The Global Race for A Better Battery
電池革新之全球競賽

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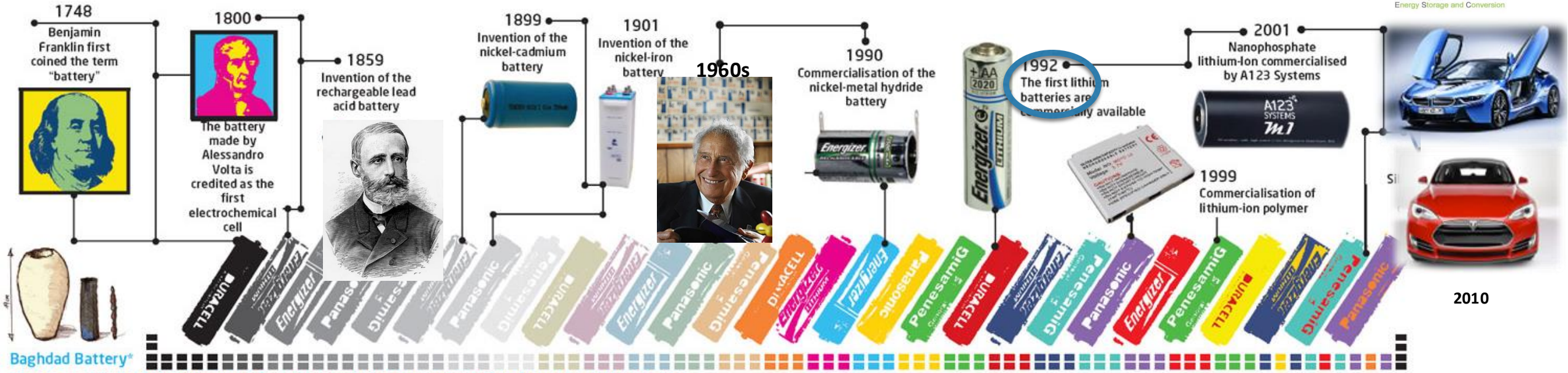
The University of Chicago

The University of Chicago Francis and Rose Yuen Campus

May 14, 2025

A Brief History of Battery and Industrialization



1976 1980

Intercalation Chemistry – Nobel Chemistry 2019 !

IoT
mWh

Robots
Wh

Drones
kWh

Aviation / SemiTruck
MWh

1Whr is a large energy unit = 3600 W.s (J)

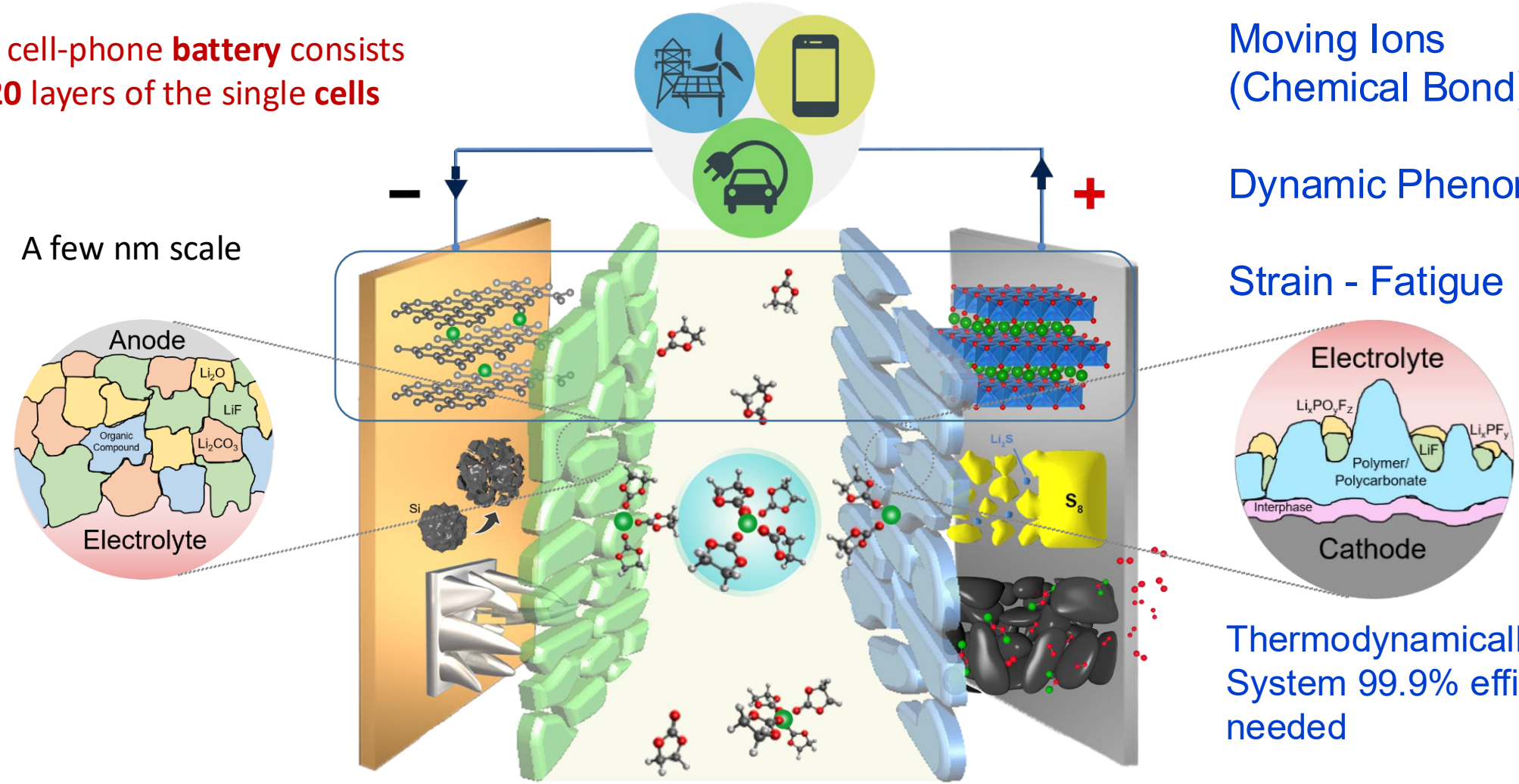
Energy Storage for Renewables
GWh

Rechargeable Battery - A Complex Engineering System

Kang Xu, Venkat Srinivasan and Y. Shirley Meng, Science 2023

One cell-phone **battery** consists **10-20** layers of the single **cells**

A few nm scale



Moving Ions (Chemical Bond)

Dynamic Phenomena

Strain - Fatigue

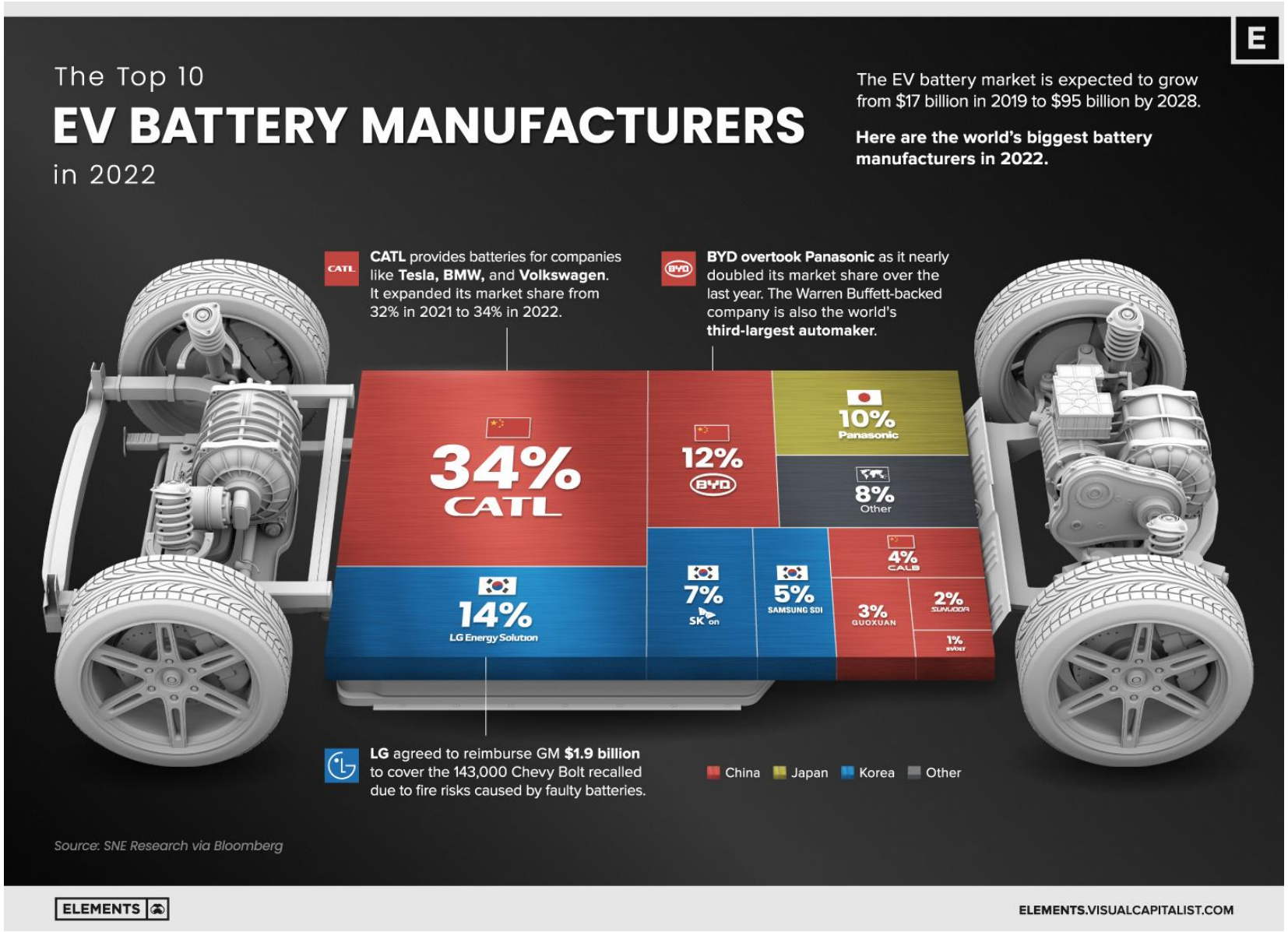
Thermodynamically Closed System 99.9% efficiency needed

SEI – Life and Safety Differentiators

THE UNIVERSITY OF CHICAGO PRITZKER SCHOOL OF MOLECULAR ENGINEERING

Argonne NATIONAL LABORATORY

World Production of LIB >1TWh/Year 2024 (Today)



In 1998, Academician Chen Liquan, built the first production line using a complete set of Chinese equipment.

