posed to miners and their communities due to the extraction of other battery commodities are less widely known. Nickel, graphite, and lithium mining all carry with them health, safety, and environmental risks.

EU's proposed Battery Regulation legislation includes a series of due diligence rules which require battery manufacturers to limit human rights abuses and environmental damage in their supply chains (rules which Amnesty International believes can go further).

"After cobalt was discovered beneath one neighborhood, Congolese began digging under their houses." From the New Yorker, Illustration by Pola Maneli

The "gold rush" surrounding battery material mining and the unsafe conditions that follow from it are a direct result of booming EV demand and production. Automakers, battery manufacturers, and governments must address this negative impact to ensure EVs are truly green.

Sustainability | Recycling

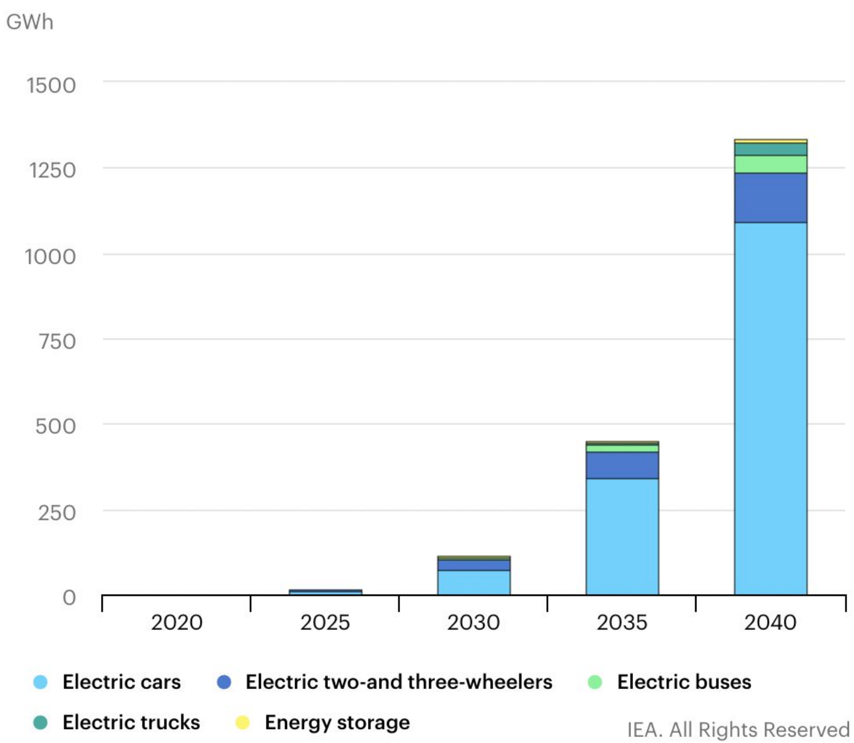
The battery waste problem

The projected volume of end-of-life (EoL) battery waste is set to increase with skyrocketing EV production. Even accounting for second-hand use, millions of tonnes worth of batteries (on the order of 1 TWh) will be scrapped annually between 2030 and 2040.

Used batteries present an opportunity as manufacturers require access to elements and materials for key components: recycled batteries from electric vehicles will provide a valuable secondary source of materials. Recyclers primarily target metals in the cathode, such as cobalt and nickel, that fetch high prices. Recycling offers an opportunity to both redirect this waste from landfills and to supply an increasingly resource-starved industry with valuable battery materials.

Government grants and subsidies are an important element of regulation and help incentivize recycling.

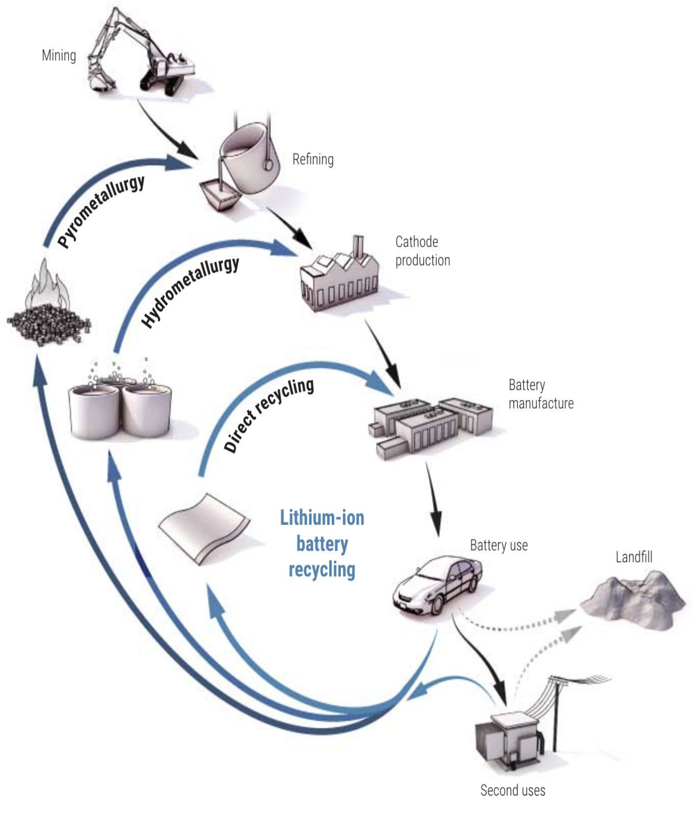
Amount of spent lithium-ion batteries from electric vehicles and storage in the Sustainable Development Scenario, 2020-2040



Sustainability | Recycling

An overview of the main recycling methods

Pyrometallurgy, or smelting, is the simplest and most established recycling method. It produces the highest CO_2 emissions and yield the lowest fraction of reusable battery components, prioritizing the recovery of valuable Ni and Co over Li, Mn, and Al.	ACCUREC, REDWOOD MATERIALS, NHA NICKELHÜTTE AUE, umicore, DOWA, SUMITOMO METAL MINING
Hydrometallurgy is a mature technique that relies on water to separate battery materials. It can recover most of the metals in battery electrode materials (including Li) and generates less waste than pyrometallurgy. Most hydro techniques use acid to selectively extract metals, however, startups like Nth Cycle are developing alternative methods.	ACCUREC, Li-Cycle, RETRIEV TECHNOLOGIES, NHA NICKELHÜTTE AUE, TES, 华友钴业 HUAYOU COBALT, SOLVAY, 邦普循环 BRUNP RECYCLING, umicore, NTH CYCLE, GEM, SungEel HiTech, DOWA, ASCEND ELEMENTS, REDWOOD MATERIALS, Duesenfeld
Direct recycling is the careful separation and removal of electrolyte, binders, and anodes separation to yield cathode powder for re-use in new batteries. It represents the greatest opportunity for retaining the intrinsic value of valuable cathode materials while minimizing waste. Direct recycling is still in its early stages of development.	KYBURZ, ERLOS Produktion und Montagen GmbH, Recell®, ReLiB REUSE & RECYCLING OF LITHIUM ION BATTERIES, OnTo Technology LLC



C. BICKEL/SCIENCE

Source: I. Morse and Bickel C.

Sustainability | Recycling

OEMs bring recycling in-house

While startups dominate the headlines for recycling, automakers and battery manufacturers have announced plans to establish their own recycling facilities. Vertical integration of manufacturing and recycling helps OEMs ensure a supply of increasingly expensive battery commodities. OEMs are also well-suited to accept their own EoL battery packs as they know their exact composition and dismantling procedure. Selected news below:

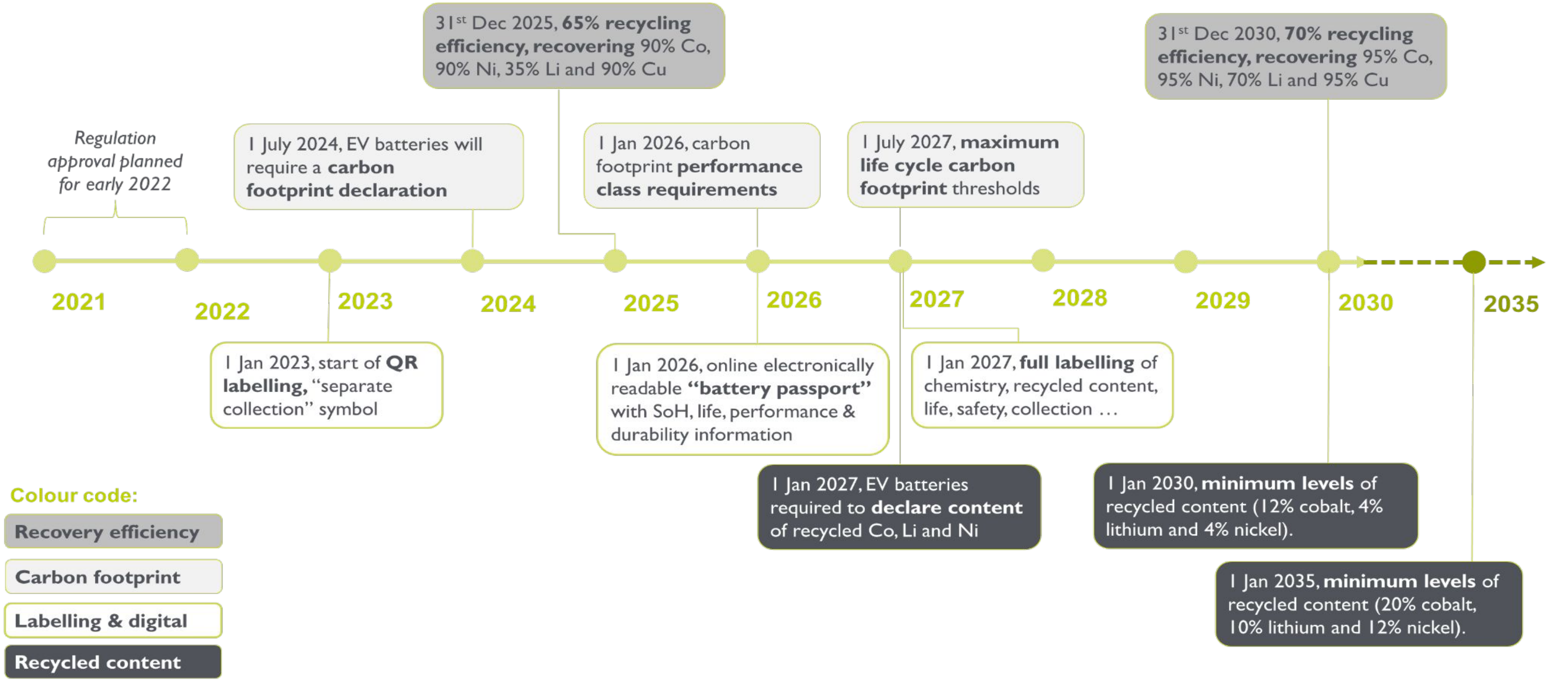
- **CATL** has announced a joint venture with Hubei Yihua Chemical Industry Co to build a $5 billion recycling facility in China. This is in addition to a planned European cathode recycling plant in partnership with BASF.
- **SK Innovations** is planning to build a major recycling facility attached to one of its international plants following internal development of recycling processes. The company is also partnered with Kia to provide closed-loop recycling.
- **Volkswagen** claims to be building recycling capabilities into their Salzgitter plant.
- **Northvolt**, a close partner of VW, has built an R&D centre in Sweden with considerable focus on battery recycling. The company claims to have built proof-of-concept batteries from 100% recycled NMC.
- **Renault** has entered into a consortium with Solvay and Veolia to develop a closed-loop battery recycling process.
- **Tesla** claims to have developed the first-phase of an onsite battery recycling facility at their Gigafactory Nevada site.

OEMs may localize recycling facilities wherever they have production. This can mean recycling facilities in multiple regions (North America, Europe, and Asia). Strategic placement of facilities allows OEMs to maintain a stable supply of battery materials.

Sustainability | Recycling

EU Battery Directive Proposal

In December 2020, the EU published its proposal for a new Sustainable Batteries Regulation to create a legal framework on the sustainability, traceability and circularity of battery production throughout a product's life cycle.

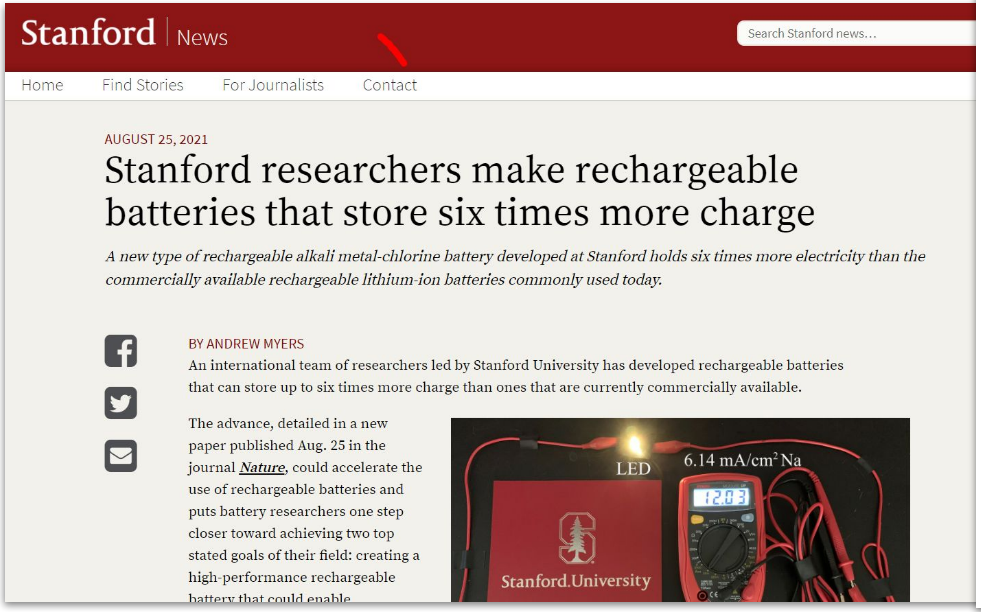


Source: ADVANCED PROPULSION CENTRE UK

Media | Accurate Reporting

The press frequently overstates “breakthroughs” and “next generation” technologies, which can send incorrect signals to industry.

We hope to see more journalists reaching out to battery experts to verify claims or explain details realistically, and focus on accurate reporting as opposed to optimizing for clicks.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AUGUST 25, 2021

Stanford researchers make rechargeable batteries that store six times more charge

A new type of rechargeable alkali metal-chlorine battery developed at Stanford holds six times more electricity than the commercially available rechargeable lithium-ion batteries commonly used today.

BY ANDREW MYERS

An international team of researchers led by Stanford University has developed rechargeable batteries that can store up to six times more charge than ones that are currently commercially available.

The advance, detailed in a new paper published Aug. 25 in the journal *Nature*, could accelerate the use of rechargeable batteries and puts battery researchers one step closer toward achieving two top stated goals of their field: creating a high-performance rechargeable battery that could enable


SCIENCE & TECHNOLOGY

Battery breakthrough for electric cars

Harvard researchers design long-lasting, stable, solid-state lithium battery to fix 40-year problem

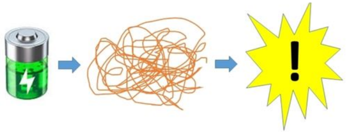
Media | Accurate Reporting

Here are some “tricks” that scientists will use in their publications that readers should be aware of.

The overinflation of results in academic writing has prompted the scientific community to help readers navigate and avoid pitfalls when reading battery research.

Ten Ways to Fool the Masses When Presenting Battery Research**

Patrik Johansson,*[a, b, c] Sajid Alvi,[a] Pedram Ghorbanzade,[a] Martin Karlsmo,[a] Laura Loaiza,[a] Vigneshwaran Thangavel,[a] Kasper Westman,[a, d] and Fabian Årén[a, c]



1. Always compare your results against the state-of-the-art from 2010
2. Use only chemical reactions for the energy density
3. Quote cost only in terms of the raw materials used
4. Carefully choose your cycling conditions
5. Quietly change the procedure, layout or materials composition
6. Play the game of loadings and ratios
7. Never do proper characterisation of your (promising) materials
8. Anything can be solid-state, right?
9. Errors? – not here
10. If all else fails, show pretty pictures and videos

Source: Johansson P., Alvi S., Ghorbanzade P., et al.