In 1999, South Korea entered the lithium-ion battery market, and LG Chem completed South Korea's first battery product.

In 2000, BYD won an order from Motorola

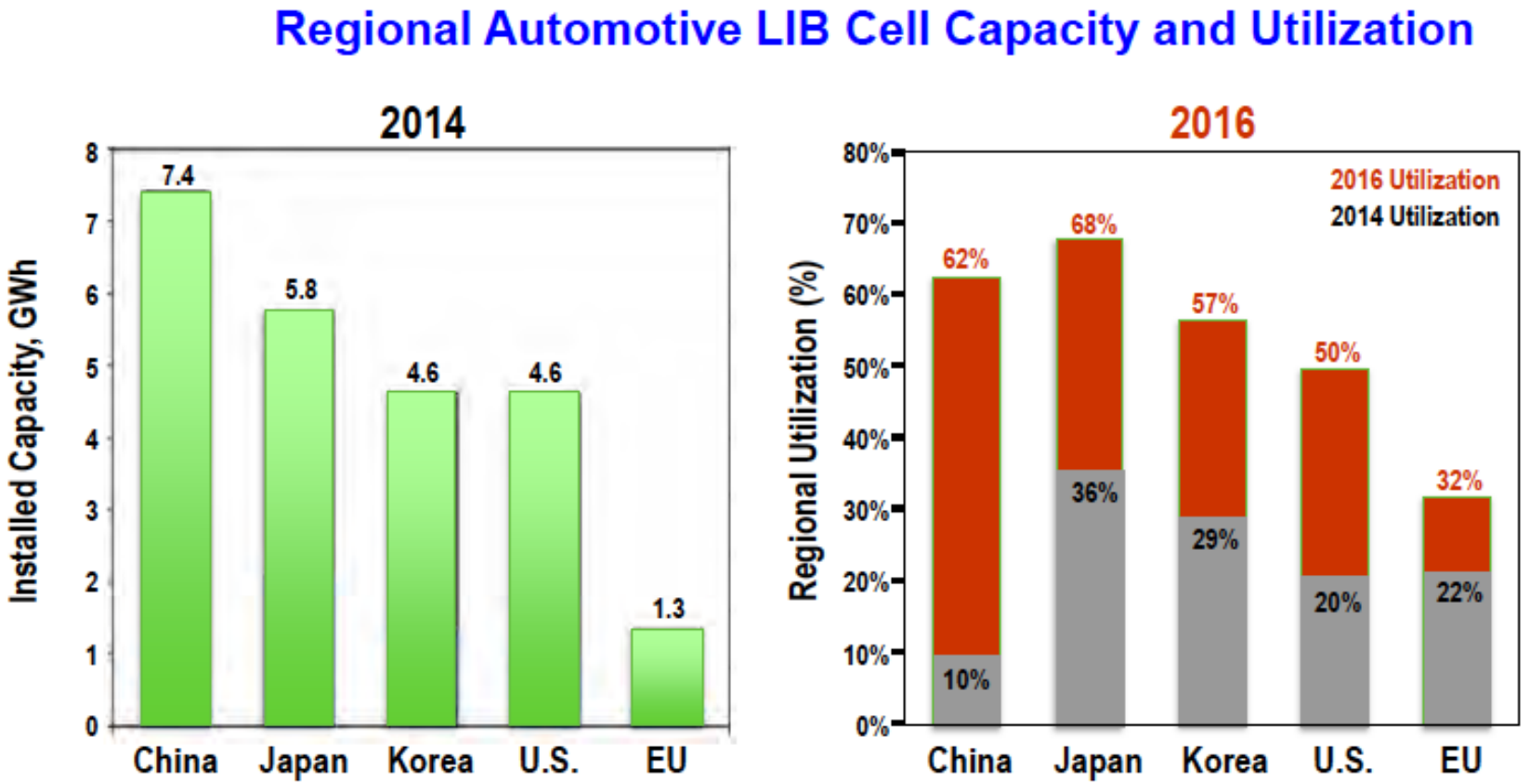
In 2001, China entered WTO

In 2004, CATL became an iPod supplier. China's lithium battery industry emerged. China's annual output of lithium-ion batteries is 800 million units, accounting for 38% of the global share, second only to Japan.

Start in 2002 "Electric Vehicle Key Project"
- 863 National High-Tech Development Plan
- Spent **880 million yuan** for EV research in five years

Start in 2013 China Central government subsidies
- 60,000 yuan for passenger electric cars (>250 km)
- 300,000 yuan for electric buses
- Exemption from vehicle purchase tax
- Local subsidies: up to 60% of EV retail price
- Non-subsidy measures: license-plate restrictions

2014 We All Started from The Same Spot! (Past)



- Automotive lithium-ion battery demand growing but short of global manufacturing capacity.
- Utilization of U.S. plants increased from 20% in 2014 to ~50% in 2016.
- Forecasted compound annual growth rates in lithium-ion demand: 22%–41% (through 2020).

China's Protectionist Policy

- 25% Tariffs on imported EVs
- 2011: Foreign JV ownership restrictions in EV batteries
- 2013: Subsidies limited to made-in-China EVs
- 2015: Battery whitelist established (no foreign JVs)

China’s Tesla Policy

Construction began in January 2019, and the first vehicles rolled out in December of the same year. The factory was completed in record time, with permitting and electrical work finished in just 168 working days.

Impact on the local area

- **Industrial development**: The factory has helped to develop the advanced manufacturing industry in the area.
- **Employment**: The factory has helped to promote local employment and train blue collar technicians. (20,000 new jobs)
- **Industrial chain**: The factory's industrial chain localization rate is over 95%.
- **Public transportation**: The factory has helped to improve the public transportation network in the surrounding areas.
- **New Megafactory** Tesla is also building a new Megafactory in Shanghai to produce Megapack batteries. The Megafactory is scheduled to begin construction in May 2024 and begin mass production in the first quarter of 2025

A Vision for the Future (USA View)

California Installation 42GWh in 5 years

- 300 Million People – 3TWh

Assuming each only own 10kWh battery for non-mobility
(10,000kWh/year – no comprise in quality of life)

- 300Million Cars – 30TWh Battery

passing 1million EVs/year mark 6% of new car sold
If heavy duty trucks 1,000,000 * 1MWh = 1TWh

- Grid is 1.2TW Peak Energy – 10TWh

4-8 hours fulfilled by battery tech
If AI takes off, grid energy might double

THE UNIVERSITY OF CHICAGO
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USA Industrial Policy from Biden Admin

Tesla	2003 Incorporated (large garage)	2008 Roadster SOP 2009 Tesla moves to small factory 2012 RAV4 EV SOP	2009 $465M DOE loan approved 2010 Fremont Factory purchase 2012 Model S SOP	2014 Giga 1 design start 2017 Model 3 SOP	**Roadster → Model 3: 10 yrs**

Tesla achieved high volume vehicle production **in ~10 years** from initial Roadster commercialization – included DOE loan (456M$) enabling Home Factory

- a tax credit of $45 per kilowatt-hour for battery manufacturing,
- a credit of 10 percent of the cost of production for critical mineral processing,
- another credit for 10 percent of the cost for electrode active material production,
- a credit of up to $7,500 for new EV purchases,
- a credit of up to $1,000 for household EV charger installation
- up to $100,000 for commercial charger installation.

MESC

Accelerating Domestic Supply Chain for Battery Manufacturing

ROUND 1 AWARDEES & ROUND 2 SELECTEES

ENERGY.GOV/MESC

Round 1 - 1.82 billion (14)

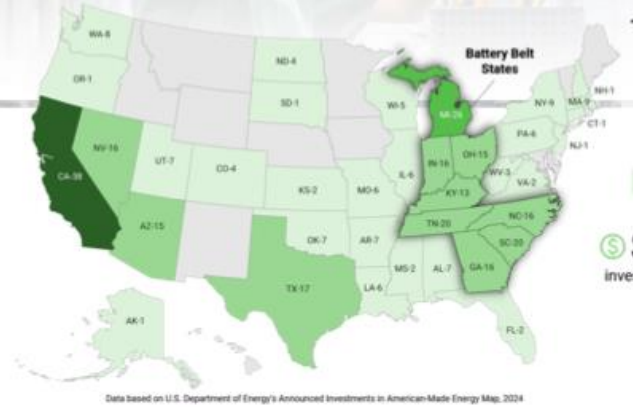
Round 2 - 3 billion (25)

KEY

- Round 1 Awardee
- Round 2 Selectee
- Raw Materials
- Separation & Processing
- Component Manufacturing
- Battery Manufacturing
- Recycling

Batteries: POWERING AMERICA'S 21st CENTURY ECONOMY

U.S. innovators developed lithium-ion battery technology. But where it once led, the U.S. now lags behind China and other nations in the manufacturing of critical battery materials and advanced battery technologies. This lag is both a danger and an opportunity for the U.S. to recharge and scale production of one of the 21st century's defining technologies.



Data based on U.S. Department of Energy's Announced Investments in American-Made Energy Map, 2024

The United States of Batteries: New U.S. manufacturing and supply chain investments across America's Battery Belt

New U.S. battery manufacturing and supply chain investments:

1-10 | 11-20 | 21-30 | 30+

$140B+ investments announced so far

90k+ new jobs

300+ new or expanded minerals, materials processing and manufacturing facilities

JOBS SUPPORTED BY SCALING THE BATTERY SUPPLY CHAIN:

- Mining and Extraction
- Chemical Processing
- Manufacturing
- Construction

INVESTMENTS

American battery makers need more than **$100 billion of new investment** to fund their comeback. A consistent and long-term commitment to scaling this industry is essential for stability and growth.

WORKFORCE

Working in tandem with states and universities, the federal government must address a **skills gap** to better prepare American workers for advanced manufacturing jobs.

INNOVATION

The U.S. must double-down on R&D investment in new battery chemistries, critical materials production, and next-generation manufacturing. The U.S. must protect and **re-invest in one of its key advantages: innovation.**

Batteries: BREAKING FREE FROM FOREIGN SUPPLY CHAIN DEPENDENCE

Over the past decade China has made massive investments in its battery supply chain. Across every stage of the value chain, from mineral extraction and processing to battery manufacturing, China holds a significant share of the global battery market. China has also demonstrated a willingness to use its control of this market for raw political advantage. Our economic well-being and national security demand that we address this challenge.

U.S. energy dominance requires a healthy U.S. battery industry

The U.S. cannot achieve energy security if its electricity, defense, and transportation sectors rely on technology and supplies controlled by a single potential adversary. **The current state of the battery market should be of extreme concern to the U.S. government.**

CHINA CONTROLS

- **78%** of global cathode production
- **91%** of global anode production
- **70%** of global battery cell production

China's Minerals Processing Cartel

Nowhere is China's battery dominance more evident than its ownership of mineral processing:

KEYS TO BATTERY SUPPLY CHAIN INDEPENDENCE

- More investment in mining, processing, and manufacturing of battery materials
- Secure supply of equipment for processing facilities and battery gigafactories
- Partner with allies, including Canada, to expeditiously secure the battery value chain
- Battery recycling to ensure vital materials and technologies stay within our borders
- Stable government policy, permitting reform, and public-private partnerships
- R&D investments in innovative manufacturing technologies and battery materials

A Vision for the Future (World View)

ONLY 2% done with what we need , that is 200-300TWh batteries !

- 8.5 Billion People by 2030 – More than half in developing countries

each person has about 10kWh battery – we will need 85TWh battery

- 6 Billion Smartphones/Smart Tablets – All connected via 5G

This is a small market now – but people with real 5G need fast charging/fast discharging

- 1 Billion Cars to be Electrified – Possibly Electric Planes

We predict that total number of cars will reduce, cars will be better utilized and we will have electric heavy duty trucks and possible V2G enabled – 100TWh

- Grid of the Future

Long duration needs can be fulfilled by technologies other than batteries (H2+Hydro+Thermal) – 100TWh

The Race is NOT Over Yet for Lithium Batteries

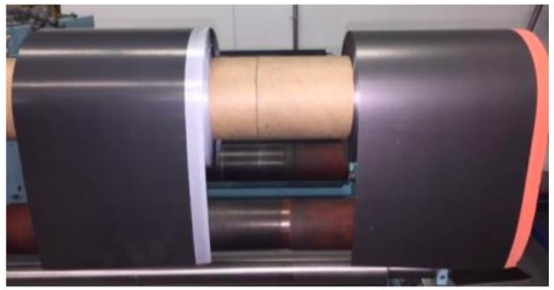
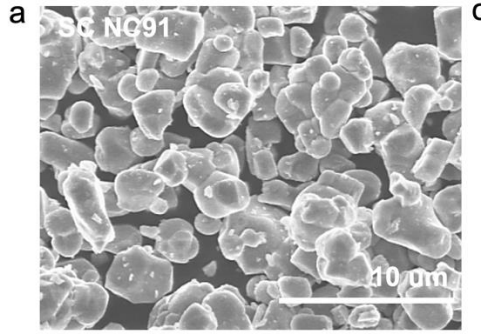


Figure 2. Dry battery electrode NMC roll (left) and graphit roll (right) double sided laminated onto current collecto which is ready for cell assembly.