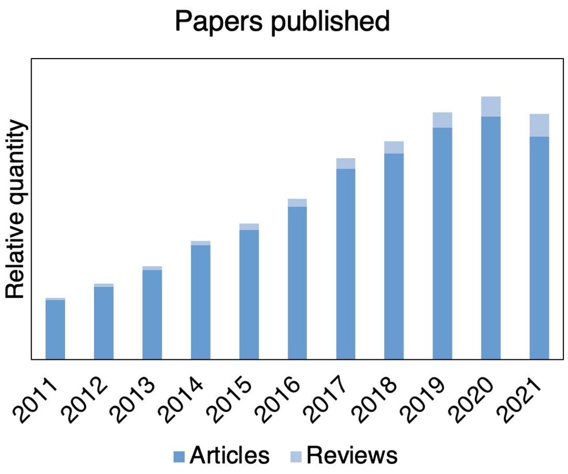
Section 2
Research

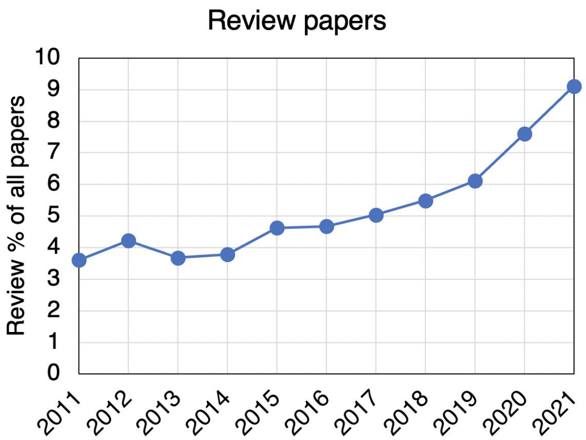
Overview | Popular Topics in Academic Research

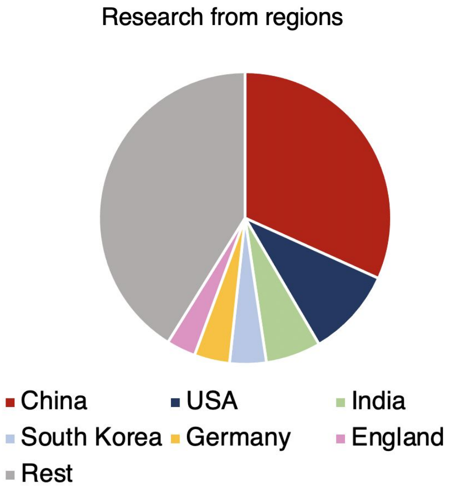
We identified some of the most interesting and noteworthy research papers we have seen this year from the following fields:

Cathode	Anode	Electrolyte
Solid-State	Characterization	Recycling
AI	Modeling	Diagnosis
Pack Design	Cost	Policy

Overview | Trends in the Research Community







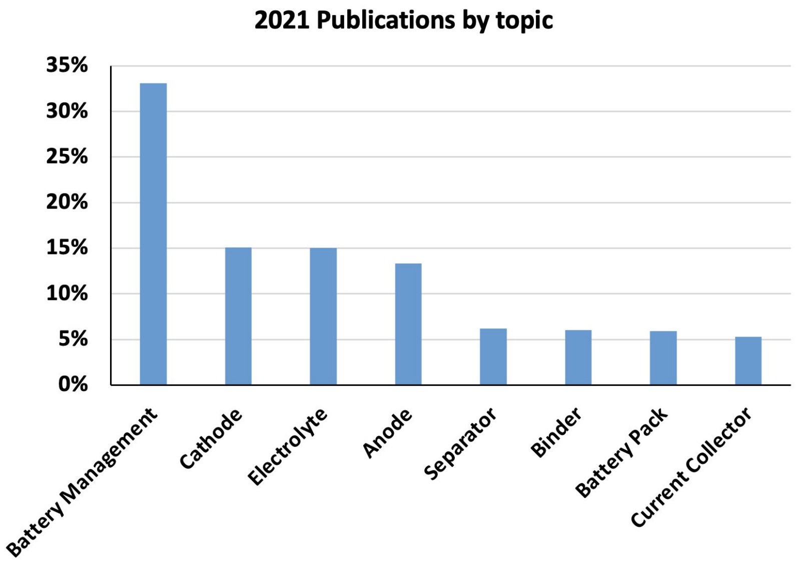
- Publishing eased off in 2021
- Total energy storage papers **down year-on-year**, likely impacted by pandemic

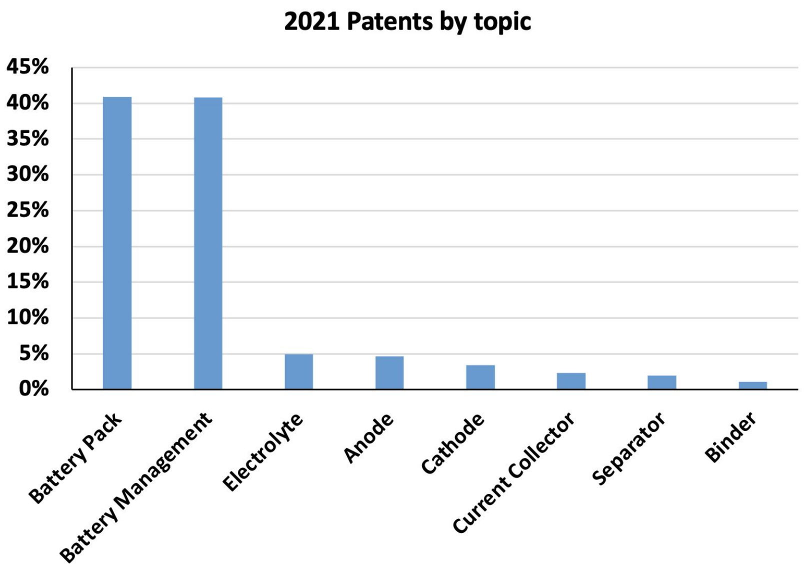
- Reviews made up 10% of all research publications
- Scientists are doing **less original research**

- China continues to dominate in number of articles published on batteries

Source: Web of Science

Overview | Battery Management Receives More Attention





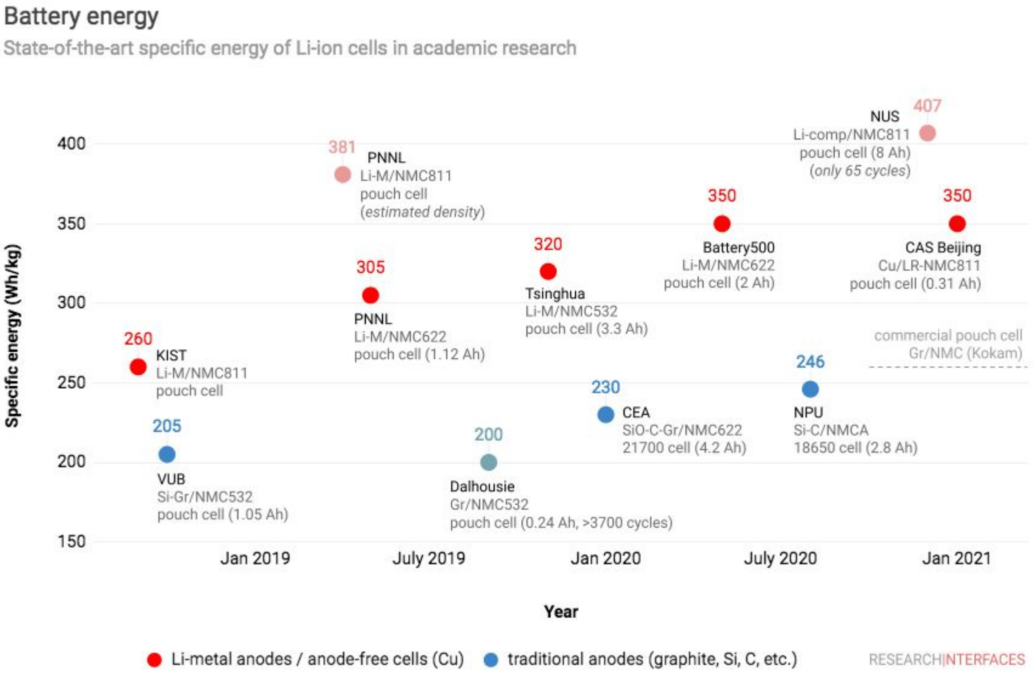
- Research gravitated towards **battery management** systems in 2021
- Combined **electrode and electrolyte** publications show overall materials focus in academia

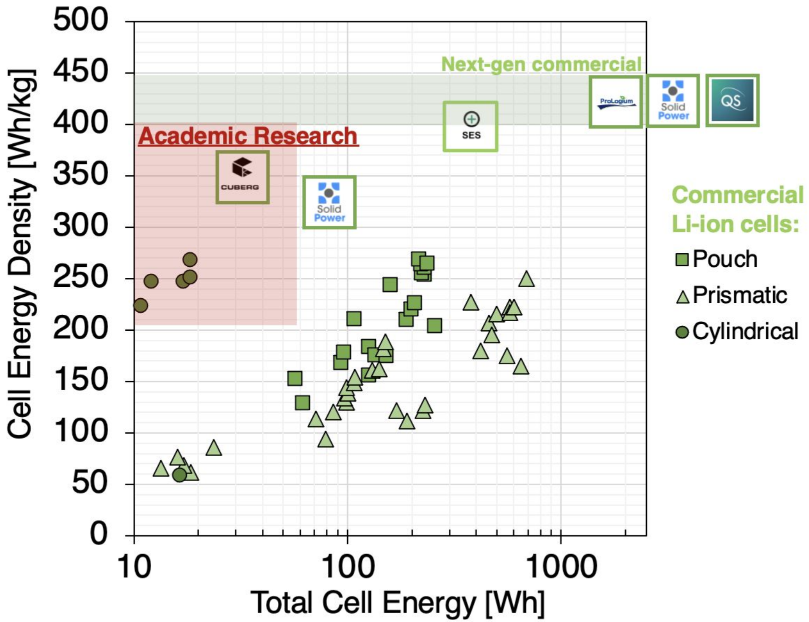
- Primary focus in industry remains on systems-level innovations, with patents on **battery packs** and **battery management** dominating

Source: Google Scholar, Google Patents

Overview | State-of-the-Art Academic Research

- The best academic cells are currently **sub-10 Ah** and **50 Wh** in total size.
- Achieved energy densities fall short of 2025-2030 industry targets (350 Wh/kg at cell level).





Source: Research Interfaces, Intercalation

Research | Fundamentals

	Confirmed	N/A	Additional comments
Battery assembly	☑	☑	
Design of cell structure (e.g., 2032-coin cell, 3 cm * 5 cm pouch type cell, or others)			
The relative weights of the active materials, conducting agent, and binder in an electrode			
The loading level of the active material (mg/cm^2) in the electrode			
The capacity balance between the cathode and anode (N/P) in a full cell			
Lithium metal thickness and size (lithium metal cells)			
Composition of electrolyte and details of additives			
The amount the electrolyte and the ratio of electrolyte to active material.			
Specifications of used materials (amount in grams, purity, concentration, vendor, etc.)			
Evaluation of electrochemical performance	☑	☑	
Type of cell (half or full cells) used for the electrochemical tests			
Number of the stacked electrodes and the corresponding total capacity (full cells)			
Cell capacity (mAh) or areal capacity (mAh/cm^2)			
Theoretical capacity to determine C-rate and C-rate for each electrochemical test			
The range of the operating voltage			
The ambient temperature during electrochemical evaluations			
Specified C-rate for each electrochemical test			
First cycle or initial pre-cycling conditions and electrochemical data			
Initial charge–discharge Ah efficiency and the capacity evaluated at a low C-rate (e.g., 0.1 C)			
Pressure applied to the cell (if additional pressure is applied during cycling)			
Method of calculation of energy density (material, electrode, cell, pack level, etc.)			
Electrochemical testing procedures and CC/CV mode			

The battery research community is developing tools to enable better collaboration, with more transparency and accountability. Key examples:

- An Experimental Checklist for Reporting Battery Performances
- Ten Ways to Fool the Masses When Presenting Battery Research
- A Minimal Information Set To Enable Verifiable Theoretical Battery Research
- Data & code availability: BatteryArchive, LiionDB, PyBaMM.

Journals continue to encourage best practices in battery research. For example, ACS Energy Letters has published standard protocols for redox flow batteries and a checklist for battery modelling, along with examples of completed checklists from previous articles.

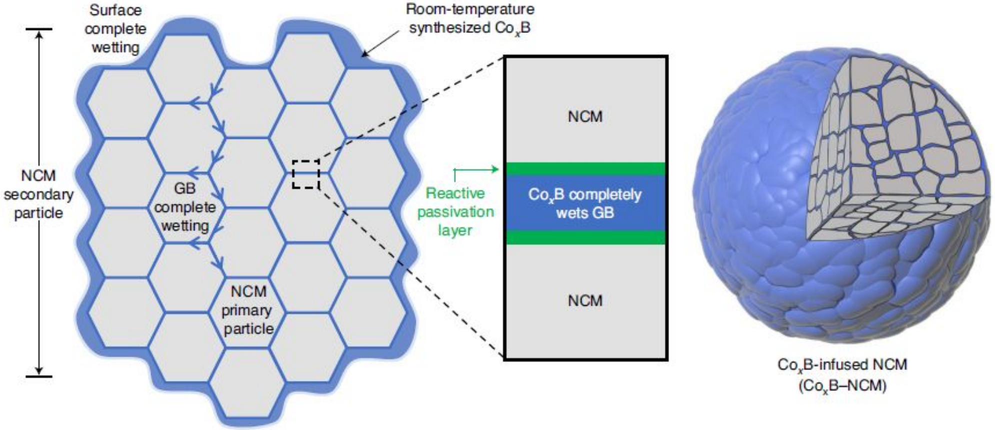
The checklists need to be concise and applicable to diverse types of battery research while offering enough structure to enable standardized reporting. A key challenge will be the widespread adoption of these checklists in new academic publications.

Source: Yang-Kook Sun

Cathode | Coatings to Stabilize Ni-rich Cathodes

Researchers from MIT have demonstrated a simple liquid-solution method to construct a high quality coating of cobalt boride via reactive wetting with the oxide active material.

A coating-plus-infusion strategy was used to achieve full surface coverage of secondary particles and facile infusion into grain boundaries. Data showed improvement in rate capability and cycling stability, including under high discharge rate (7 C) and elevated temperature conditions (45 °C) in full-cell pouch cells.



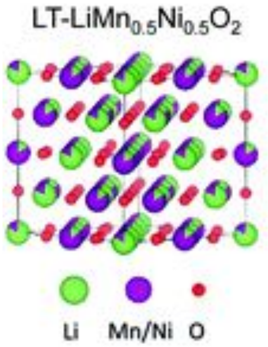
The superior performance originates from a simultaneous suppression of the microstructural degradation of intergranular cracking and of side reactions with the electrolyte. Data also shows that boron infusion treatment improves safety and can help delay the occurrence of thermal runaway and reduce the total heat released.

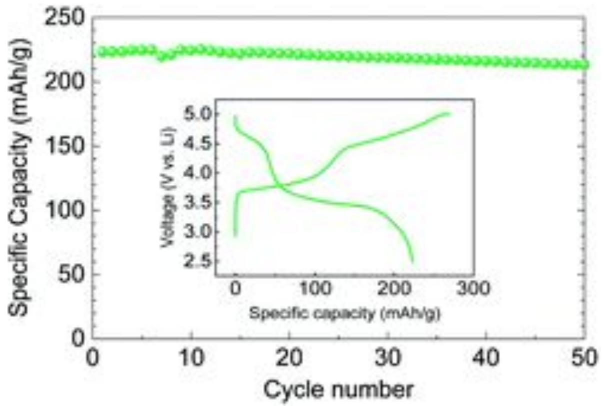
Source: Yoon M., Dong Y., Hwang J. et al.,

Cathode | Co-free Cathode for High Energy Li-ion Cells

Researchers from Argonne National Laboratory and Pacific Northwest National Laboratory have worked on the cobalt-free cathode $LiMn_{0.5}Ni_{0.5}O_2$ with a lithiated-spinel- and layered-like structure.

The material is synthesized at a low temperature of 400 °C with an operating voltage between 2.5 and 5.0V, capacity of 225 mAh/g, and an early evaluation has shown minimal degradation through 50 cycles. During charge and discharge, the unit cell volume expands only 2.7% compared to $Li_xMn_2O_4$ (16%) and $Li_xMn_{1.5}Ni_{0.5}O_4$ (12%).



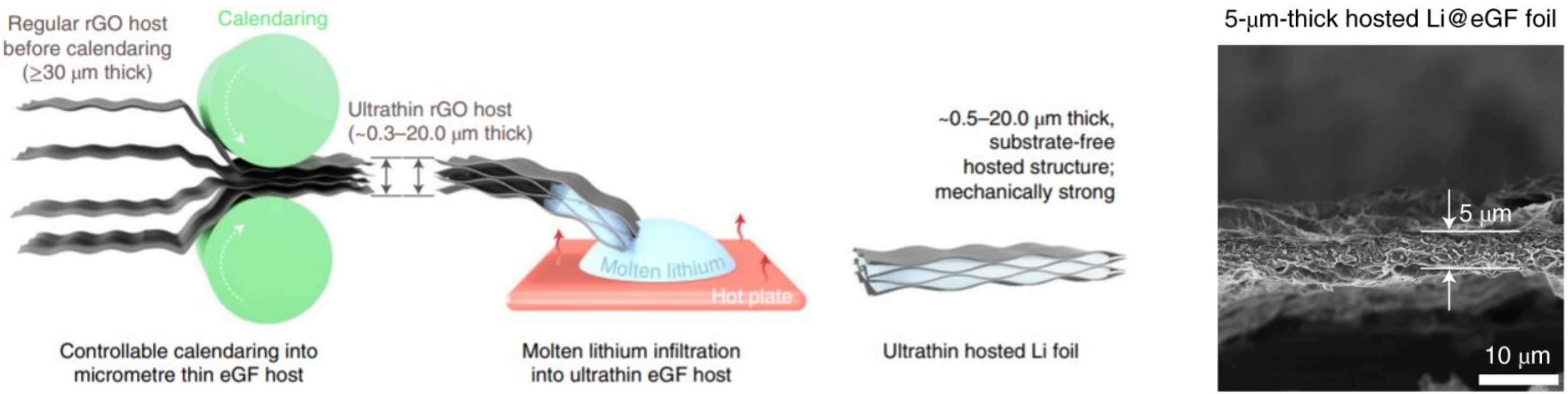


The demonstration of cathode materials without cobalt having promising performance, due to the small change in the volume of the unit cell, is significant as the industry moves towards a cobalt-free future.

Source: Boyu S., Jihyeon Gim., et al.

Anode | Ultra-thin Li Metal Graphene Oxide

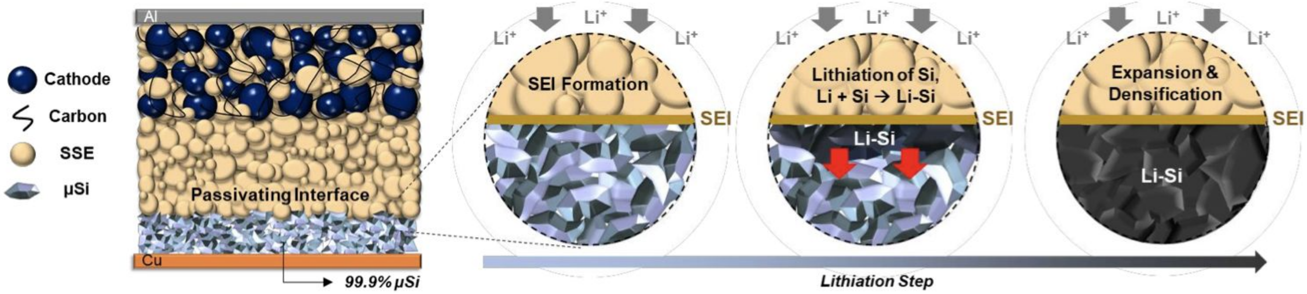
Researchers from Stanford University designed and fabricated an ultra-thin Li metal anode (minimum 0.5 μm) by infiltrating molten Li metal into a graphene oxide host. The anode is free-standing, mechanically stable, with adjustable thickness, achieving a coulombic efficiency of “close to” 100% and increasing the capacity of Li ion full cells by 8%.



Completely anode-free cells remain unavailable commercially, and novel methods to form this lithium anode may accelerate the development of lithium metal batteries.

Source: Chen, H., Yang, Y., Boyle, D.T. et al.

Anode | Carbon-free High-loading Silicon Anodes



Researchers from UC San Diego demonstrated a shift towards Si anodes in solid state batteries (SSB) due to (1) cheaper Si (2) Si with solid electrolytes (SE) bing less reactive compared to lithium metal anodes, while maintaining similar capacities (3) 10x greater capacity compared to graphite anodes. During lithiation, 99.9 wt% micro-Si is passivated by the sulfide solid electrolyte (SE) to form a solid electrolyte interface (SEI). The Li-ions at the SE/Si interface alloy with Si to form a dense Li-Si, which is highly reversible.

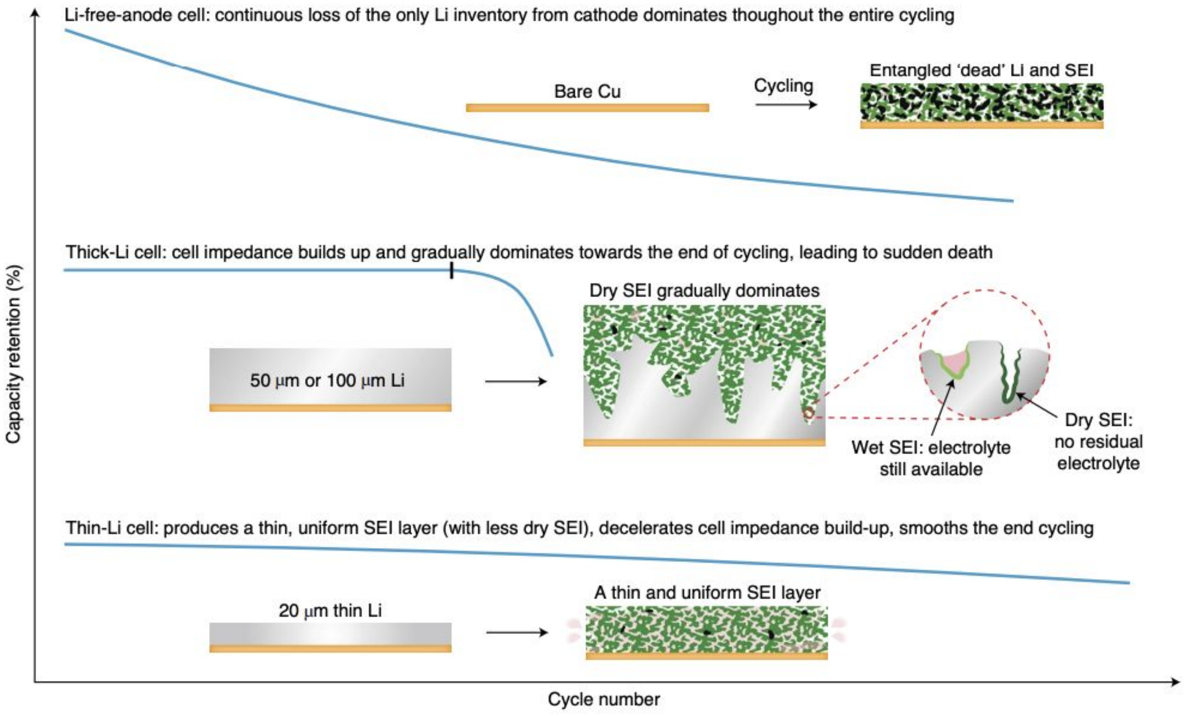
Performance achievements

- High micro-Si loading of >5 mA cm^{-2}, removal of C binders.
- High cycle life: 500 cycles with 80% capacity retention over -20 to 80 °C temperature range.

Si anode, solid-state electrolyte, and wide range operating temperature are all very challenging and highly desirable properties, and this work has achieved all of them.

Source: Tan D., Chen Y., Yang H. et al.

Anode | Optimizing Lithium Metal Anode Thickness



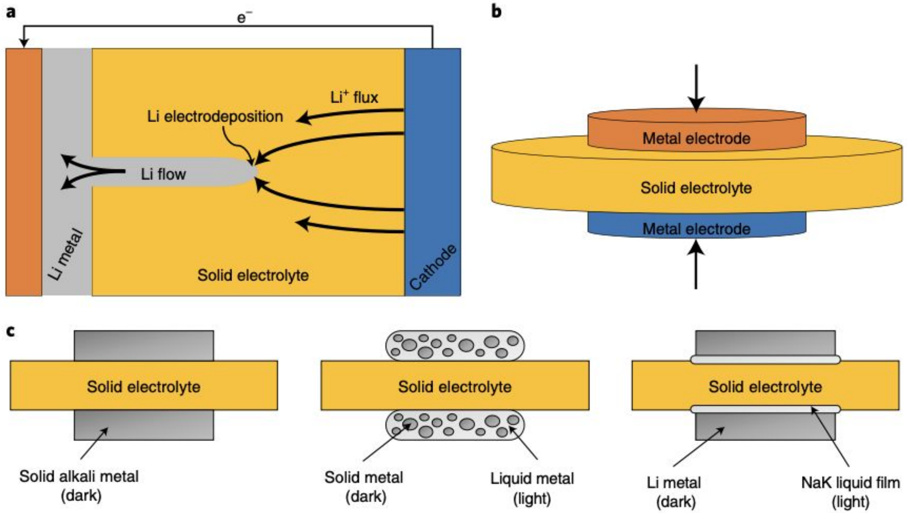
Researchers from Pacific Northwest National Laboratory published a comparison of Li-free, thick, and thin Li-metal + liquid electrolyte pouch cells. The cells, which used a LiFSI:DME:TTE electrolyte, showed that the "goldilocks" 20 um thin Li had the most stable cycling, while thick and Li-free anodes had poor lifetimes due to competing SEI effects. The best cell lasted 600 cycles with an energy density of 350 Wh/kg.

A commercially viable strategy to optimize the anode thickness in Li metal batteries.

Source: Niu, C., Liu, D., Lochala, J.A. et al.

Anode | Alkali Metal Alloy Electrodes

Researchers from MIT, Carnegie Mellon, Brown University, and Texas A&M demonstrated semi-solid alkali metal electrodes with high current densities in solid-state batteries, which used lithium alloys by combining lithium metal with an interfacial Na-K film.

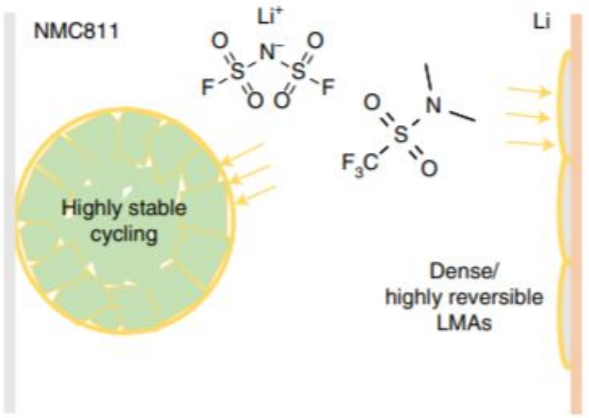


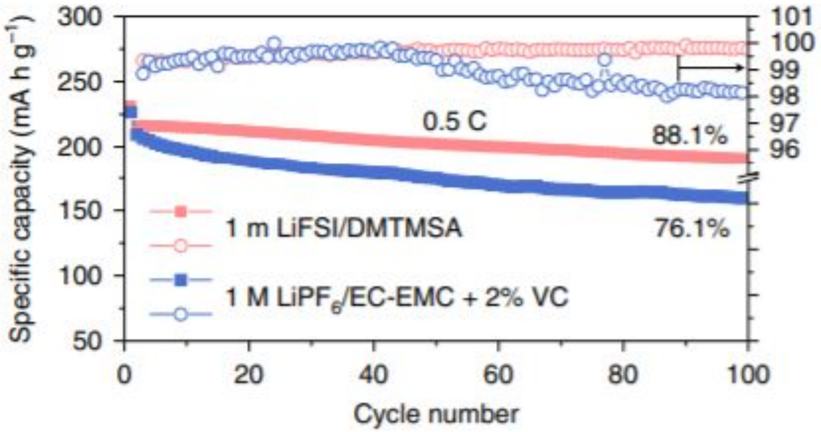
These designs show promise for improving the interfacial layer between lithium metal and the solid electrolyte, and may help overcome electrochemical and mechanical stability issues with solid-state lithium metal batteries.

Source: Park, R.JY., Eschler, C.M., Fincher, C.D. et al.

Electrolyte | Sulfonamide-based Electrolyte for Ultra-high Voltage for Ni-rich Cathodes

Researchers from MIT designed a sulfonamide-based electrolyte to increase cycling stability for cells with a Ni-rich cathodes and Li metal anode. The newly designed electrolyte enables NMC-811 cathodes to be cycled to 4.7 V by suppressing side reactions, gas evolution, transition metal (TM) dissolution, and intergranular stress corrosion cracking (SCC). It also minimizes Li metal pulverization.





This new electrolyte enables Ni-rich cathodes to be operated at dramatically higher voltage, potentially as a drop-in solution on existing manufacturing lines.

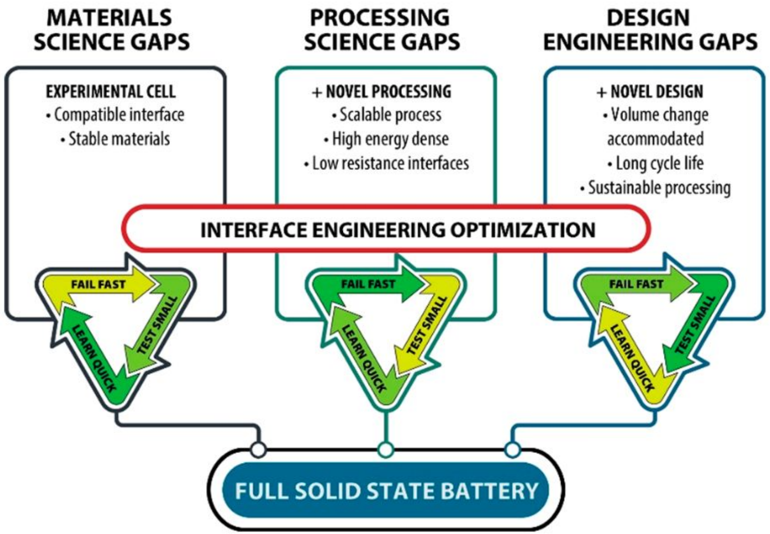
Source: Xue, W., Huang, M., Li, Y. et al.

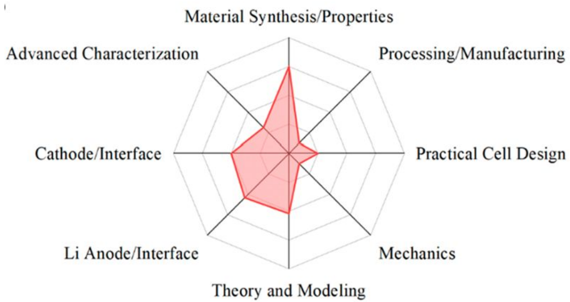
Solid-State | Pathways toward All-Solid-State Batteries

Oak Ridge National Labs (ORNL) hosted a workshop to highlight materials, processing and scale-up challenges associated with Li-metal SSBs. 30 SSB experts ranging from national labs, universities and companies were present at the workshop.

Challenges for commercialization

- Control of interface between solid electrolyte (SE) and electrode.
- Address scalability and cost challenges, potentially <$100/kWh.
- Paramount to demonstrate superior Li-ion performance, >500 Wh/kg and >1500 Wh/L targets.
- Maintain optimal stack pressure for SSB packs and reduce volumetric changes during cycling.
- Practical, scalable cell and manufacturing design and solid-state mechanics underreported in academic literature.



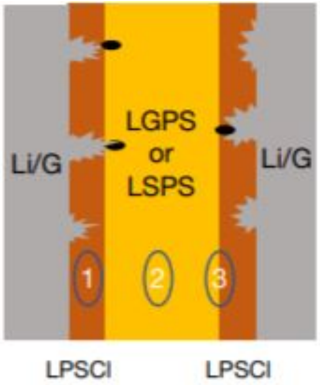


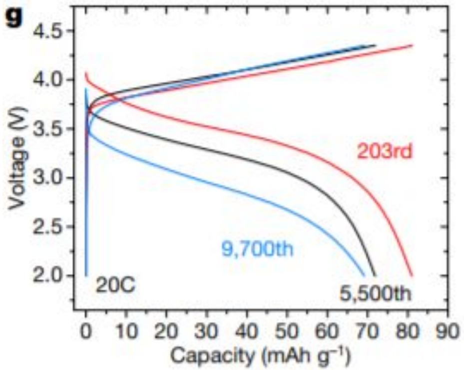
The most comprehensive must-read review* on Li metal solid state batteries this year, covering insights from academia to industry, knowledge from fundamental research to product design.

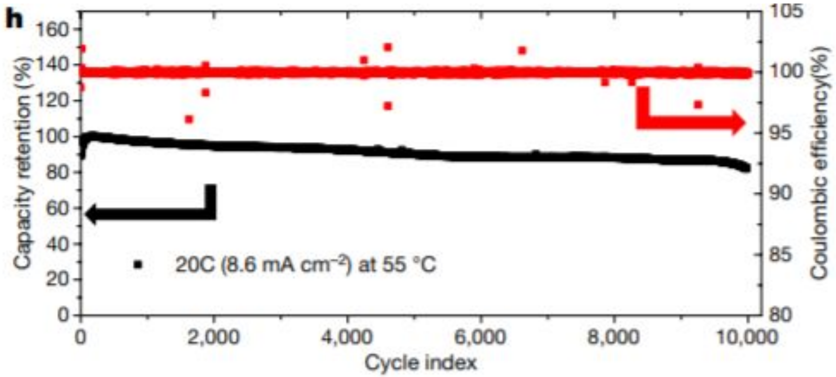
*Source: Albertus P., Anandan V., Ban C., et al.

Solid-State | Multilayer Dynamic Stability Design of Solid Electrolyte

Researchers from Harvard University designed a multilayer solid electrolyte with the feature of dynamic stability. The designed solid electrolyte prevents any lithium dendrite growth through well localized decomposition. Coupled with an NMC-811 cathode, the fabricated solid-state battery cell exhibited an extremely long cycle life under an ultra-high C rate, with an 82% capacity retention after 10000 cycles at 20C. The corresponding specific energy density can reach 631 Wh/kg.







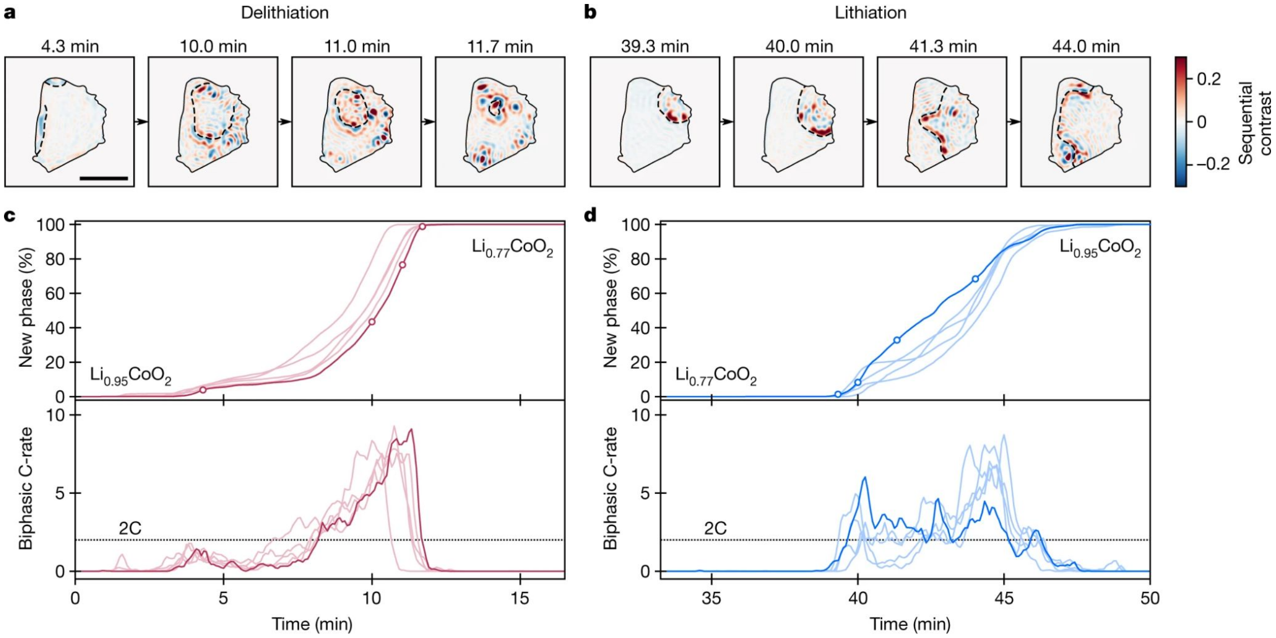
The development of a solid state cell with a lifetime of 10,000 cycles at 20C and an energy density of 631.1 Wh/kg at the same time is a striking achievement. Although this work is on the materials and cell level, the potential is huge.

Source: Ye L., Li X.

Characterization | Single Particle Ion Dynamics

Researchers from the University of Cambridge have developed a simple optical interferometric scattering microscope capable of resolving nanoscale detail within operational electrodes.

Unsurprisingly, fast charging happens quickly. This makes characterization of nanometer-level structural features during these time-scales highly challenging. This method can be applied to a variety of electrode materials and has massive potential for future studies.



Breakthroughs in 2D structural characterization now permit the lithiation and delithiation processes to be monitored and quantified throughout operation.

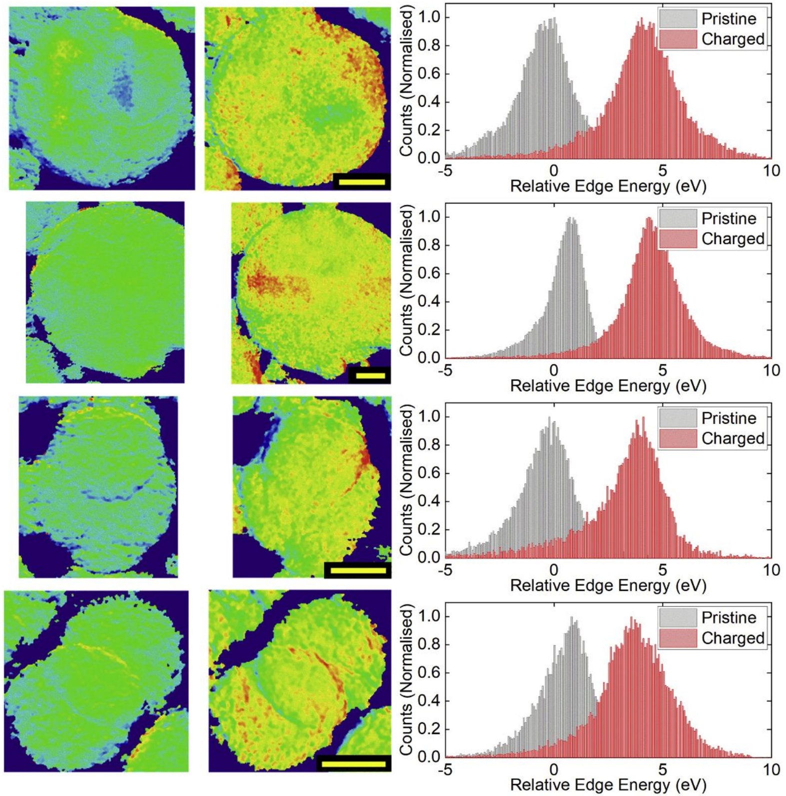
Source: Merryweather, A.J., Schnedermann, C., Jacquet, Q. et al.