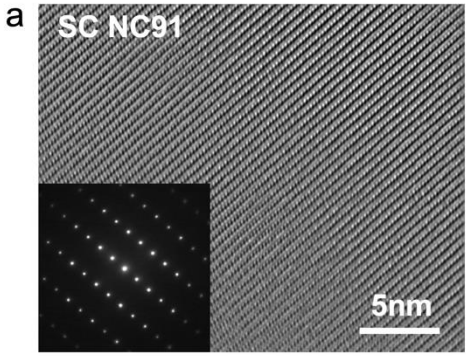
Maxwell Technologies 2017

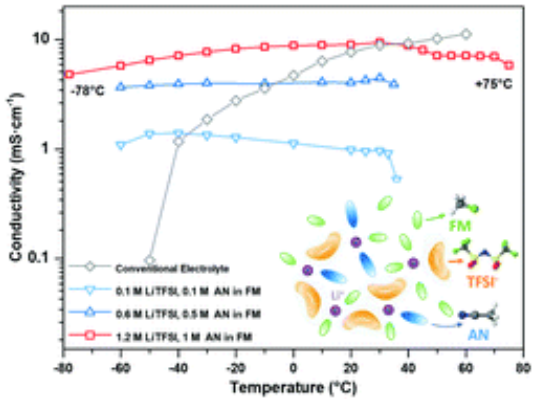
Tesla Acquisition 2019

All Dry 4680 in Cybertruck 2024



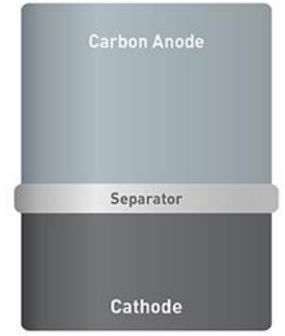
Better Cost Performance Ratio



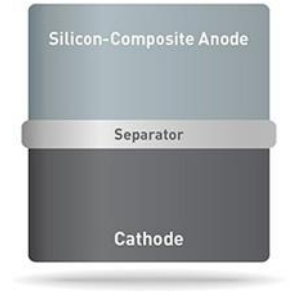


-60 to +60 C
Wider operation temperatures

Gen 0
Li-Metal
100-200 Wh/kg
200-300 Wh/L
Dangerous



Gen 1
Li-ion
200-250 Wh/kg
600 Wh/L
Safe



Gen 2
Li-ion
250-300 Wh/kg
700 Wh/L
Safe

Gen 3
Li-Metal
400-500 Wh/kg
1200 Wh/L
Safest

Dry Battery Electrode (DBE) Processing

Single Crystal NMC/NCA

Electrolyte Genome

Anode-Free

NOV. 11, 2024

BEST INVENTIONS of 2024

TIME

DIGIT, A HUMANOID ROBOT FROM AGILITY ROBOTICS, CLOCKS IN AT WORK

FIREFLY PETUNIAS, FROM LIGHT BIO, GLOW IN THE DARK

+

APPLE'S HEARING AIDS

GOOGLE'S PROTEIN PREDICTOR

YONDR'S ATTENTION-SAVING PHONE POUCHES

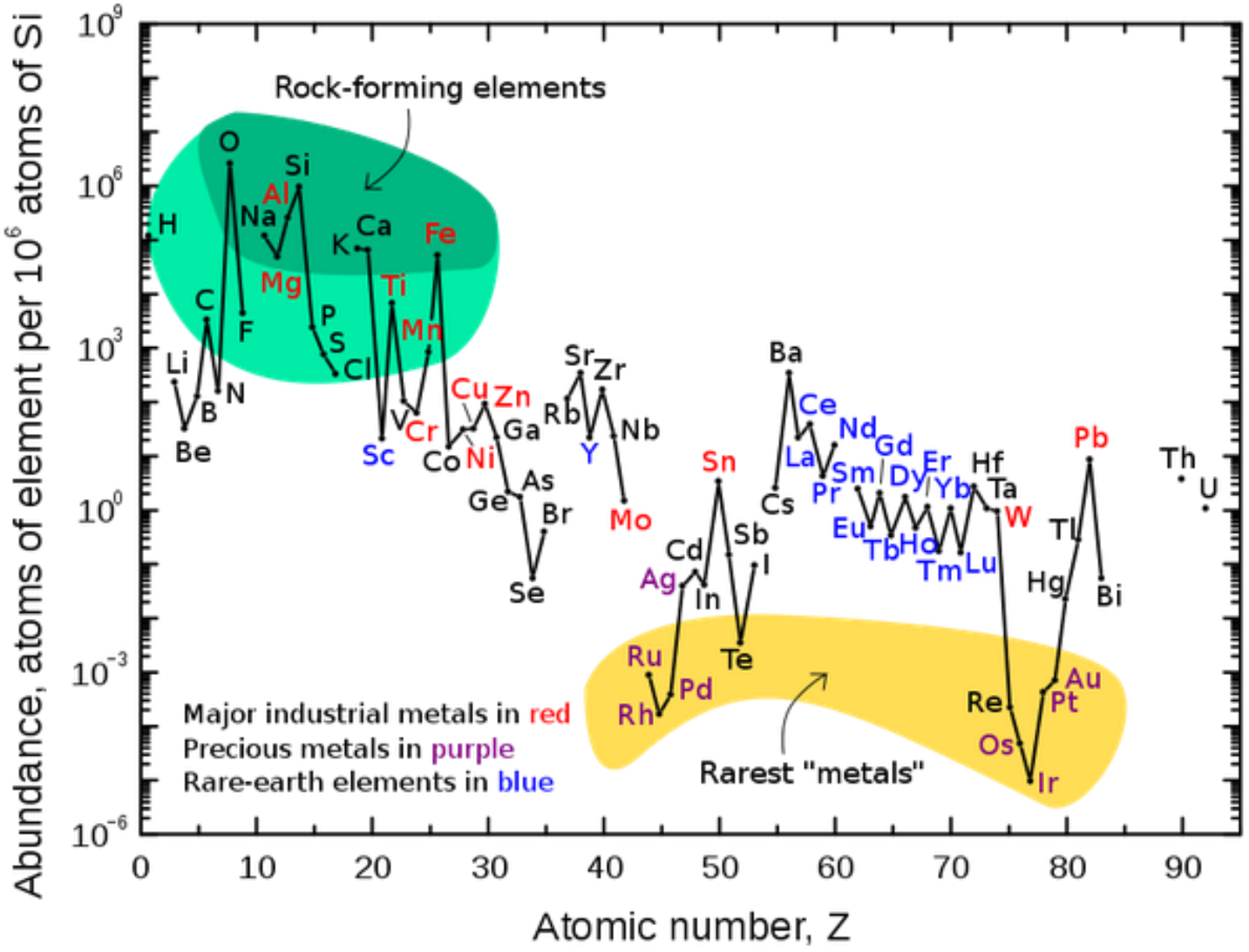
VOLKSWAGEN'S ELECTRIC BUS

ON'S NEXT-GEN RUNNING SHOE

& 193 MORE

time.com

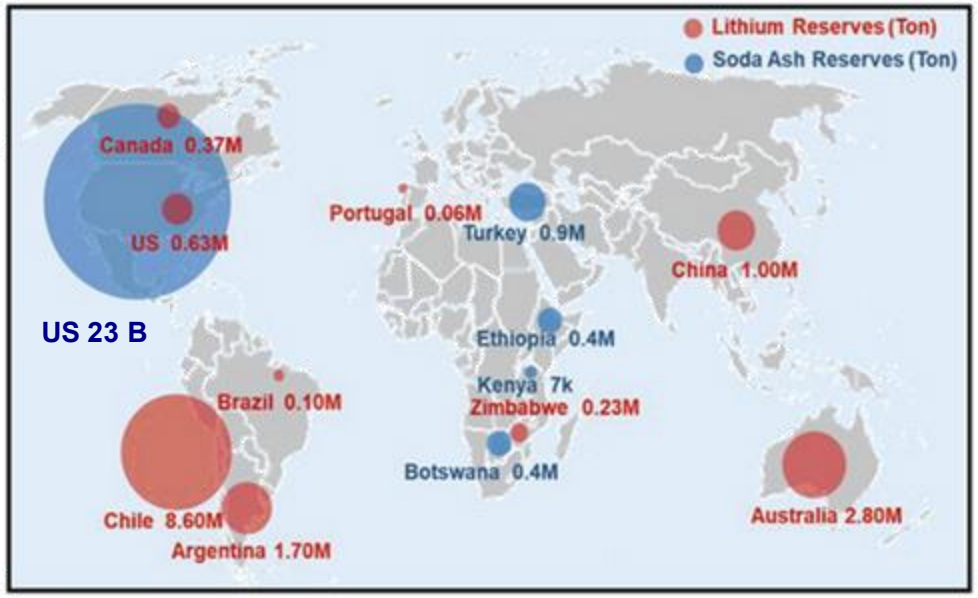
Rock-forming Elements for Battery Tech

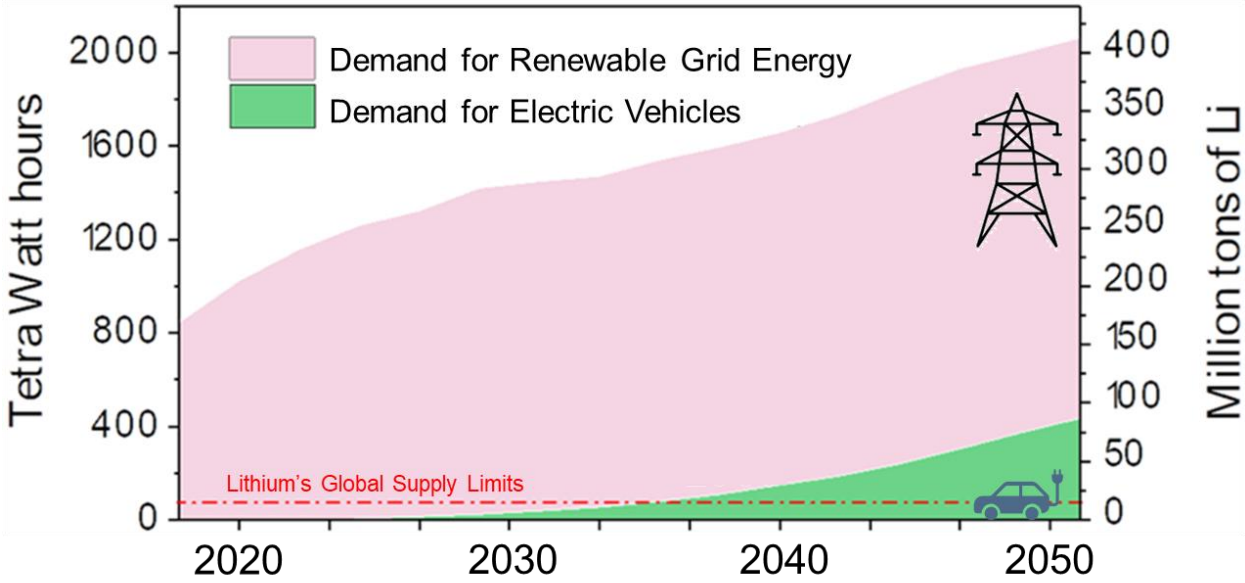


We have enough Li for the first 100TWh (if recycling is fully solved)

Then if we would like to enable energy transition with 300TWh batteries, we do have to look at “rock forming elements”