Characterization | Identification of SoC in Nano Scale

Researchers from Stanford Synchrotron Radiation Lightsource (SSRL) and University College London (UCL) developed a novel sample preparation and advanced characterization method capable of quantifying the SoC of individual particles and monitor their changes throughout operation.

Synchrotrons produce high intensity X-rays allowing 4D (3D + time) studies but the lack of accessibility of these specialist facilities has driven a surge in laboratory-based systems capable of comparable image resolution (albeit with substantially longer acquisition times) that can act as a powerful complement to their synchrotron counterpart.

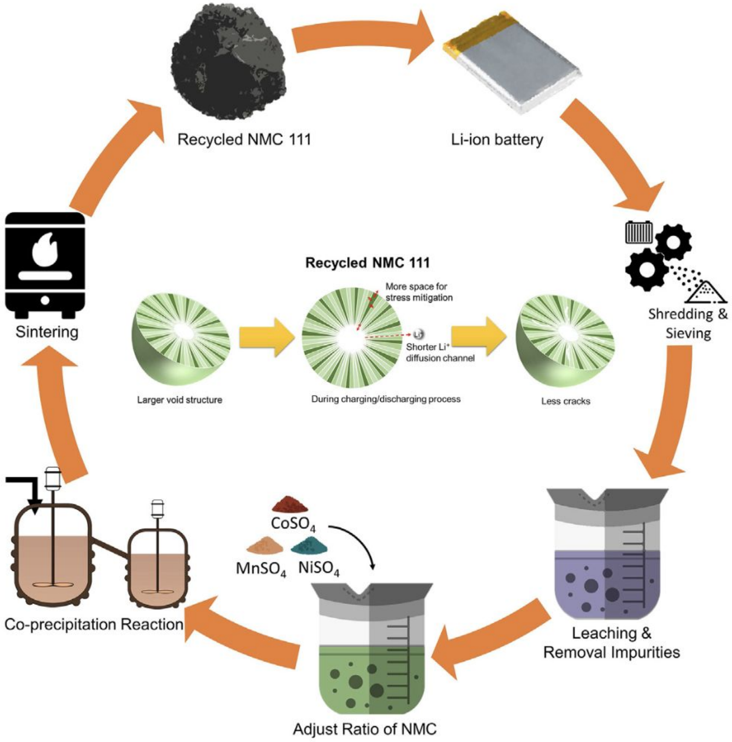
In this study, laboratory systems allowed the iterative design of a novel sample preparation technique to be accelerated and optimized before beginning time-sensitive synchrotron testing.



Breakthroughs in 4D structural characterization now permits the SoC of individual particles to be quantified and monitored throughout operation.

Source: Tan, T., Leach, A., et al.,

Recycling | Superior Performance Enabled by Recycled Materials



A collaboration between A123 and USABC has led to the development of a recycling technique for cathodes that creates a unique microstructured NMC111, which allows for the recycled material to outlast commercial materials.

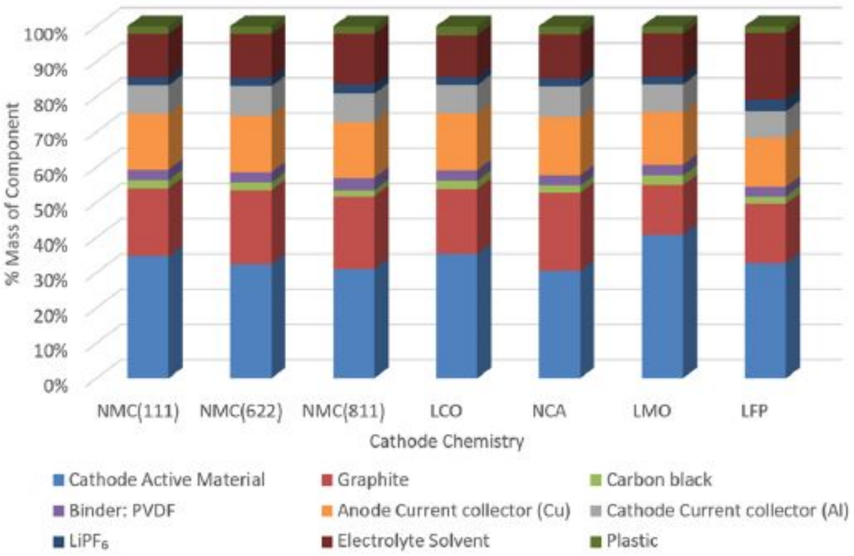
Performance achievements

- 1Ah cells with recycled NMC111 achieve 4200 cycles and 11600 cycles at 80% and 70% capacity retention, a 33% and 53% improvement compared to state-of-the-art commercial NMC111.
- Recycled materials have optimized microstructures for larger surface area, cumulative pore volume, and larger internal voids.
- This yields a higher Li chemical diffusion coefficient, mitigating the strain during cycling and leading to less phase transformation.

Producing high-performing recycled materials comparable to pristine cathode materials will be essential in driving a circular economy.

Source: Ma X., Chen M., Zheng Z., et al.

Recycling | Assessment of Battery Recycling Processes



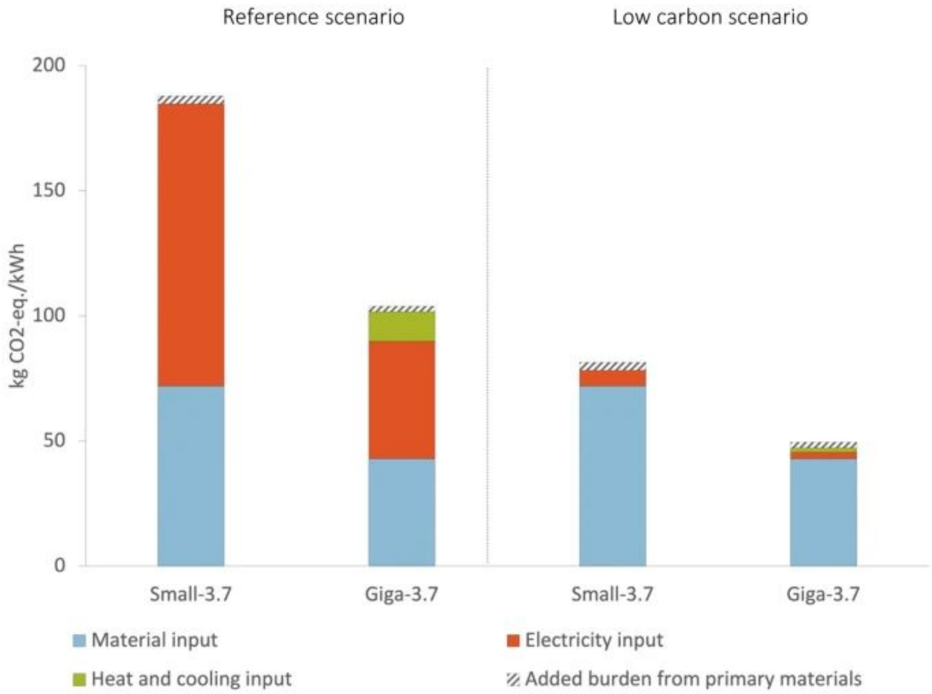
The majority of recyclers use one or more of mechanical treatment, pyrometallurgy, or hydrometallurgy, concentrating on high value metal extraction rather than closed-loop recycling of the metals or component materials, highlighting an environmental and technological gap.

Researchers from the University of Birmingham, University of Warwick, and Newcastle University proposed a novel qualitative assessment matrix termed “Strategic materials Weighting And Value Evaluation" (SWAVE) to compare the strategic importance and value of various materials in end-of-life (EoL) lithium-ion batteries.

To improve the current circular economy of batteries, reusing and repurposing materials (closed-loop recycling), instead of pure recycling or recovery of metals, need to be considered for further development.

Source: Sommerville R., Zhu P., Rajaeifar M.A., et al.

Recycling | Impact of Upscaling Battery Production



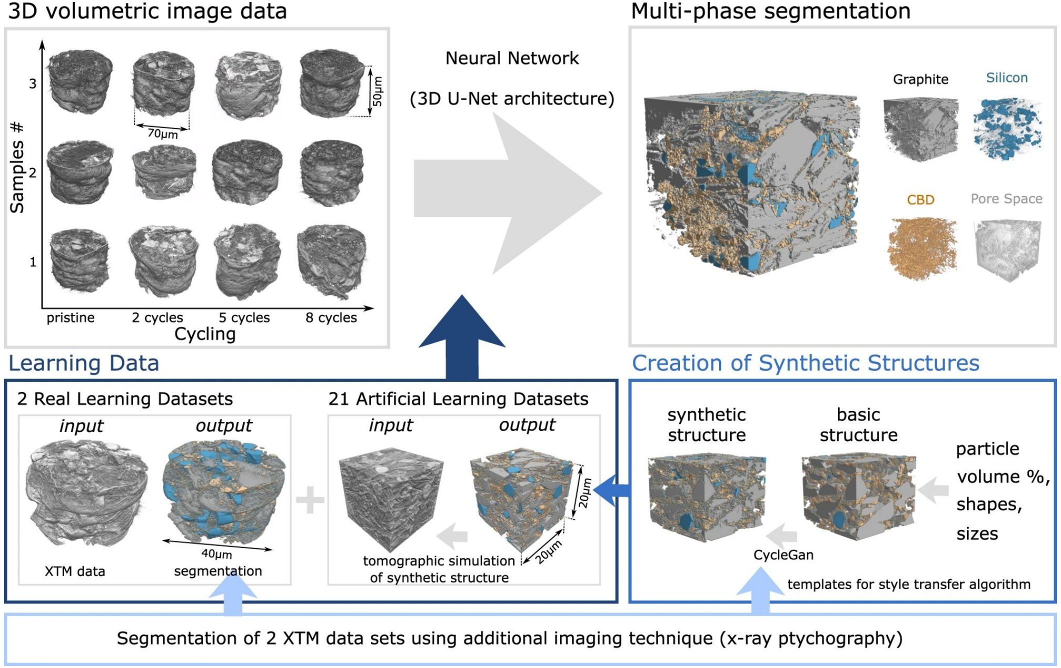
Researchers from Chalmers University of Technology and Institute of Transport Economics published a study to investigate the effect of Li-ion production scaling on environmental impacts through a Life Cycle Assessment (LCA). The paper modeled an NMC811 cylindrical cell factory and explored various carbon intensity scenarios.

- Resource use impacts are highest for active cathode materials such as nickel sulfate and cobalt sulfate.
- Upscaling reduces emissions by up to 45% though economies of scale, more if a clean energy mix is used.
- Emissions estimate of 102 vs 62 kg CO2e/kWh for cells produced in Korea vs Sweden (assume 16GWh factory).

Further reduction of emissions is possible, but the energy use of the upstream supply chain has the greatest impact.

Source: Chordia, M., Nordelöf, A. & Ellingsen, L.AW.

AI | Deep Learning to Improve Spectroscopy



Researchers from ETH Zurich and Argonne National Lab used deep learning image segmentation models to improve tomographic reconstruction of the Li-ion electrode microstructure during battery operation.

AI can act as a powerful microscope to untangle hidden data in spectroscopy, allowing for better fundamental understanding of complex electrochemical mechanisms.

Enabling reconstruction will be valuable for post-mortem analysis and characterization of battery cells to reduce overall failure rate.

Source: Müller, S., Sauter, C., Shunmugasundaram, R.

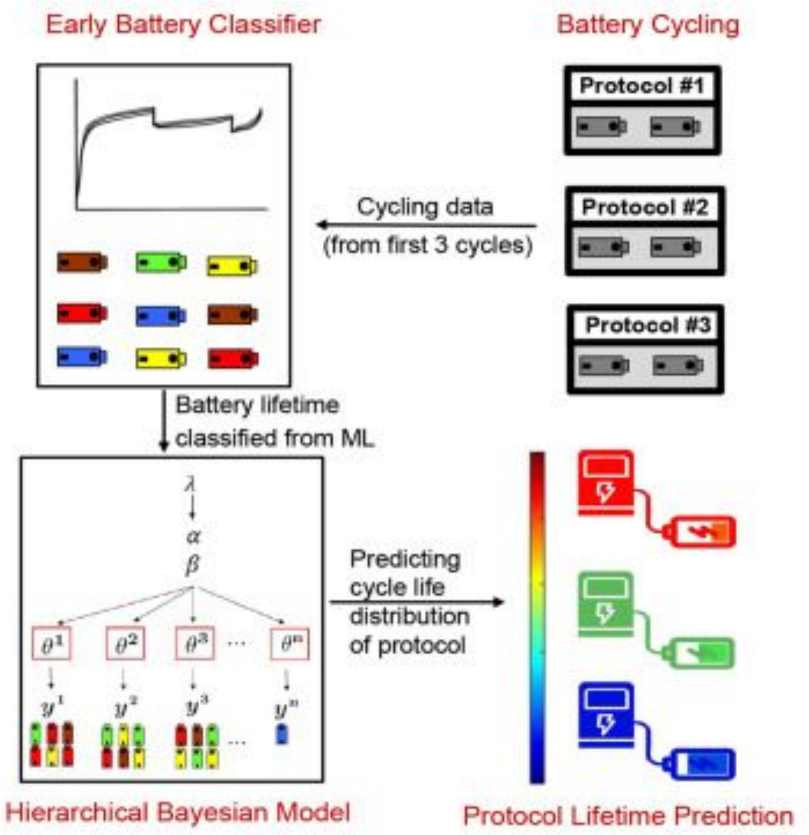
AI | Cycling Lifetime Prediction

Researchers at MIT and Stanford reduced cycling time required for prediction by another order of magnitude.

Previous work reduced cycling time from 500 to 16 days to predict cycle life. This most recent work reduces test cycling to 3-18 cycles.

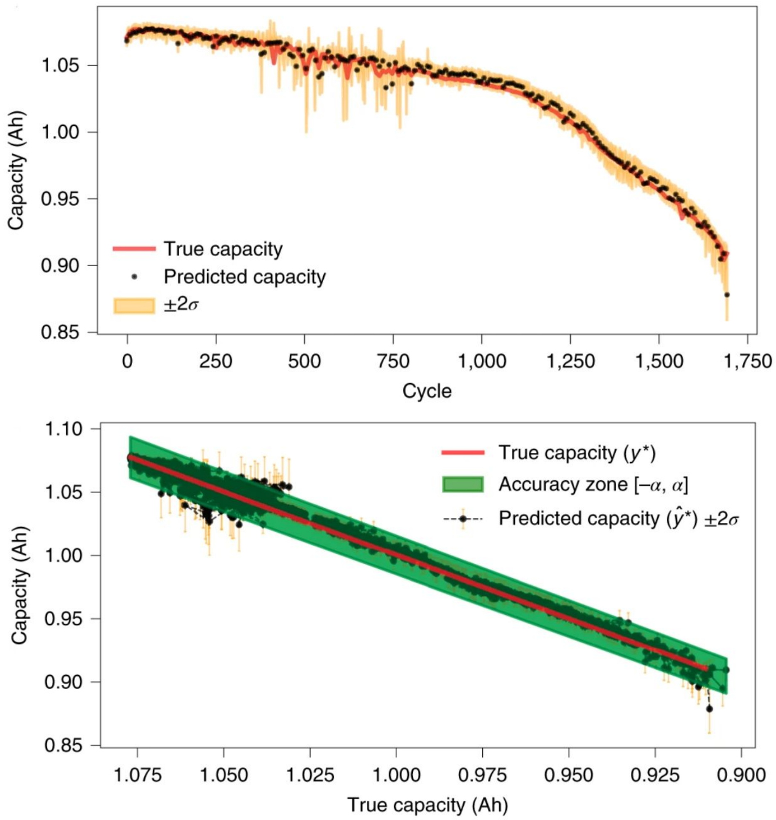
AI methods are shifting battery protocol design from theory-driven to data driven. Such optimizations can provide an important competitive advantage in industry and manufacturing.

Predicting lifetime accurately with only the first 18 cycles can speed up testing processes and allow new cell designs and chemistries to be evaluated at a faster rate.



Source: Jiang B., Gent W., Mohr F., Das S., et al.

AI | Predicting State of Health



Researchers from Heriot-Watt University, TU Delft, and University of Maryland designed and evaluated a machine learning pipeline for estimation of battery capacity fade on 179 cells cycled under various conditions. An ensemble of AI models provides probabilistic time-series predictions for state of health.

AI ensembles can generalize better to capture the complex, non-linear dynamics of battery capacity degradation. When deployed in the field, these methods have the potential to improve large-scale battery operations and management.

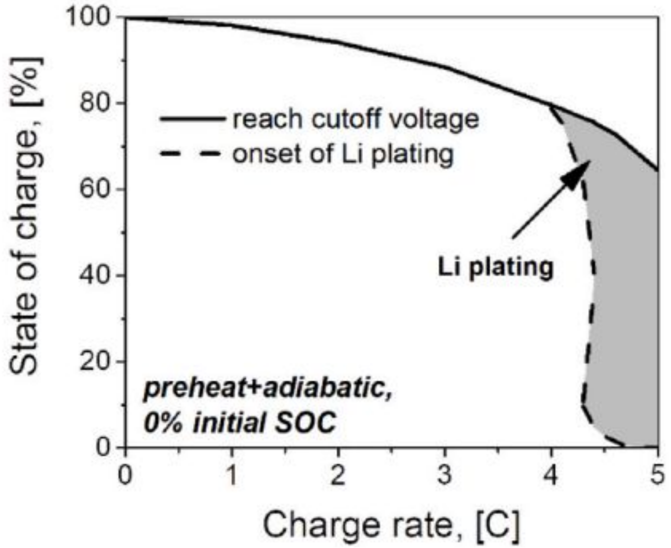
Reliable real-time estimation of battery state of health by on-board computers is crucial to safe operation of the battery, ultimately safeguarding asset integrity.

Source: Roman, D., Saxena, S., Robu, V. et al.

Modeling | Effect of Thermal Environments on Fast Charging Li-Ion Batteries

Researchers at Penn State University and EC Power evaluated the impact of various thermal environments on fast charging performance for lithium-ion batteries. Contrary to common practice, rapid pre-heating followed by conditions close to an adiabatic environment will provide an optimal combination of charge rate and cycle life.