Na vs Li Materials Sustainability



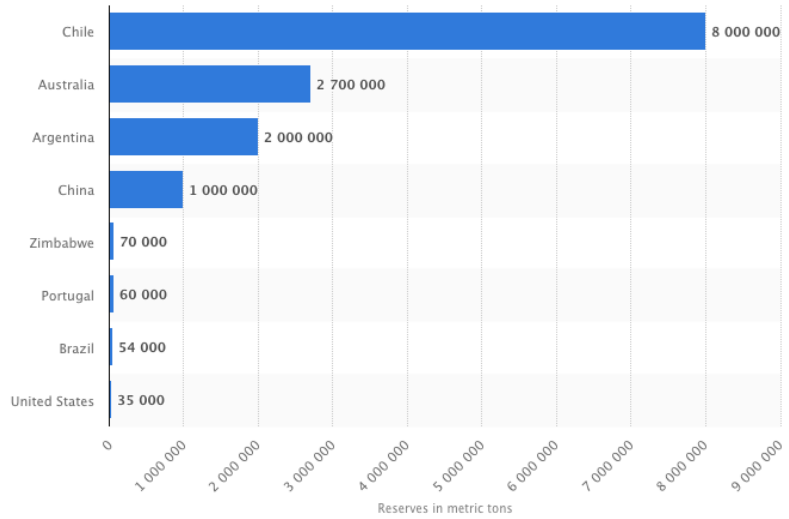


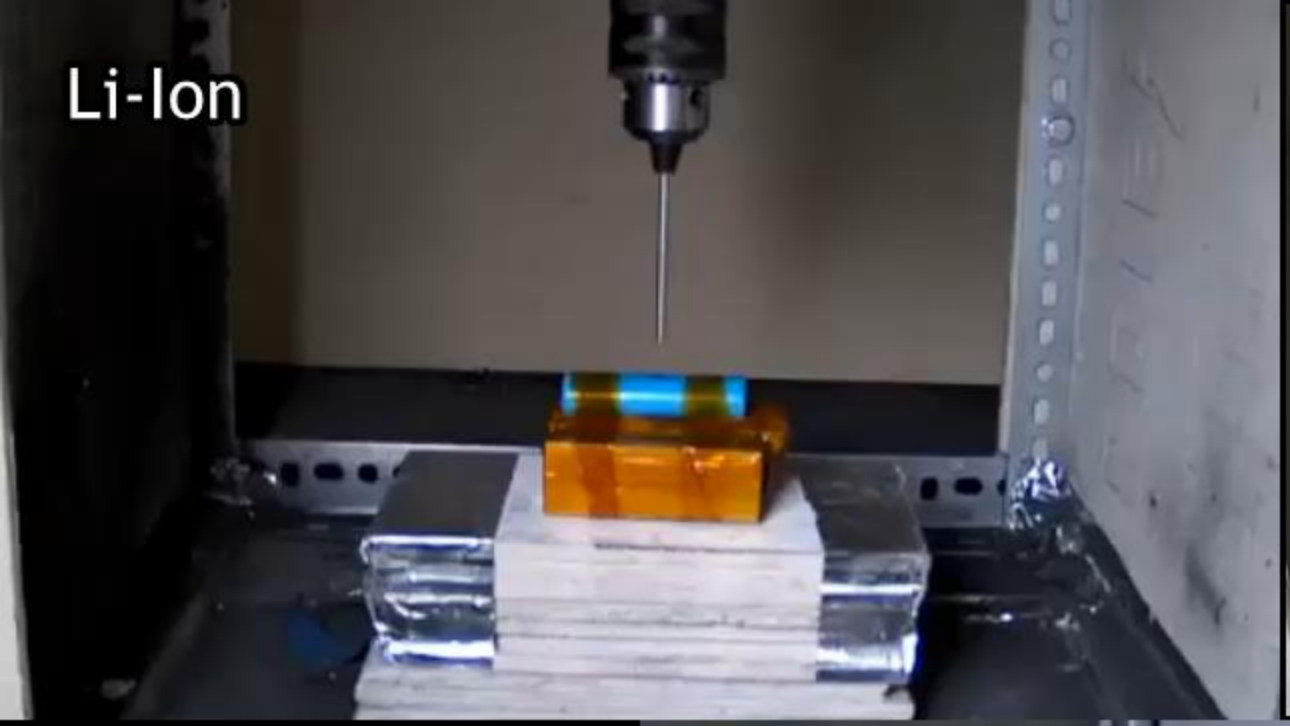
US Energy Storage : Scale

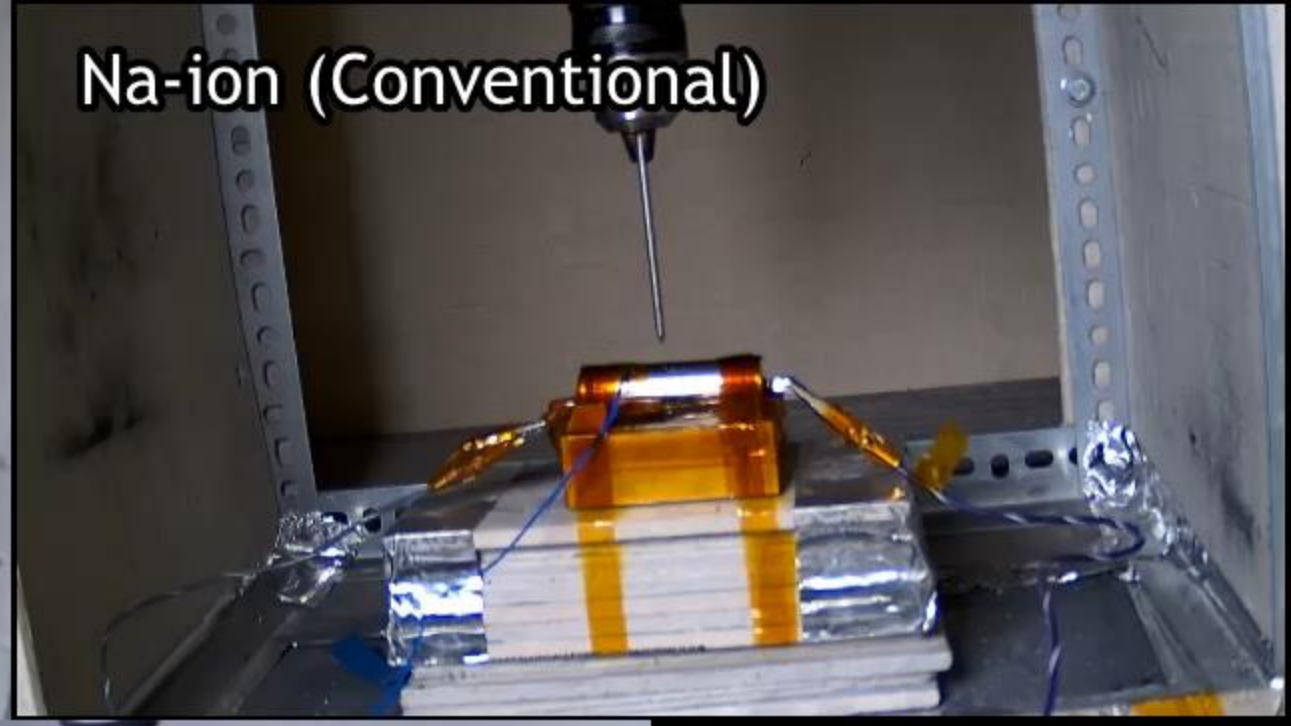
1) **Electrical Grid**
   - Per capita - 12000 kWh / year
   - 400 tera-watt hours if just 10% storage
     → 60 million tons of Li Needed

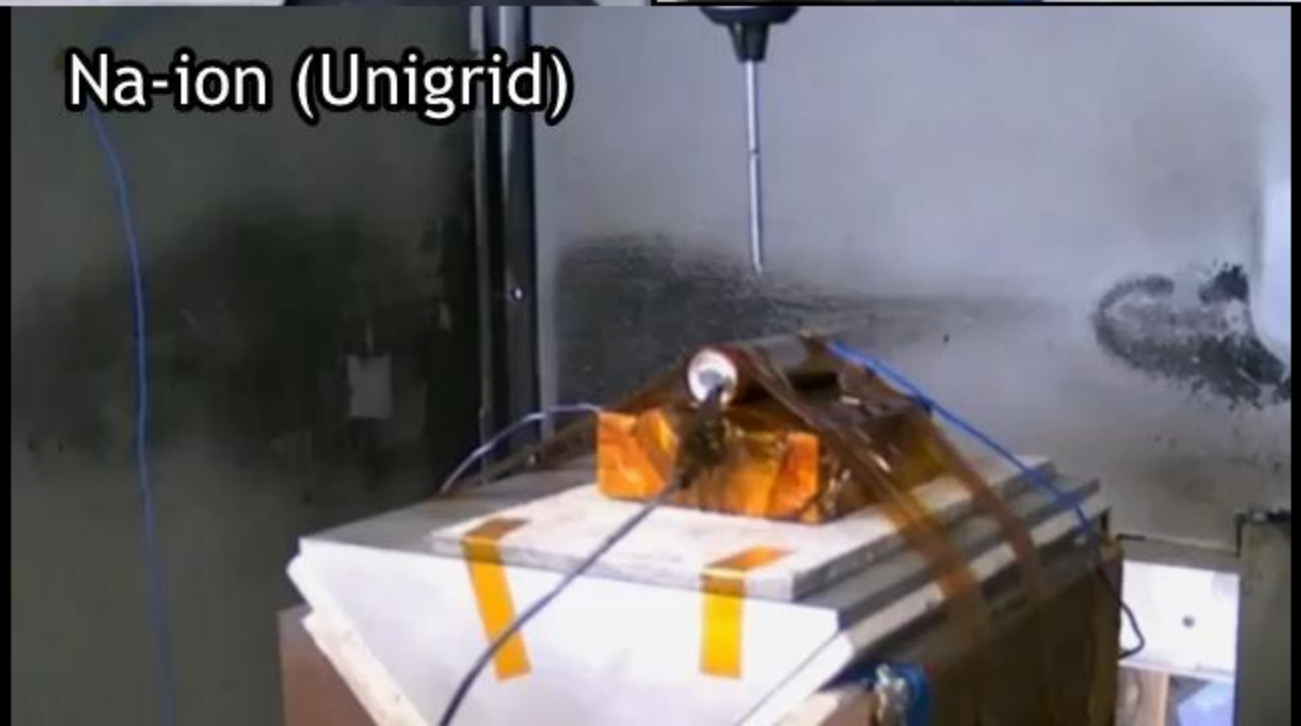
2) **Vehicles**
   - 17 million / year, if all EVs
   - 0.85 tera-watt hours
     → 0.13 million tons of Li Needed

Abundant Sodium in the U.S. is needed to accelerate energy transition

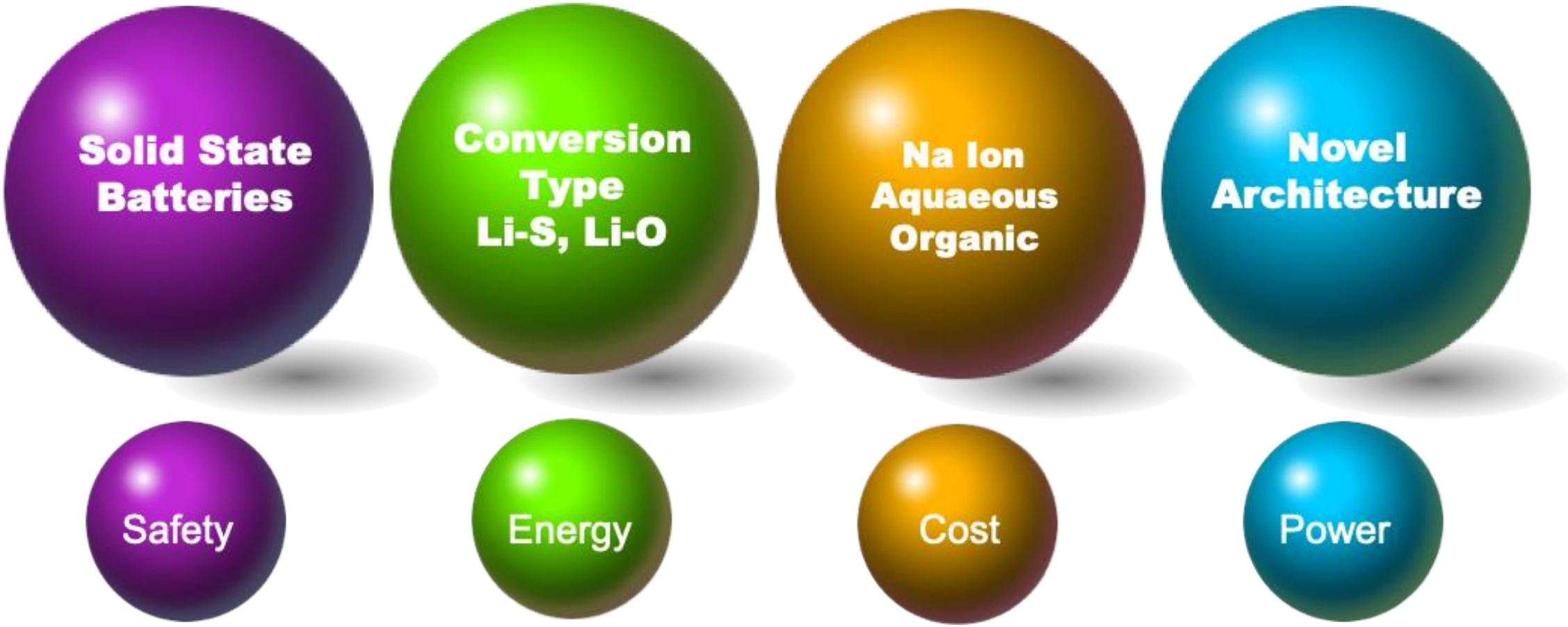



Li-Ion


Na-ion (Conventional)