High cooling capacity solutions are often employed in practice to maintain a specific temperature set-point. With progressively larger cells being utilized in practice, this leads to unfavorable temperature gradients within the cell. Fast charging under an adiabatic condition from a specific temperature set-point provides the greatest stability and uniformity and ultimately results in very limited exposure to elevated temperatures. The principal challenge to employing this methodology is how to rapidly pre-heat, but the authors note this has been solved in past work through the use of heaters embedded within the cell.

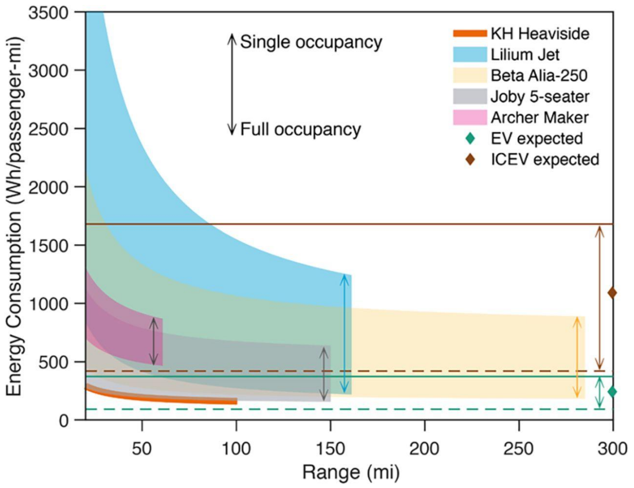


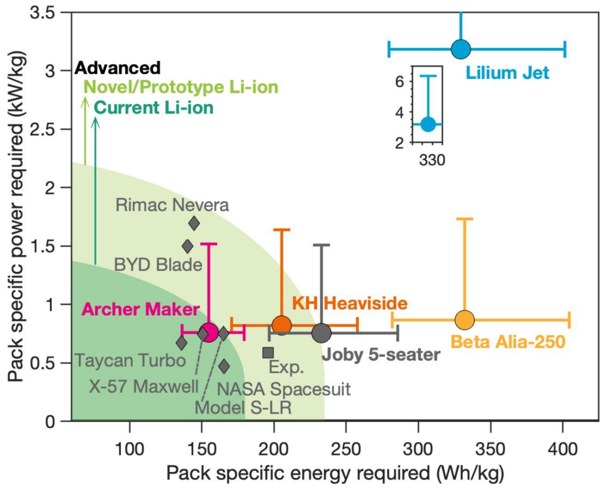
Rapid charging is a key barrier for mass market adoption. A thermally modulated cell can support fast charging performance, especially in colder climates.

Source: Liu T., Ge S., .et al.

Modeling | Energy-efficient Battery-powered Flying Cars

Researchers at Carnegie Mellon University explored the technological readiness of battery powered urban aircraft and found that several aircraft designs are reaching technically feasible regimes based on the specific power and energy of lithium-based batteries, although questions about charging and lifetime remain.

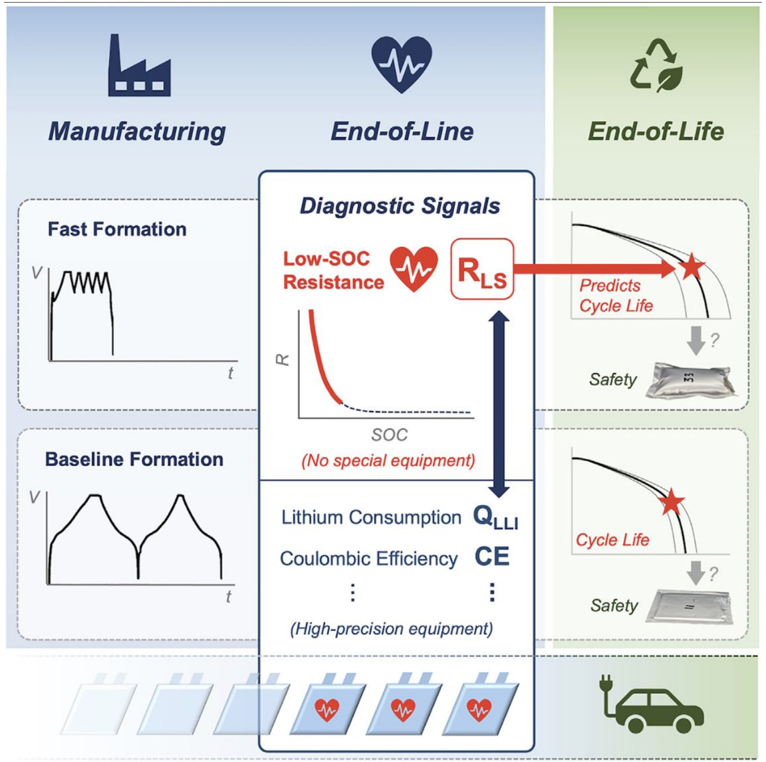




Battery powered urban electric aircraft promise a new mode of transportation for passengers and goods 2–6x faster than equivalent ground-based transportation and several aircraft designs exploiting fixed-wing cruising can be more energy efficient than ground-based EVs!

Source: S. Sripad, V. Viswanathan

Diagnosis | Evaluating Formation Protocols in Manufacturing



Formation and aging comprises a significant portion of battery manufacturing costs.

Researchers from the University of Michigan demonstrated that low state-of-charge (SOC) resistance is a good indicator of the relationship between formation protocol and cycle life.

This signal shows early-life lithium consumption during formation. The fast formation protocol can cause excessive gassing. This diagnostic has potential to be easily implemented without specialized equipment.

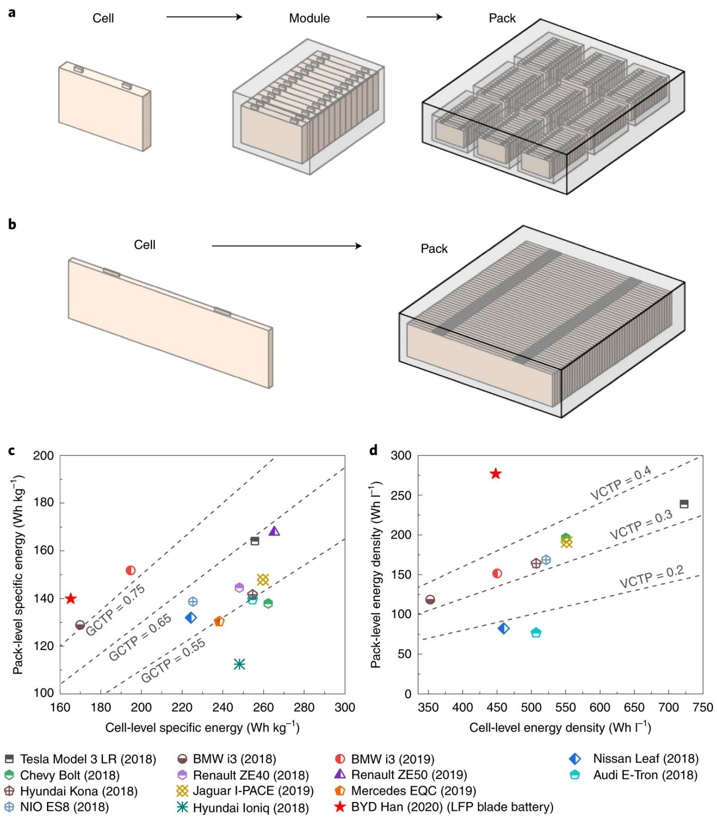
Predicting lifetime accurately can speed up manufacturing processes and improve factory yield rates, which will be key to doing “more with less”.

Source: Weng A., Mohtat P., Attia P.A., et al.

Pack Design | Thermally Modulated Cell-to-Pack LFP Battery

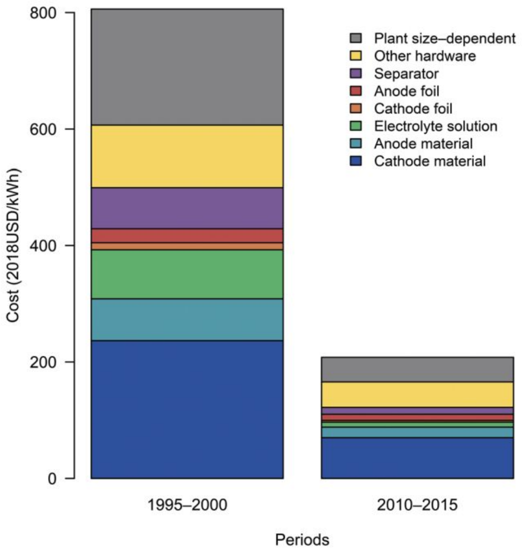
Penn State reported that a preheated cell-to-pack LFP “blade” battery can charge up to 80% SOC at 6C (10 min) and have a 2 million mile lifetime. These claims were based on simulations, meaning the battery was computationally designed with an electrochemical- thermal-model but has not (yet) completed real-world testing. Rapid pre-heating followed by near adiabatic conditions will provide a peak combination of charge rate and cycle life. The same research group has shown effective thermal modulation with heaters embedded within the cell.

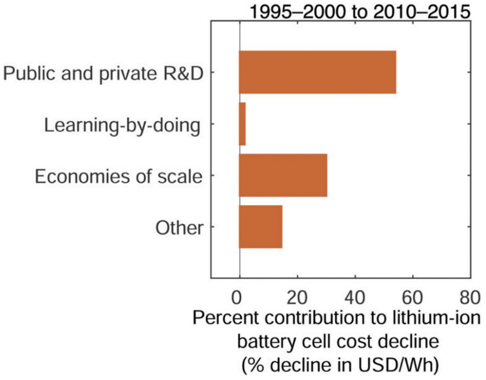
Today’s li-ion batteries have difficulty performing in low temperature environments. A thermally modulated cell can help drive adoption in mass market, especially in colder climates.

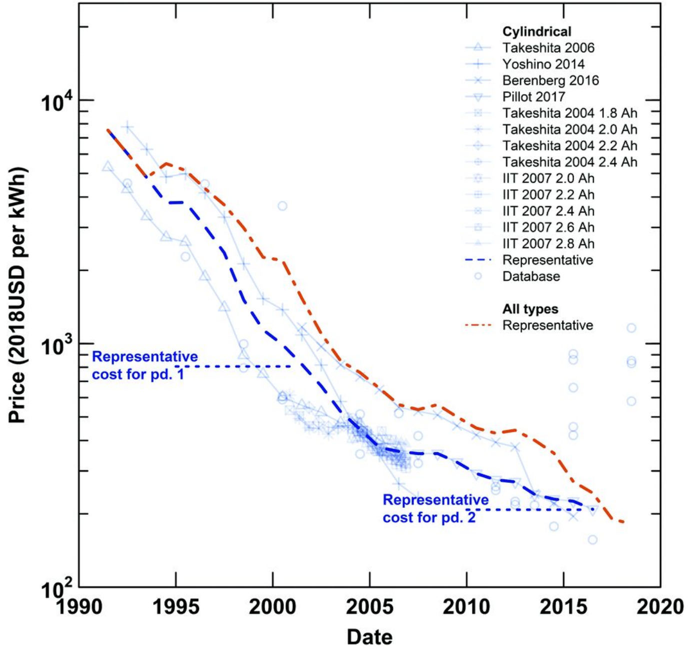


Source: Yang, XG., Liu, T. & Wang, CY.

Cost | Key Contributors to Battery Cost Decline







Researchers from MIT investigated the factors resulting in the 97% cost decrease in Li-ion batteries since their commercialization in 1991. In terms of physical properties, increases in charge density contributed the most to the decrease in cost. Materials and chemistry R&D played a greater role than economies of scale in terms of bringing down cost.

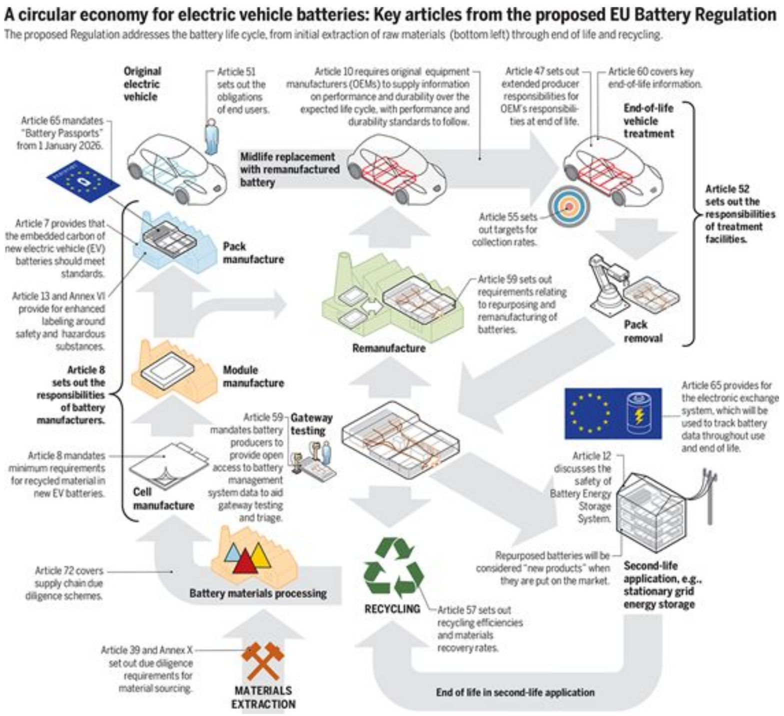
Characterizing and attributing contributions is critical for guiding future research and policy efforts towards further cost reduction.

Source: Ziegler M., Song J., Trancik J., Mauler L., Duffner F., Zeier W., et al.

Policy | Global Implications of New EU Battery Regulation

Researchers from Circular Energy Storage Research and Consulting and Newcastle University studied global implications of the European Union's new regulation on batteries. The regulation has admirable intentions and takes sustainability of batteries to a completely different level beyond that of any other product.

The researchers suggest that the new EU battery regulation may pave the way for a sustainable battery value chain creating a level playing field on a global scale. This could create competitive advantages for European players who are able to comply. There may be unintended consequences, however. At worst, the regulation may slow down growth and investment in European battery companies and hamper the pace of electrification and the use of batteries in vehicles, ESS and other applications.



This paper provides a comprehensive and interdisciplinary analysis on one of the first major international regulations in this very complex and quickly evolving industry.

Source: Merlin H.E., Rajaeifar M.A., Ku A., et al.

Section 3

Talent & Community

Talent | Job Creation

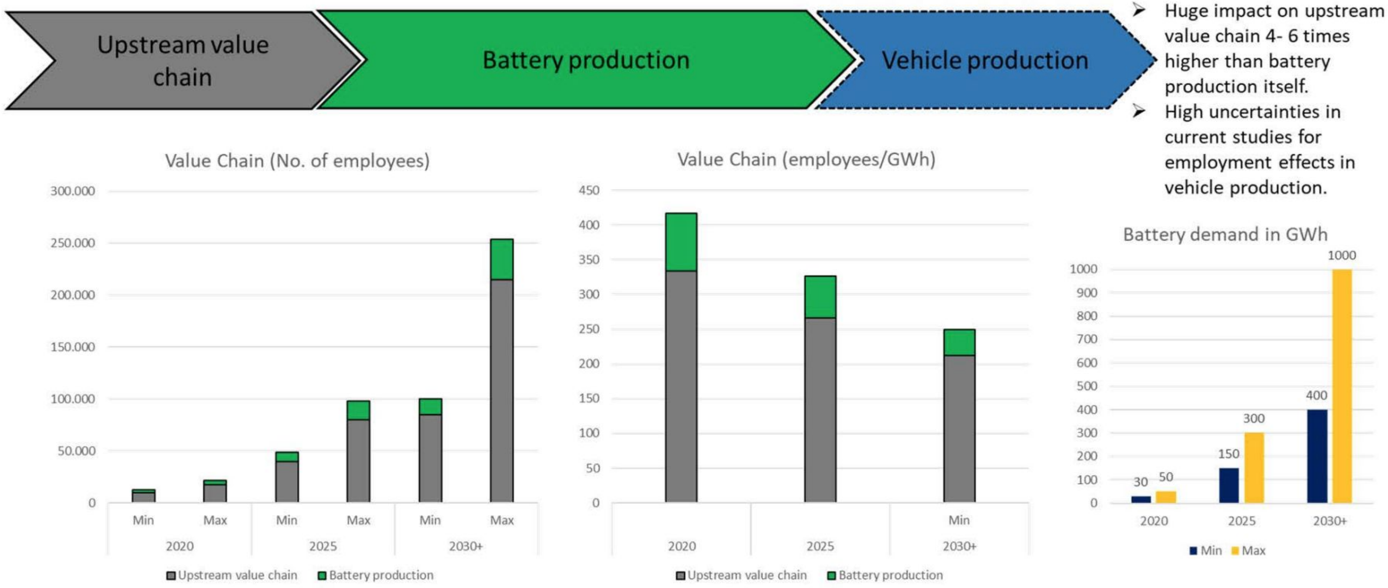
The battery value chain provides a great opportunity for job creation with many new roles to come.

Profiles by stage of the Battery Value Chain

	Raw materials	Active materials	Cells and Battery Packs		Applications			Recycling & 2nd life
White Collars	▪ Electrochemistry ▪ Material refinement and purification processes ▪ Environmental management	▪ Electrochemistry ▪ Wet chemistry processes ▪ Cleanroom processing ▪ Integration of processes in the environment ▪ Materials synthesis	▪ Inorganic chemistry ▪ Materials science ▪ Electrochemistry and cell design ▪ Energy storage ▪ Power and energy density ▪ Energy conversion efficiency ▪ Performance factors and optimisation ▪ Modelling and simulation ▪ Data Science	▪ Packaging and Security ▪ Testing and Monitoring ▪ Data Science ▪ Mechanical Engineering ▪ Systems Management ▪ DC system design ▪ Thermal and kinetic properties	▪ EV typologies ▪ Charging infrastructures ▪ Vehicle to Grid ▪ Sustainable mobility ▪ Business models ▪ Policy and Regulation ▪ Batteries in trains and planes	▪ Smart buildings ▪ Sustainability ▪ Energy management ▪ Power plants ▪ Smart grids, off grids and micro grids ▪ Battery banks ▪ Business models ▪ Policy and Regulation	▪ Solar Energy Storage ▪ Control and regulation of wind turbines ▪ Coupling to fuel cells ▪ System optimisation ▪ Cost calculation ▪ LCA ▪ Policy and Regulation	▪ Material properties and life cycles ▪ Rare resource processing and recovery ▪ Chemical resources ▪ Separation processes and technologies ▪ Electrochemistry ▪ Control and processing ▪ Circular economy models ▪ Environmental management and legislation ▪ Standardisation
Vocational & Professional	▪ Materials extraction and refining ▪ Sourcing ▪ Logistics ▪ Measurement and Control ▪ Chemical safety ▪ Waste management ▪ Environmental management	▪ Chemical processes ▪ Physical processes ▪ Design of chemical equipment ▪ Measurement and control ▪ Chemical safety and waste management	▪ Physical processes ▪ Mixing, coating, drying ▪ Measurement and control ▪ Chemical safety ▪ Waste management ▪ High speed mechanical assembly	▪ Electromechanical manufacturing ▪ Automation engineering ▪ Vehicle technology ▪ Electronics ▪ Electrical safety	▪ EV Fundamentals ▪ Operation, diagnosis and repair ▪ Systems ▪ Electric motors and controllers ▪ Diagnostic tools and equipment	▪ Energy installations ▪ EV charging systems ▪ Automation and control ▪ Electronics ▪ Digital ▪ System security	▪ Robotics and Automation ▪ Renewables and Electrical Grids ▪ Digital skills ▪ Electrical safety	▪ Materials extraction and refining ▪ Chemical and physical processes ▪ Logistics ▪ Digital skills ▪ Chemical and electrical safety ▪ Waste management

Talent | Job Estimates

Number of jobs is expected to 10x in the coming decade, with severe demand for workers in the upstream value chain.