Na-ion (Unigrid)

Next Decade of Energy Storage and Battery Technology

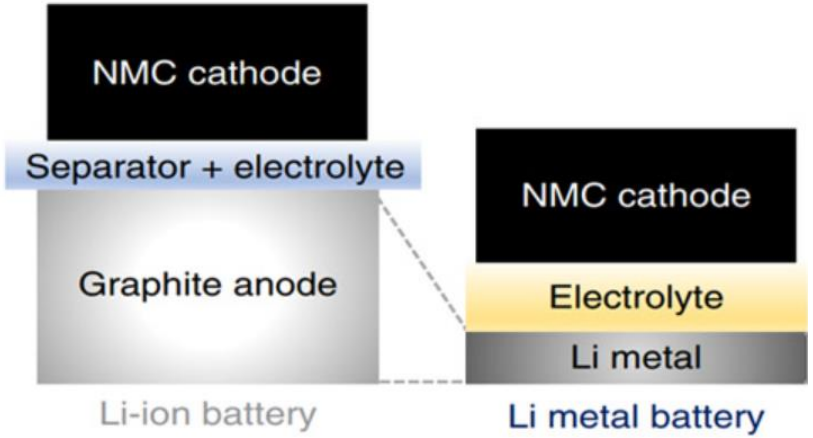


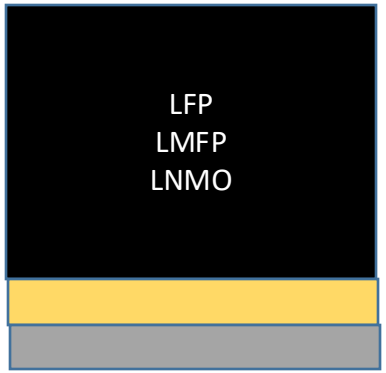
High energy batteries that never catch fire	Batteries last more than 30 years	Batteries can be 100% recycled	Batteries that can be charged full in 5 minutes

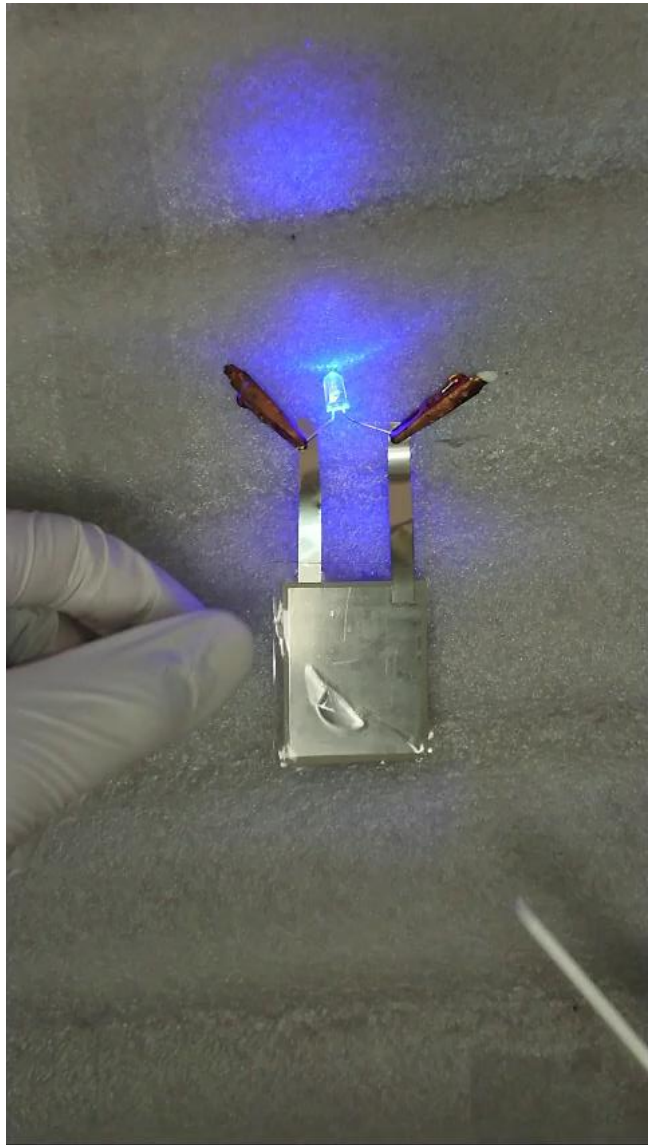
All Solid-State Batteries – Platform Technology

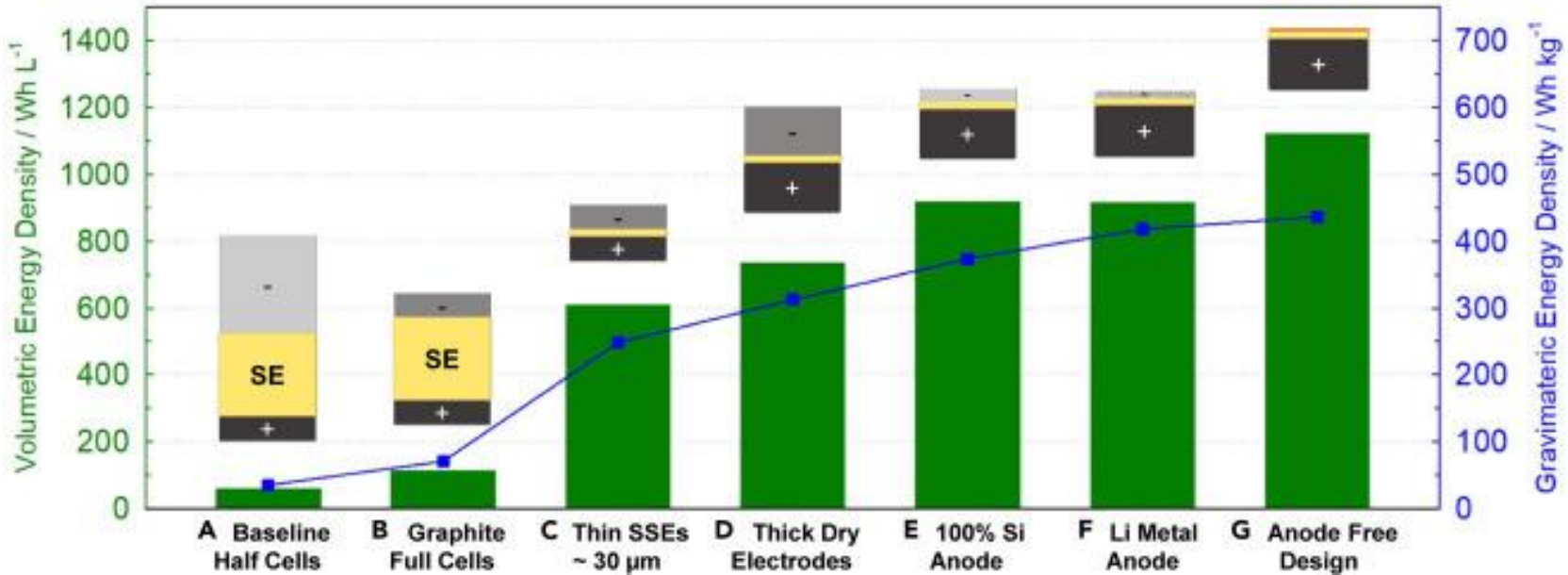
High-Energy-Density *and* ***Safe Batteries***