- Huge impact on upstream value chain 4- 6 times higher than battery production itself.
- High uncertainties in current studies for employment effects in vehicle production.

Source: Own calculations based on BatPac Model (ANL) & Hettesheimer et. al (2018): Employment effects and value chains in the battery machinery and plant engineering industries VDMA/Fraunhofer ISI (10/2018). Battery demand from Position Paper on Education and Skills

Figure 2: Absolute number of employees needed in Europe and employees per GWh connected with the battery (materials, cell to pack) production.

Source: Fraunhofer Institute

Talent | Job Estimates

Number of jobs is expected to 10x in the coming decade, with severe demand for workers in the upstream value chain.

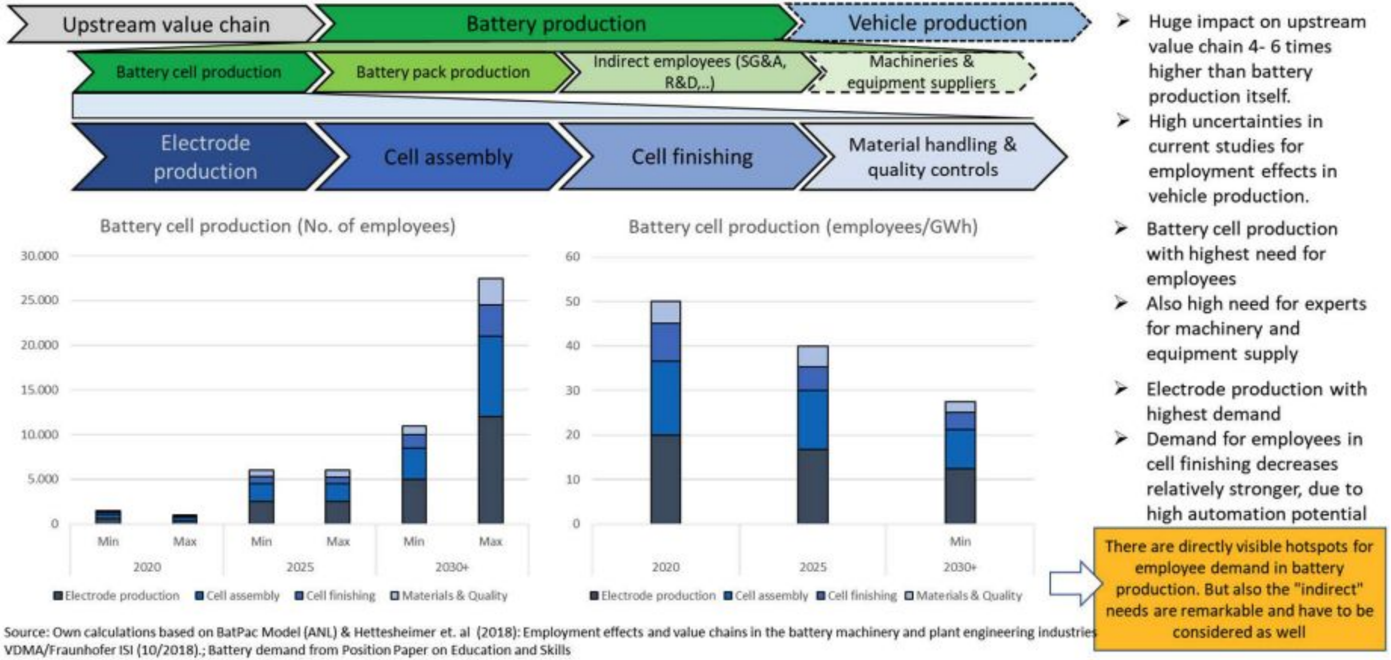


Figure 4: Absolute number of employees needed in Europe and employees per GWh connected with the battery cell production.

Source: Fraunhofer Institute

Talent | Job Creation

A wide range of skills will be needed to meet the demands of this sector.

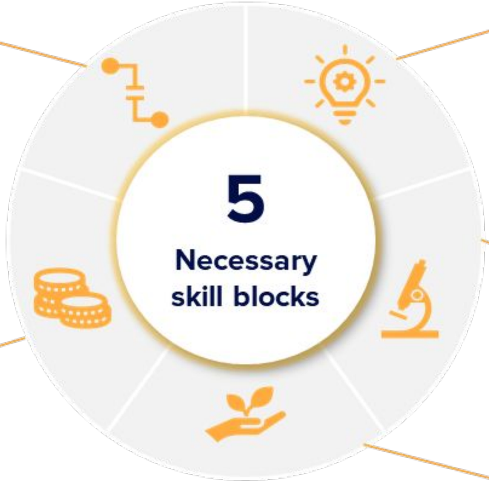
Required skills in the energy storage industry

Processes, operations and digitisation

It includes those activities linked to the development and implementation of the operational processes and activities to be developed within the value chain, as well as continuous improvement processes linked especially to digitalisation

Integration and applications

Includes those profiles associated with the development and identification of solutions to be implemented in the different applications / needs identified in the battery market



Technology and R&D

It comprises those jobs and activities associated with the technological and scientific development of the value chain

Management

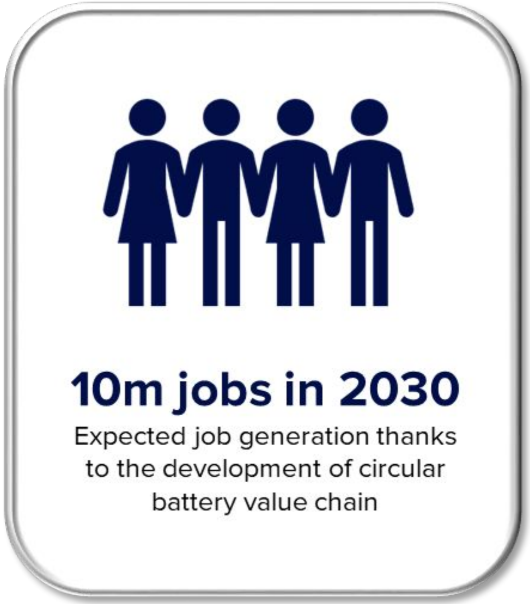
Composed of profiles linked to the management, from an economic, legal, human, etc. point of view, of the different activities included

Social and environmental impact

Contains those profiles and activities associated with the effect of the value chain stages on their environment

Talent | Job Estimates

The development of a circular battery value chain could generate 10M jobs globally in 2030.



According to the **World Economic Forum**, employment in the **battery value chain** is expected to increase to a total of **10M jobs** in **2030**, with more than half of these jobs in **developing countries.** This translates to ~3800 jobs/GWh. The total estimate of 10 million jobs would be on the same level of the global automotive industry employment today (i.e. around 1 job per 5–10 vehicles produced).

Production Scale	Jobs Creation per GWh
Small (~50 GWh)	90-180 (Direct) 350-1400 (Indirect)
Large (<1000 GWh)	40-90 (Direct) 400 (Indirect)
TWh (>1000 GWh)	250 (Direct & Indirect)

Source: Fraunhofer Institute

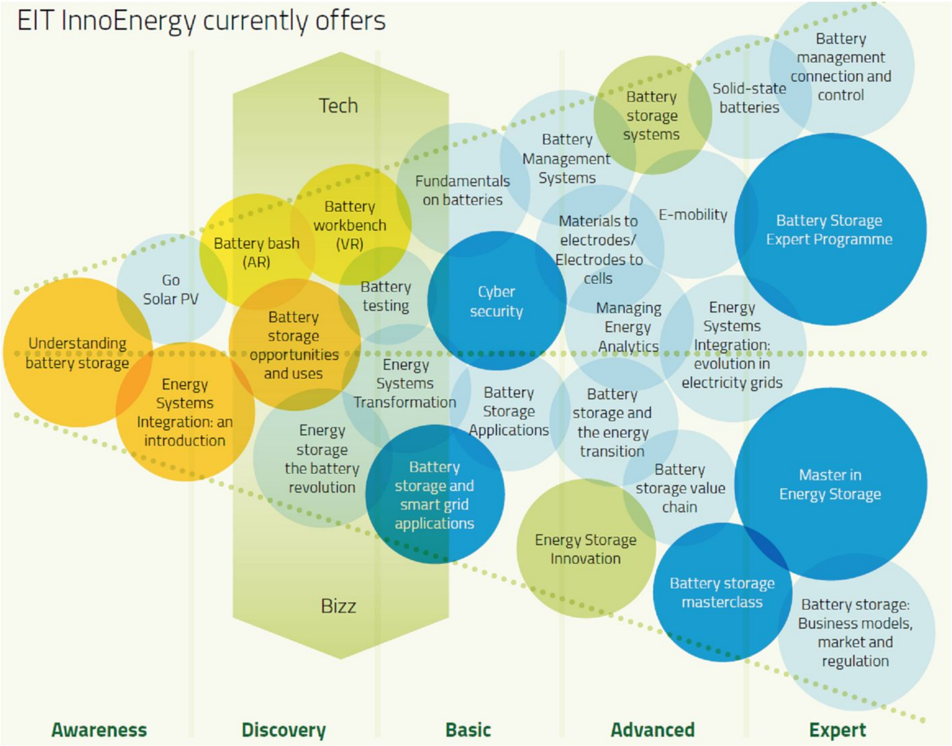
Talent | Europe

Europe launches aggressive training programs to tackle the supply shortage.

European Commission expects up to 4M new jobs to be created by 2025, and plans to train 800,000 workers by 2025 (roughly 160,000 workers need to be trained per year).

EIT InnoEnergy partners with Member States of the European Battery Alliance to launch EBA250 Academy, developing curricula and training content based on industry's needs and in partnership with local training professionals to "reskill and upskill" workers.

EBA250 Academy Partners: Spain, France, Central Europe, Benelux, Germany, Portugal, Scandinavia.



Source: EBA250

Talent | South Korea

LG, SK, Samsung face a shortage of research and engineering specialists.

- Small incoming talent pool: South Korea is short of almost 3,000 graduate degree-level positions in areas such as research and design (Korea Battery Industry Association). Battery specialists with newly graduated with doctorate degrees can earn as much as 100 million won ($85,000) a year, and those without that level of qualification average about 80 million won after gaining a few years of experience, according to two sources at major South Korean battery firms. South Korea's average annual salary was 37.4 million won in 2019, according to tax agency data.
- Talent competition with overseas companies: Talent shortage is compounded by some existing employees moving to foreign competitors for better pay (Reuters). More immediately to address this talent shortage, Korean companies are recruiting more strongly overseas. LG Energy Solution CEO and his managers went to Los Angeles while the SK Innovation CEO and staff hosted an event in San Francisco.
- Build in-house training pipeline: LG Energy Solution (South Korea's #1 battery maker by volume) plans to launch a new "battery-smart factory department" at the prestigious Korea University in Spring 2022 with guaranteed jobs for graduates.

Source: Reuters

Talent | China

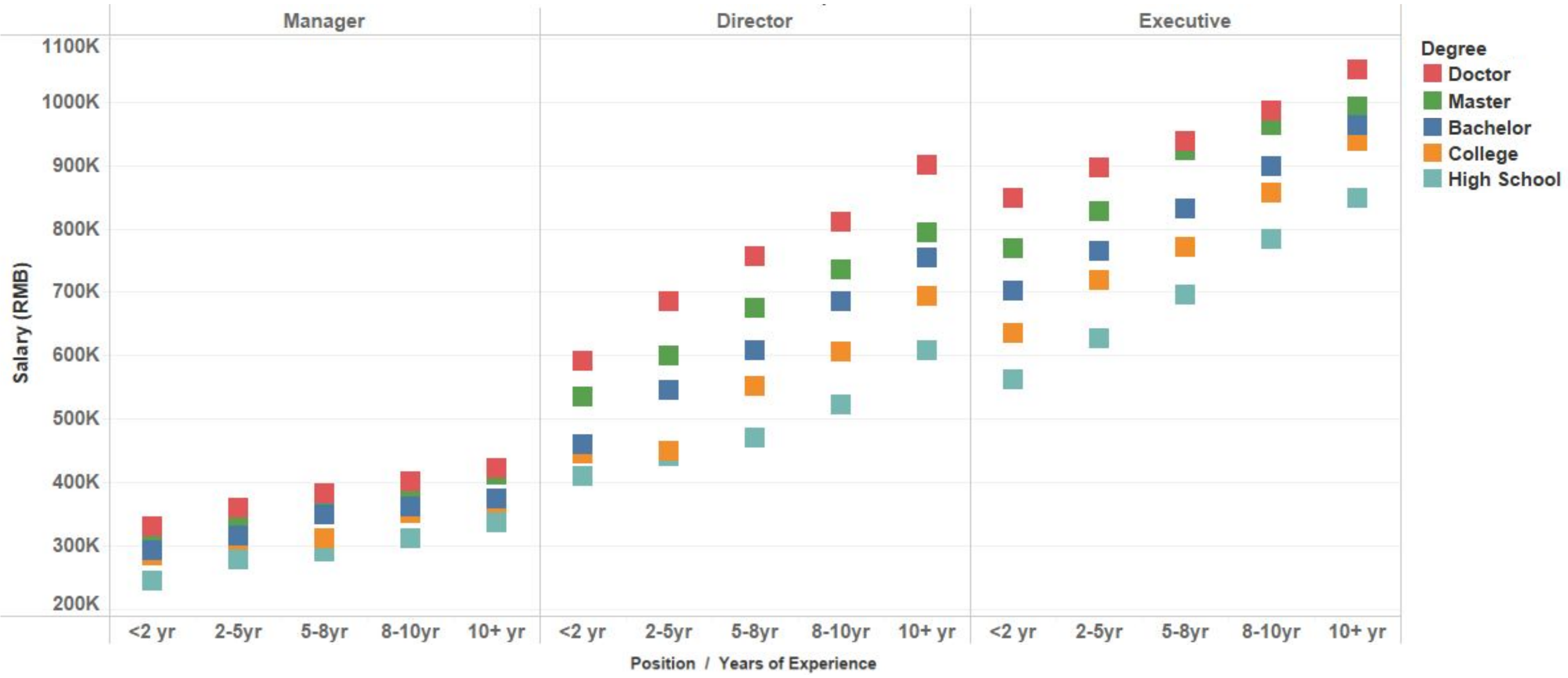
Talent Shortage, Warfare and Involution

- Small incoming talent pool cannot meet demand. China's Manufacturing Talent Development Planning Guide estimates that the overall talent needs for China's clean energy industry in 2025 will be 1.2M people, with a talent gap of 1.03M people. The thousands of new graduates each year is insufficient to meet current demand. Furthermore, curriculum need to be updated to balance theory and practice to meet market needs.
- Intense Talent Warfare. It is not uncommon for workers in prominent companies to receive ~10 phone calls per day from headhunter companies. Companies are willing to pay 100% higher salary for experienced workers, and 30-50% for those with less experience. As a result, the fastest way for workers to get a raise is to switch companies, as internal increases are limited. For reference, CATL pays manufacturing and technical engineers monthly salaries of ¥15.6k and ¥20k while Gotion pays ¥9.9 and ¥10.2k respectively.
- "Talent Involution": "Some large companies do not have a talent shortage. They would rather hire excess talent at high salaries than to let potential competitors hire them." "Once talent leaves for larger scale companies, it is unlikely for them to return to smaller scale companies. This is also one of the reasons why a lot of small battery startup eventually shut down."
- China continues its vocational training program. Since Aug 2020, China has already held 12 sessions of its Battery Production Engineer vocational program, with more than 1000 personnel receiving certification.

Source: 时代财经

Salary | China

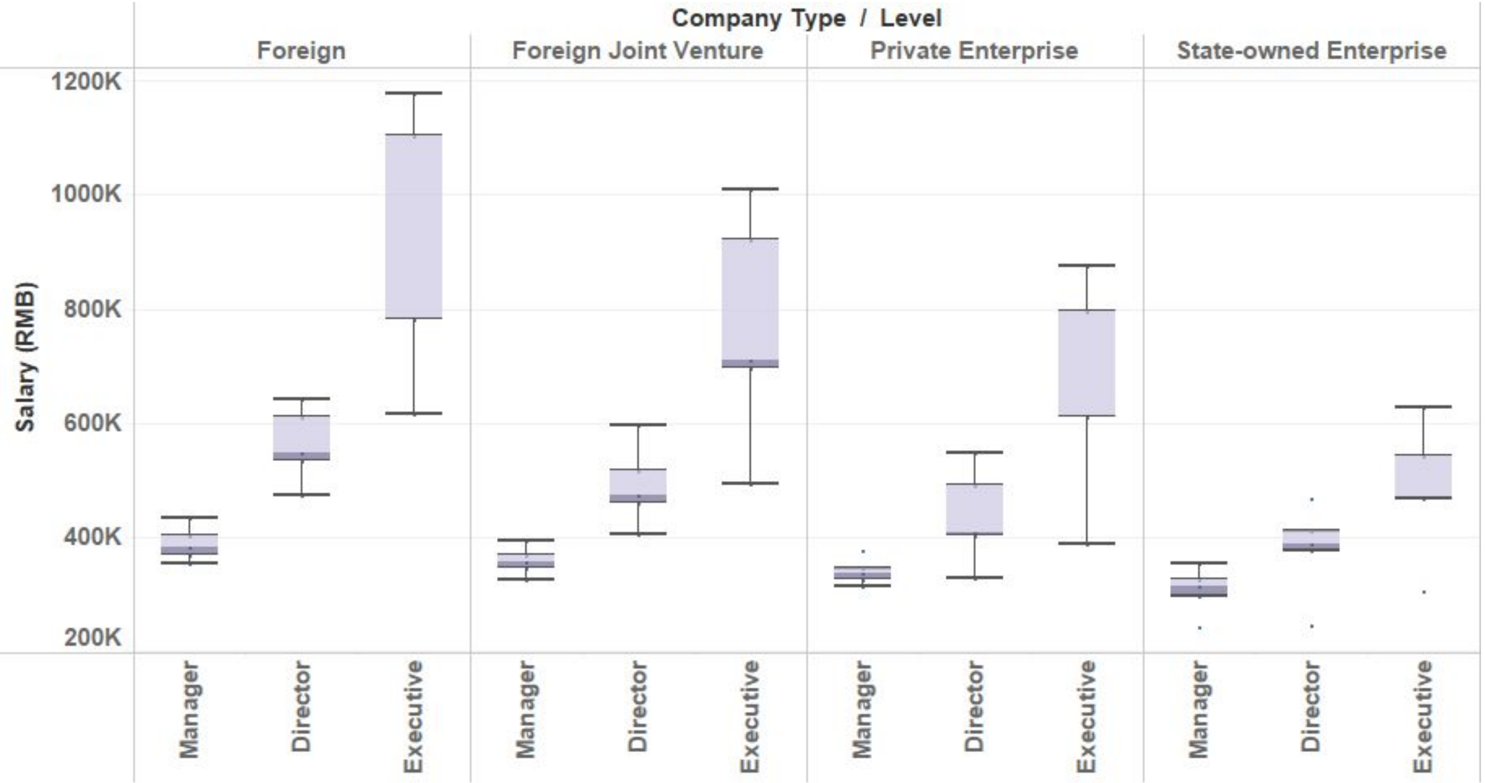
Education degree and years of experience have a more prominent impact on salary at the director and executive levels.