with ***Solid-State Electrolyte***

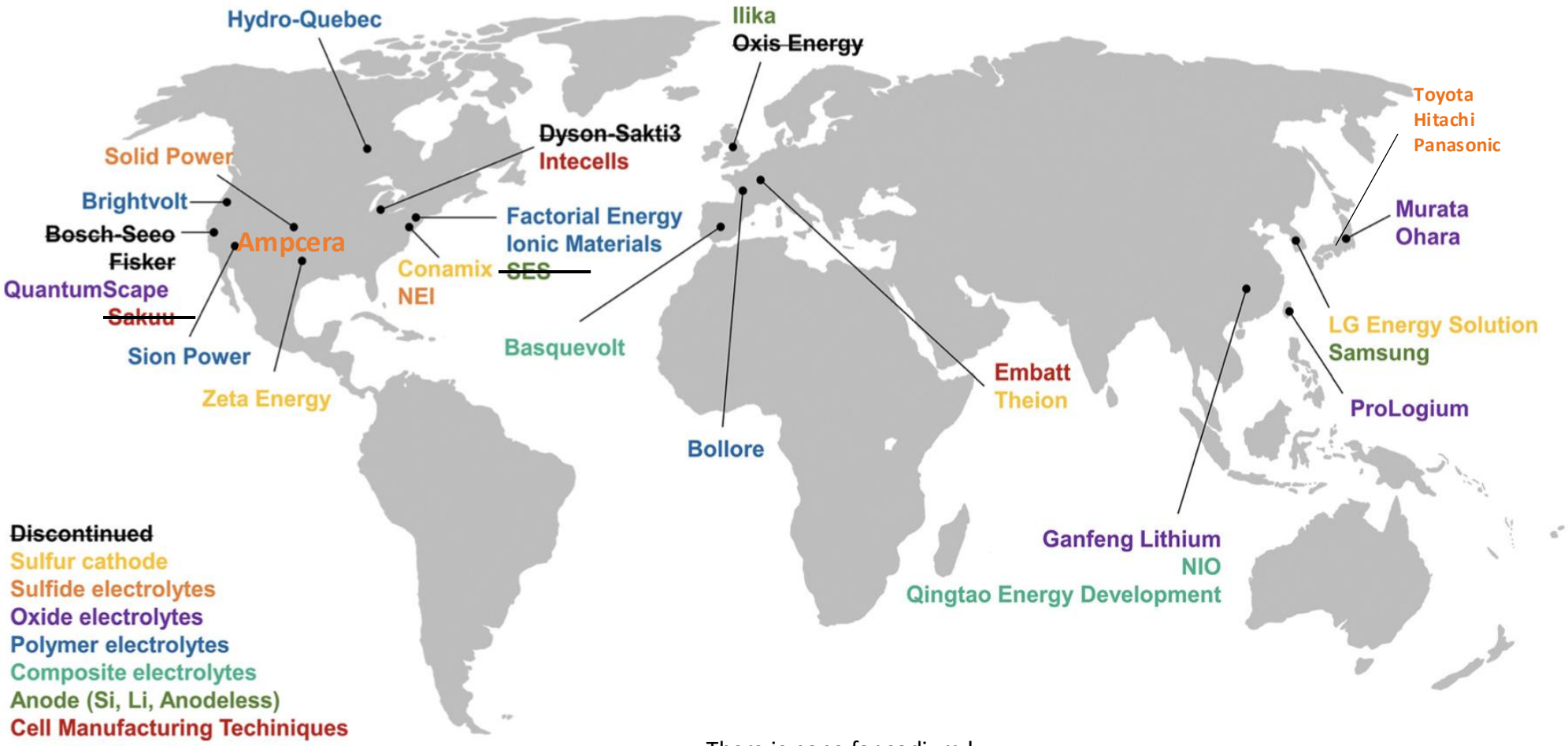








Global R&D of All Solid-State Batteries



There is none for sodium !
The Renaissance is here !!

Chem. Soc. Rev., 2024, (NOT done by our Group ☺)

Where I Will Spend My Time Next Decade

Shirley Meng's Personal View

- Heavy Duty Truck - 300Wh/kg is about **1MJ/kg** (most engine 150kg and diesel 300kg, even though liquid fuel 40MJ/kg) – EV can be lighter than ICE car if we double the battery energy density

Media/Investors/Policymakers needs to be better informed

- Long Cycle No thermodynamic limit to extend 10X (we have the track record) 300 to 3000 and now towards **10,000** cycles

V2G – increase profit margin to incentivize

- Recyclable True circularity is possible! Mining and manufacturing must be improved for **sustainability** – North America and Europe can lead by example!

Bring in experts from companies with scaling/supply chain expertise

Trillion-dollar investment for a decade – yes (Reimagine and re-invest in the Grid – innovation is the way to win the race, tariff can help with our timing)

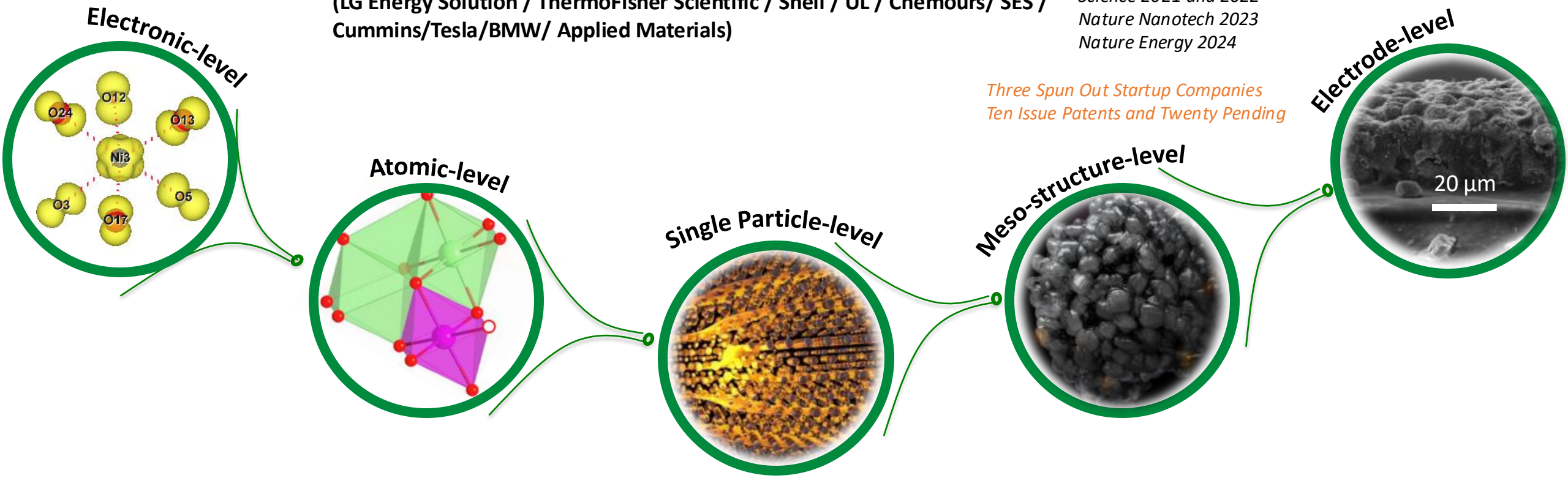
Atom to System - Build Talents, Ideas and An Ecosystem

Workforce from Meng Group
2010 – 2024
30 + 9 Postdoctoral
47 + 20 Ph.D.
50 + 6 Master and Undergrad

Funded by
US Department of Energy (2010 – present)
US National Sciences Foundation (2010 – present))
EFRC – NCCESS (2010-2020)
Battery500 (2016 – present)
MRSEC (2020 – present)
Various Industrial Partners including
(LG Energy Solution / ThermoFisher Scientific / Shell / UL / Chemours/ SES / Cummins/Tesla/BMW/ Applied Materials)

Science 2015
Science 2017 (**South 8 Technologies, Inc**)
Nature Energy 2018
Joule 2018, 2020
Nature 2019
Nature Nanotechnology 2020 (**UNIGRID**)
Nature Materials 2020
Nature Energy 2021
Science 2021 and 2022
Nature Nanotech 2023
Nature Energy 2024

Three Spun Out Startup Companies
Ten Issue Patents and Twenty Pending



UChicago Climate & Energy Research Pillars

Energy Policy & Markets

Understand the costs and tradeoffs of our climate and energy choices

Energy Technologies

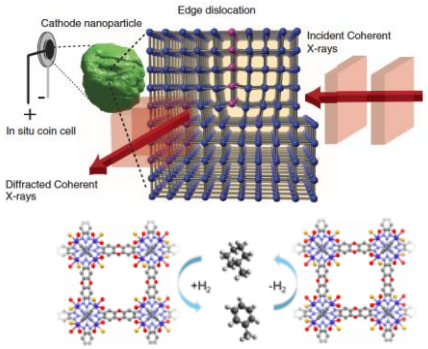
New sustainable and energy efficient products that will drive down the costs of energy products

Climate System Engineering

New approaches to reduce the risks of accumulated greenhouse gasses

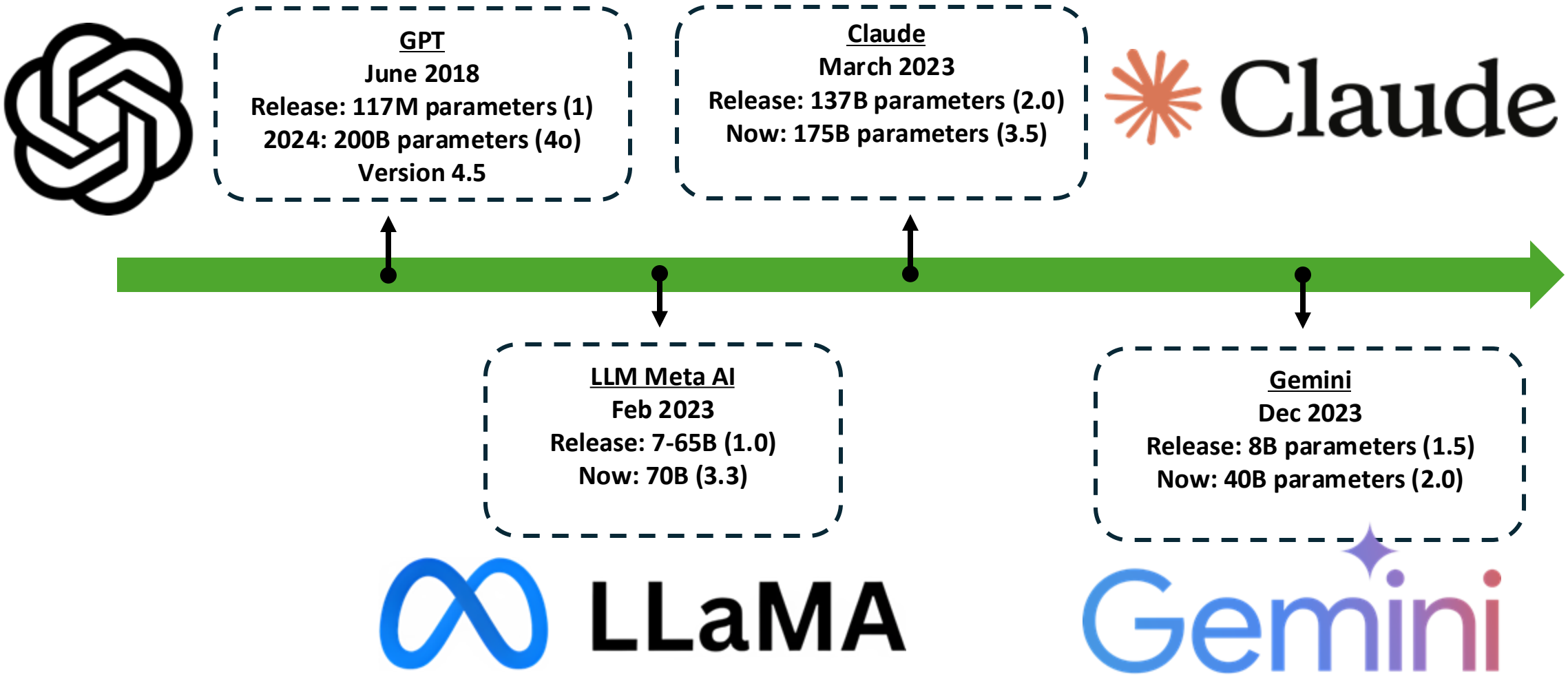
The Energy Transition Network: Solving industry relevant problems across the supply chain

- Pre-competitive convening of academia and industry of partners across the clean energy value chain to enable the clean energy transition goals



APPLIED MATERIALS make possible · ThermoFisher SCIENTIFIC · Gotion · SES · BMW · Mercedes-Benz · UL Solutions · ENSURGE · accelera by Cummins · Shell · MTI · UNIGRID · SOUTH 8 · ExPost · Argonne NATIONAL LABORATORY · POLSKY Center for Entrepreneurship and Innovation THE UNIVERSITY OF CHICAGO · Breakthrough Energy · RESURGENCE INNOVATING FOR RESILIENCE

Timeline of GenAI Models



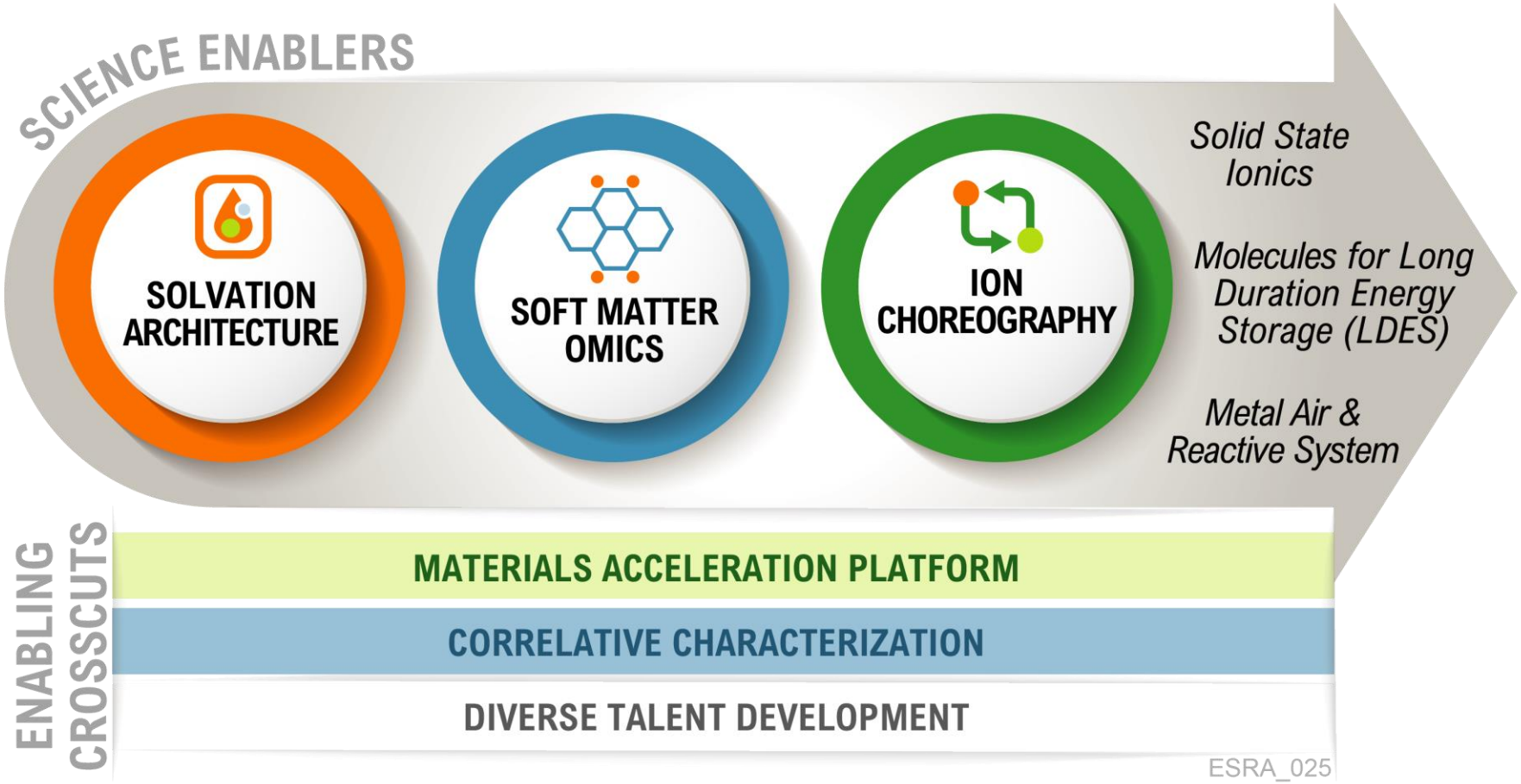
Case study 1: Data tabulation from literature

Q: Can you tabulate electrolyte formulations for lithium-metal battery systems based on a localized high concentration electrolyte design? Also tabulate key metrics such as salt concentration, ionic conductivity, and etc. with references.

Outputs	ChatGPT 4.0	LLaMA 3.3	Claude 3.5	Gemini 2.0
Conceptual explanation	✓	✗	✗	✗
Salt Concentration	✓	✓	✓	✓
Electrolyte Composition	✓	✓	✓	✓
Ionic conductivity	✓	✓	✓	✓
Viscosity	✓	✗	✗	✗
Li+ Transference Number	✓	✗	✗	✗
Electrochemical Stability Window	✓	✓	✓	✗
References	✓	✓	✓	✓


AI MEETS
MATERIALS
A Renaissance in Materials Discovery
TEMASEK

Energy Storage Research Alliance



ESRA GOALS

- ✓ **Integrative and autonomous materials discovery with advanced AI**
- ✓ **Most cutting-edge facilities covering all relevant temporal and length scales**
- ✓ **Close to unity transference number in liquids**
- ✓ **Order-of-magnitude higher transport in soft matter**
- ✓ **Suppression of parasitic reactions in all solids**

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An Energy Innovation Hub funded by DOE Office of Science

Shirley Meng ESRA Director

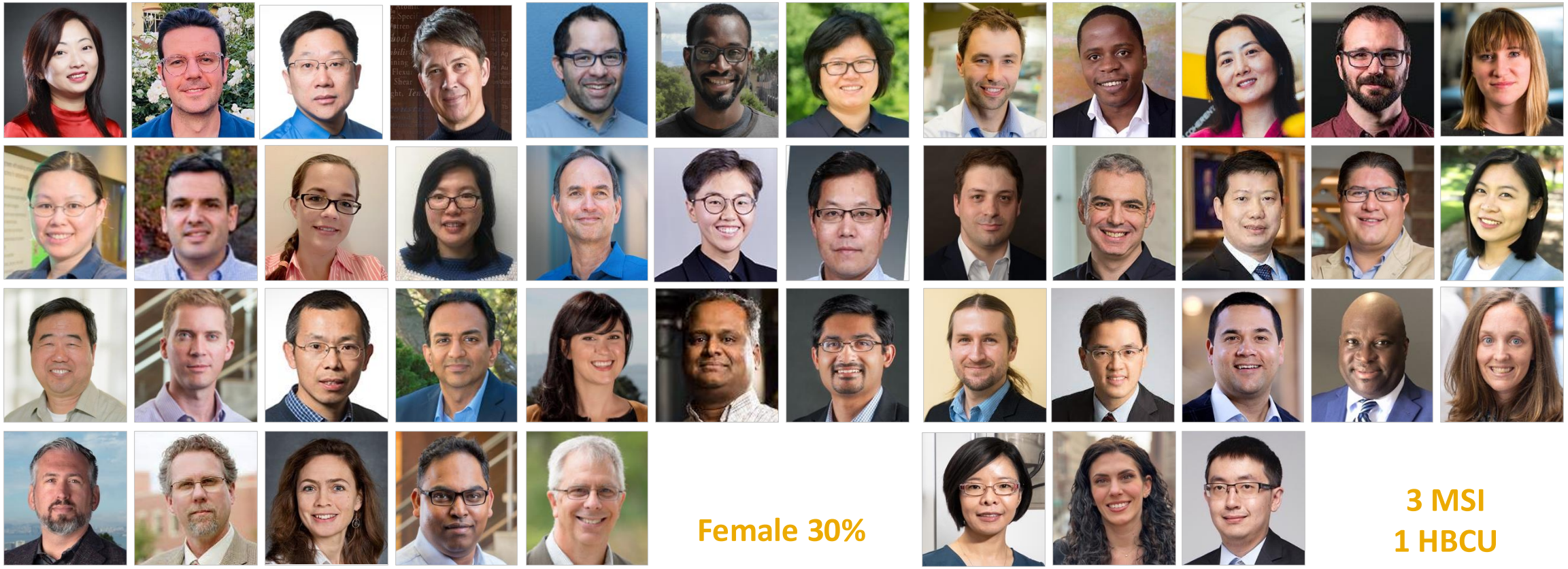
ESRA Core Team

ESRA

https://energystoragera.org/

3 National Laboratories

12 Universities



Female 30%

3 MSI
1 HBCU

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