Source: 中国薪酬网

Salary | China

Foreign companies in China show the highest salary jumps between levels.

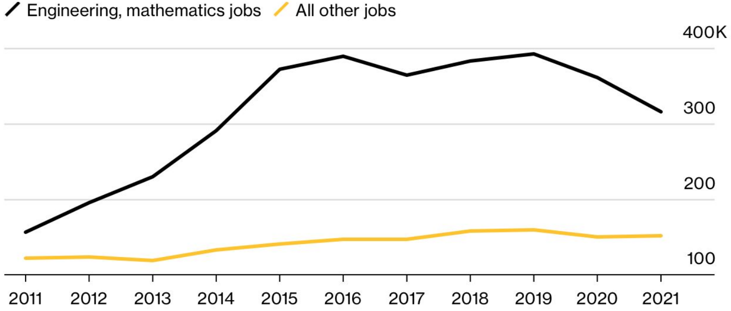


Source: 中国薪酬网

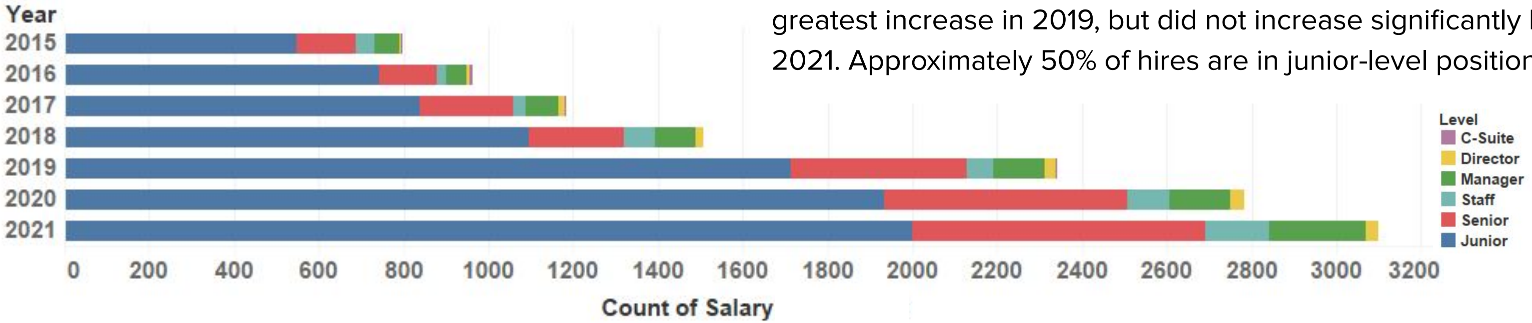
Salary | US

H-1B visas overview

Number of applications for H-1B visas



U.S. Department of Labor data complied by Bloomberg News
Data includes government-certified full-time jobs receiving annual salaries.



The H-1B is a visa in the United States under the Immigration and Nationality Act, section 101 that allows US employers to temporarily employ foreign workers in specialty occupations.

Applications: Number of applications filed for foreign high tech workers on H-1B visas dropped the most in a decade due to slowdown in visa processing and tightened immigration policies due to the pandemic. Applications for STEM jobs fell by 19% compared to pre-Covid levels in 2019.

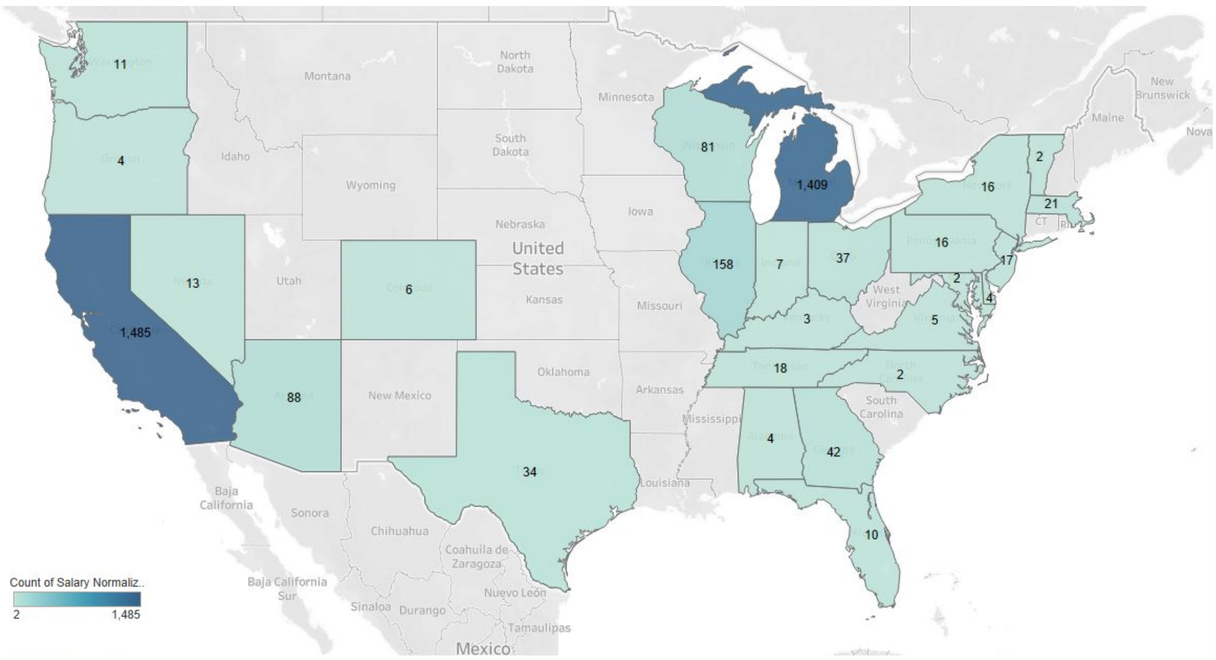
Issued Visas: Approval rates for H-1B visas increased (97-98%), compared to about 84% in 2018 and 2019 during the previous Trump administration. (Note the application approval process is different to the H-1B lottery process).

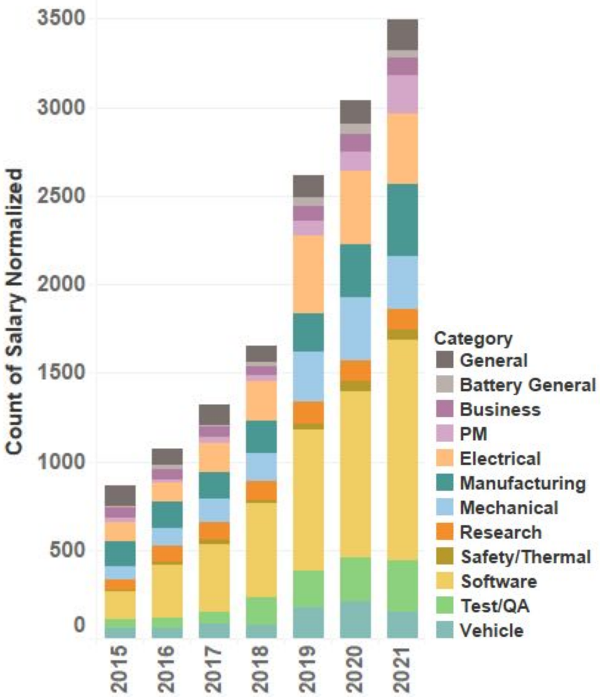
Battery Relevant Roles: Number of H-1B hires for battery relevant roles saw the greatest increase in 2019, but did not increase significantly between 2020 and 2021. Approximately 50% of hires are in junior-level positions.

Source: H1B Salary Data, US Inflation Rates, Bloomberg, Economic Times

Salary | US

2021 H-1B Jobs are dominated geographically by California and Michigan, with Software as the leading category. Across categories, software shows the biggest YoY growth in number of positions.





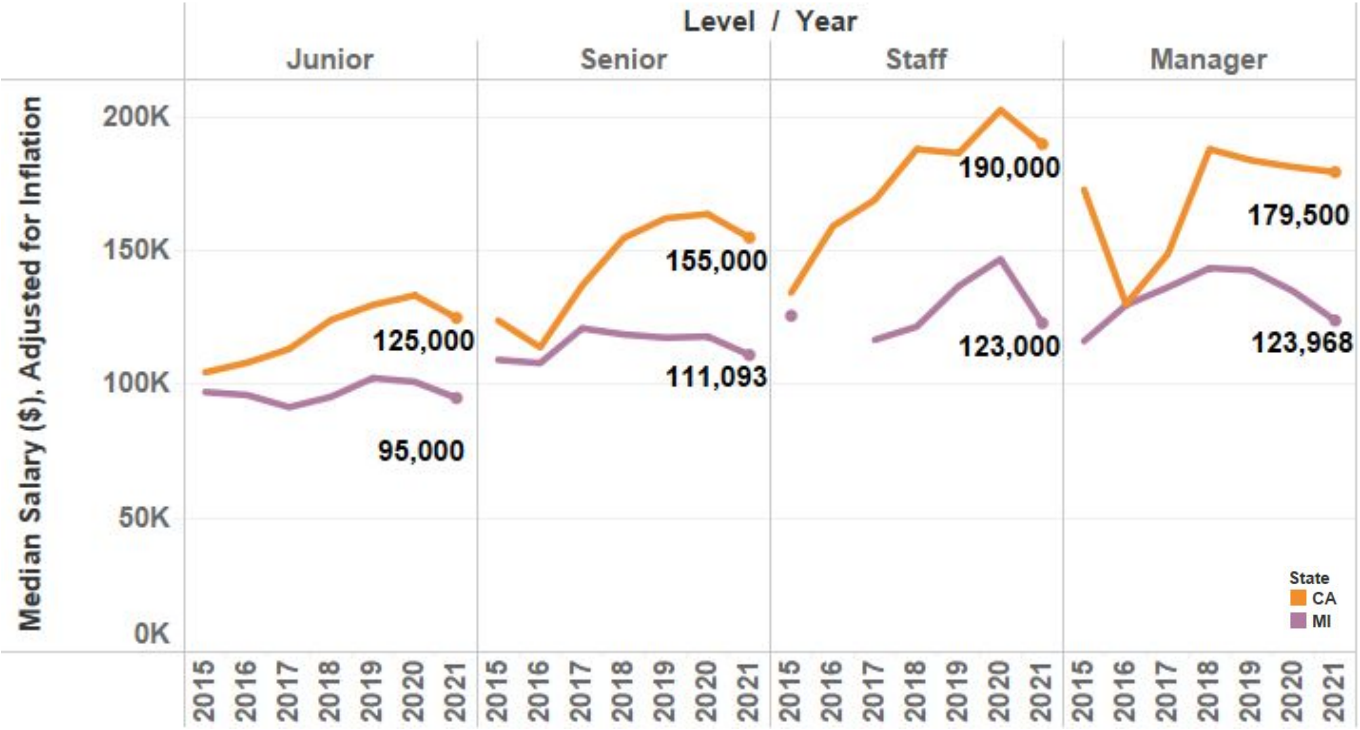
Salary | US

US reported salaries (H1B) for battery industry roles increased 2.3% in 2021, but did not keep pace with inflation (6.8%).

Source: H1B Salary Data, US Inflation Rates

Salary | US

After segmentation by state, Staff and Manager salaries are comparable. California (CA) salaries are on average 40% higher than Michigan (MI) salaries.



Source: H1B Salary Data, US Inflation Rates

Talent | Resources

A few things we like to stay up to date with the industry!

Social

Twitter

@stevelevine
@MjLacey
@DavidHowey
@venkis
@DennisKopljar
@BrianTHeligman
@UldericoUlissi
@JamesTFrith
@bout_kieran
@electrochemicat
@TECHtricityblog
@kristinaEdstrm2
@BatteryPapers
@mart_de_bi
@ndrewwang
@sdmoores

Reading

Newsletters

BatteryBits
Intercalation Station
The Limiting Factor
The Mobilist
The Electric
Batteries are Complicated
Battery Discovery
Climate Tech VC
EV Universe
TECHtricity

Books

Lithium: The Global Race for Battery Dominance and the New Energy Revolution
Power Play: Tesla, Elon Musk, and the Bet of the Century Hardcover

Community

Groups

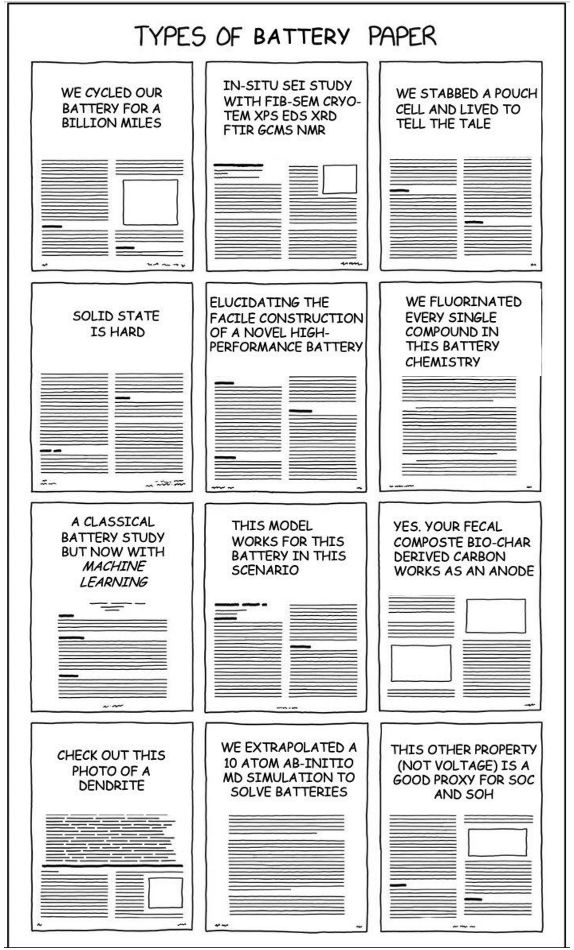
Battery Brunch
Battery Pub
Battery Modelling Webinar Series
Battery Street Slack
Stanford StorageX

Climate Communities

My Climate Journey
On Deck
Terra.do

Talent | Social

Meme of the year



Source: Andrew Wang

Section 4
Policy

Policy | Overview

Governments seek to accelerate a healthy battery ecosystem and promote economic development.

1. **International Legislation:** At COP26, over 100 national governments, cities, states and major businesses signed the Glasgow Declaration on Zero-Emission Cars and Vans to end the sale of internal combustion engines by 2035 in certain leading markets and by 2040 worldwide. At least 13 nations also committed to end the sale of fossil fuel powered heavy duty vehicles by 2040.

2. **Examples of National Legislation (Demand Side):**

	ICE Ban Year	EV Incentive	YTD 2021 Plug-in Market Share
Norway	2025	No purchase or VAT tax	85.1%
Netherlands	2030	€4,000 subsidy, tax exemptions	24.0%

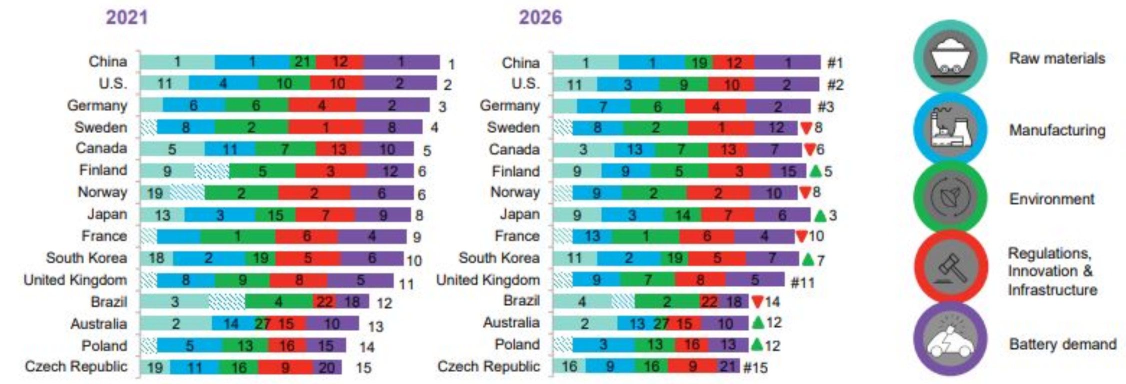
3. **Examples of National Legislation (Supply Side):** Global themes of regional autonomy in battery supply chain and technology development embodied in leading government programs:
   - EU: €2.9B European Batteries Innovation Project, EU Batteries Regulation, Horizon Europe
   - US: $17B DOE ATV Manufacturing Loan Program, Energy Storage Grand Challenge

Policy | Nationalization of Production

The world sprints to catch up on China's lead in battery production, raw materials, and infrastructure.

Companies have announced ~2300 GWh of production by 2025 and governments are competing to host the next gigafactory by providing incentives around prime locations, government subsidies/grants, access to labor and raw materials/components, lower taxes, lower import and export fees, efficient transportation methods and costs, adjacency to customers/markets, low cost and reliable energy, least onerous regulations, etc.

Global battery supply chain ranking (Top 15)



Source: BloombergNEF. Note: Shaded areas for manufacturing and/or raw materials indicate that the country has no capacity and comes joint last in the rankings with other countries. Final rankings are an average of the five metrics. The overall ranking for countries in 2026 is shown in the data label but the list is not ordered. The arrow indicates whether the new ranking is higher or lower than in 2021.

"Northvolt has been among our frontrunners, set to **build Europe's first home-grown Gigafactory for lithium-ion battery cells**, with a minimal carbon footprint… we also confirm our resolve to boost **Europe's resilience and strategic autonomy in key industries and technologies**."

Maroš Šefčovič, European Commission Vice-President

"We urgently need to **build up our capacity to research, develop, manufacture, and market batteries right here at home**.... Today, the U.S. relies heavily on importing advanced battery components from abroad, **exposing the nation to supply chain vulnerabilities**.... **Currently, the U.S. has less than a 10% global market share for manufacturing capacity** across all major battery components and cell fabrication."

Jennifer M. Granholm, U.S. Secretary of Energy

Policy | United States

Building a domestic supply chain | Appraising and implementing other successful EV programs

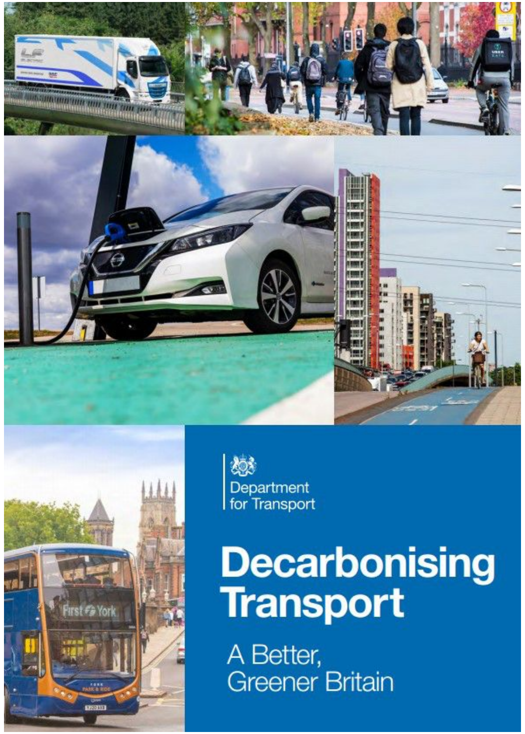
The $1.2T Infrastructure Investment and Jobs Act was passed into law on November 15, 2021. Included in the spending bill is $7.5B for EV charging networks, $7.5B for electric buses and ferries, and $108B for upgrading the electric grid, part of which will likely include batteries. On the technology front, the US Department of Energy is administering programs that are intended to advance American battery companies and domestic manufacturing. Among the key initiatives and programs are The National Blueprint for Lithium Batteries, Long Duration Storage Shot, and the Energy Storage Grand Challenge Roadmap. The Biden Administration announced the target that half of all vehicles sold in the US will be BEV, FCEV, or PHEV by 2030. The pending $1.7T Build Back Better Act includes a proposal to augment the current federal EV tax credit with the goal of making most EV purchase prices lower than comparable ICE vehicles.

	Current	Proposed
Maximum Credit Amount	$7,500	$7,500-$12,500
Minimum Income	~$90,000*	None
Maximum Income	None	$400,000
Maximum Vehicle Cost	$80,000	$55,000-$74,000
Excluded OEMs	GM, Tesla	None

*Minimum income required to realize full credit amount. Based on 2021 tax rules, 2 W-2 employees married filing jointly.

Policy | Europe and United Kingdom

EU and UK setting up a sustainable battery economy.



The **EU Batteries Regulation** proposal was released in December 2020 and will be in force starting January 1, 2022. The new regulations will impact virtually every part of the battery value chain over the next decade and influence the nascent European battery manufacturing industry. The intent is both economic and environmental; Extended Producer Responsibility (EPR) and recycled content mandates should produce greener, cheaper batteries and keep critical battery minerals inside the EU. The **Fit for 55** program in Europe includes a proposal to cut passenger car CO_2 by 55% by 2030 and 100% by 2035. **Energy storage** will be an area of focus for Horizon Europe's €95.5B research and innovation program. Funding is available for fundamental research, industry, lifecycle management, and sustainability.

UK Transport Decarbonisation Plan - On July 14, 2021, the UK government published the world's first "greenprint" to decarbonise all modes of domestic transport by 2050. The Transport Decarbonisation Plan highlights the role finance will play in decarbonizing transport and the need for public-private collaborations to tackle the largest contributor to UK domestic greenhouse gas emissions at pace and scale.

Policy | Asia

Countries in Asia take measures to assert dominance in the global market

	2020/21 Policy Measures
China	Under the new policy for 2021, Chinese EV subsidies are extended until 2022 (originally planned to end in 2020), albeit at a lower subsidy rate. The subsidy for pure electric vehicles (PEVs) with a driving range of 300-400km will be lowered to 13,000 yuan ($2,013) per vehicle, a 20% decrease from 2020. The subsidy for PEVs with a driving range of 400km or more will be lowered to 18,000 yuan ($2,787) per vehicle, also a 20% decrease from 2020. The subsidy extension and slowing of rate of reduction are in line with China's goal to have EVs make up 40% of all car sales by 2030.
Japan	Japan will commit $877M to subsidize construction of battery factories. In addition, the Battery Association for Supply Chain (BASC) was established and includes the largest industry stakeholders in Japan. It seeks to influence policy for its members including Nissan, Honda, Panasonic, and others.
Korea	President Moon Jae-in announced $35B in battery industry investments by 2030. Korea seeks to maintain and expand its presence as a global battery leader and remain competitive against other Asian countries.
India	The government's new $2.46B plan "National Programme on Advanced Chemistry Cell (ACC) Battery Storage," is aimed at domestic battery manufacturing.
Indonesia	The Indonesia Battery Corporation (IBC) was formed in March 2021 by four state-owned enterprises to create an end-to-end EV battery supply chain in Indonesia. IBC plans to partner with other companies, most notably China's CATL and South Korea's LG Chem.

Policy | Equal Access

Using energy storage as a catalyst to alleviate poverty in the developed and developing world

Low-income households can spend 10% or more of their income on energy expenses. Frequently, their status as renters precludes them from installing batteries and/or solar panels, which would lower their electricity bills and improve resiliency. In the US, state governments have developed policies and provided funding with the goal of equal access:

- California - Self Generation Incentive Program - Equity Budget
- Massachusetts - ConnectedSolutions

Over 700 million people globally have no access to electricity, creating negative economic, health, and other social impacts. Energy storage can improve lives in off-grid communities similar to the positive impacts from growth in wireless telecommunications. Global organizations like the UN and the World Bank set goals and guidelines to enable the deployment and long-term viability of energy storage projects:

- United Nations - Goal 7 - Affordable & Clean Energy
- World Bank - Manufacturing & Performance Warranties

Policy | Minimum Battery Performance Standards

India and China introduce performance standards to access subsidies or encourage innovation

In December 2021, the Chinese government released requirements to introduce minimum performance standards for batteries manufactured in China. The note threatened that non-compliance would result in facilities being *"demolished, or strictly controlled in scale and gradually moved out"*.

	Consumer	EV Energy	EV Power	ESS
Cell Energy	≥230 Wh/kg	≥210 Wh/kg	≥500 W/kg	≥145 Wh/kg
Pack Energy	≥180 Wh/kg	≥150 Wh/kg	≥350 W/kg	≥100 Wh/kg
Cycle Life	≥500	≥1000	≥1000	≥5000
Retention	≥80%	≥80%	≥80%	≥80%

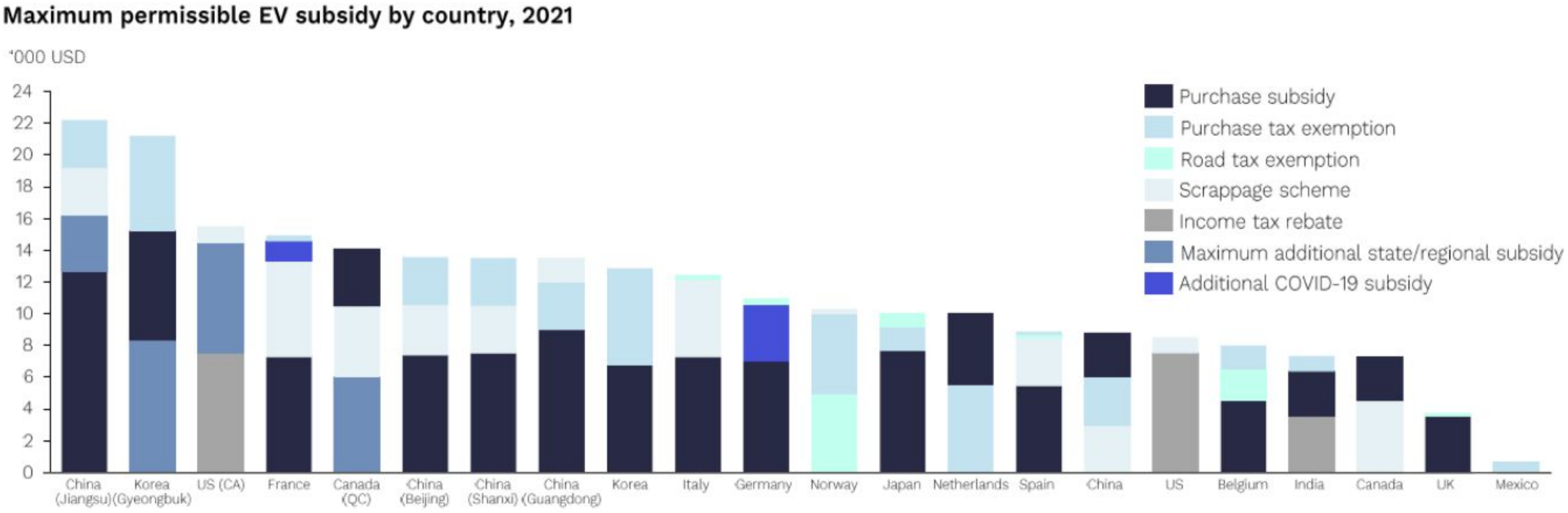
The Indian government has introduced a subsidy regime to incentivize up to 50 GWh of local battery manufacturing. The subsidy is capped at up to 2,000 rupees ($26.84) per kWh with performance multipliers. Letters of award will be issued on February 4, 2022. ($1 USD = ₹74.51 INR Jan 1, 2022)

Maximum Subsidy Performance Matrix ₹INR per kWh		Energy Density (Wh/kg)				
		≥50	≥125	≥200	≥275	≥350
Cycle Life	≥1,000	-	-	-	965	1,157
	≥2,000	-	-	965	1,157	1,389
	≥4,000	-	965	1,157	1,389	1,667
	≥10,000	965	1,157	1,389	1,667	2,000

Policy | Comparison of Demand Side Incentives

Local and national demand side measures enacted to stimulate the sale of electric vehicles

Demand side subsidies are a short term intervention to incentivize EV purchases until manufacturers achieve economies of scale. As time progresses, subsidies will likely be replaced by penalties for owning and operating ICE vehicles.



Policy | Fossil Fuel Vehicles

ICE vehicle ban timeline

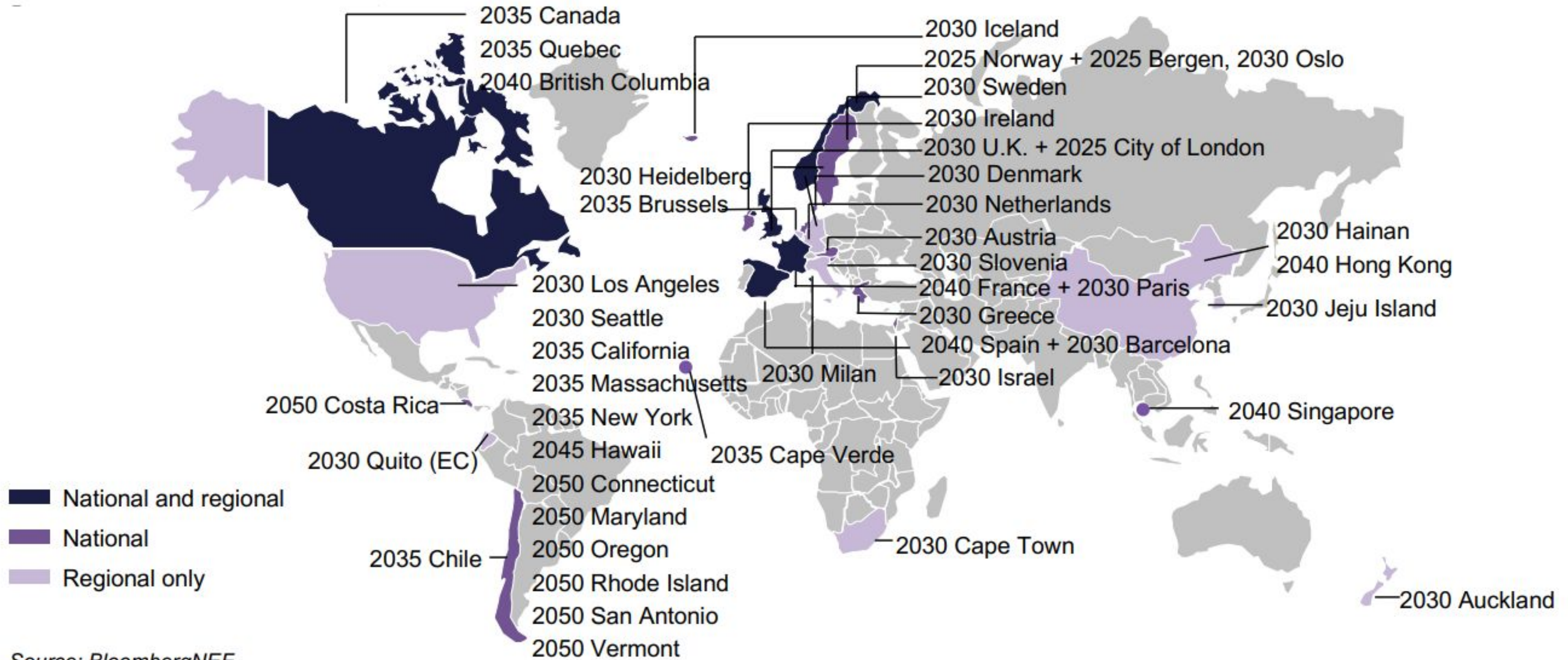
			2020 ICE sales (million)	% change (from 2019)
	Hainan province **2030** all vehicle ICE ban	China **2040** new vehicle sale and production ICE ban (government target)	22.17	↓ 13.6
No USA national ban announced	Washington **2030** all diesel & petrol ban	California and New York **2035** PC & LDV sales zero emission only	14.26	↓ 16.1
Diesel ban multiple German cities **2014-19**	Germany **2030** all new vehicles sales ICE ban (passed by Bundesrat vote – not in legislation)		2.53	↓ 22.0
	UK **2030** new car sales petrol & diesel ban		1.74	↓ 35.6
Paris **2025** diesel vehicles ban		France **2040** new vehicle sales ICE ban (government target)	1.86	↓ 31.1
	India **2030** 30% new vehicles sales ICE ban (government target)		2.81	↑ 7.7
British Columbia **2025** diesel & petrol ban		Canada **2040** new vehicle sales ICE ban	1.51	0.0
	Netherlands **2030** all cars diesel & petrol ban		0.27	↓ 4.7
Norway **2025** all cars diesel & petrol ban	Oslo **2030** all emitting vehicles ban		0.07	↓ 6.7

2025 2030 2035 2040

PC: passenger car, LDV: light duty vehicle

Policy | Fossil Fuel Vehicles

Electric vehicles are the largest market for batteries today. To date, 30 countries/states/regions (and counting) have publicly announced commitments to phase out fossil fuel vehicles.



Source: BloombergNEF.

Policy | Fossil Fuel Vehicles

Electric vehicles are the largest market for batteries today. To date, 30 countries/states/regions (and counting) have publicly announced commitments to phase out fossil fuel vehicles.

- Austria, 2035
- Belgium, 2026
- California, 2035
- Canada, 2040
- Chile, 2035*
- China, 2035
- Costa Rica, 2050
- Denmark, 2030
- Egypt, 2040
- France, 2040
- Germany, 2030
- Hong Kong, 2035*
- Iceland, 2030
- India, 2030
- Indonesia, 2050*
- Israel, 2030
- Japan, 2035
- Lausanne, 2030*
- Massachusetts, 2035
- Netherlands, 2030
- New York, 2035*
- Norway, 2050
- Singapore, 2040
- Slovenia, 2030
- Spain, 2040
- Sri Lanka, 2040
- Sweden, 2030
- Taiwan, 2040
- Thailand, 2025*
- United Kingdom, 2030

* announced in 2021

Section 5
Predictions

Predictions | The next 12 months

1. Venture Capital and Private Equity funding for battery companies continue to gain momentum. Energy storage startups will raise >$5B USD of private funding in 2022.
2. Segments of the EV market will start a pivot to 'new' battery chemistries to optimize for range or cost. "Beyond-NMC" chemistries such as NMCA and LFP will be shipped in new EVs.
3. Price volatility in battery raw materials will continue as the supply chain searches for new equilibriums. Lithium metal, carbonate, and hydroxide prices to see 30%+ swings.
4. Development of solid state battery technologies to achieve 120Ah cell demonstration in industry.
5. Traditional auto OEMs to accelerate EV product introduction. 40+ EV car models will be available for consumers in the US in 2022.
6. M&A activity to gain momentum as large companies seek to acquire new technology and hard-to-find talent. 5+ battery startups will be acquired by larger companies.
7. Volume of batteries reaching end-of-life (EoL) will increase in lockstep with EV production. 5+ startups will be created to capture opportunities in 2^{nd} life, recycling, and adjacent businesses.
8. Total global installed battery cell manufacturing capacity to surpass 800 GWh.

Contact Us

Thank you for reading the 2021 Battery Report!

We reviewed and highlighted key developments in the battery industry in 2021. This report is meant to be a comprehensive and accessible guide to battery research, industry, talent, and policy, and aims to foster conversations on the state of batteries and its trajectory in the future.

For collaborations, partnerships, and presentations, please reach out to us at editors@batterybits.com.

Thank you!

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Intercalation provides technical insights and assessments for energy storage technologies to help build knowledge gaps across the industry, academia, and government. We actively track 100+ companies and we publish our research and analysis in our newsletter as well as the annual State of Batteries report. Intercalation is based in London, UK.

You can read more on our website, twitter, and our newsletter.

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