2[ND] ANNUAL ENERGY STORAGE GRAND CHALLENGE SUMMIT

Innovation in Manufacturing and Securing Domestic Supply Chains

ENERGY STORAGE GRAND CHALLENGE
U.S. DEPARTMENT OF ENERGY

Innovation in Manufacturing and Securing Domestic Supply Chains

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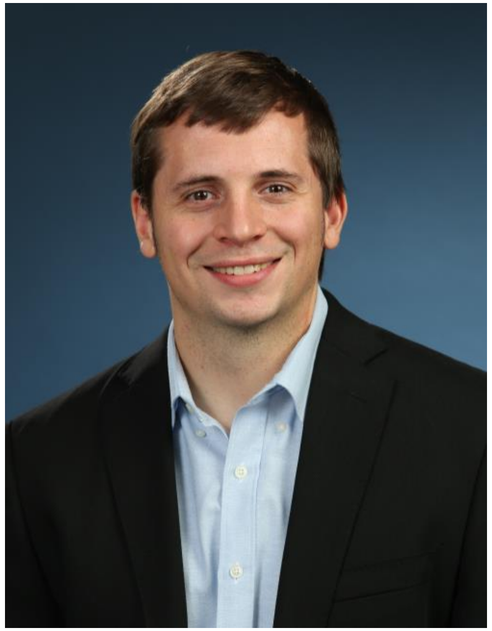

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ESGC Summit: Innovation in Manufacturing & Securing Domestic Supply Chains

Diana Bauer

Acting Deputy Director of the Advanced Manufacturing Office,
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U.S. Department of Energy

September 27, 2022

U.S. DEPARTMENT OF ENERGY

Agenda

- **Innovation in Manufacturing for Energy Storage**
  - Focus areas
  - Challenges
- **Manufacturing and Supply Chain Track**
  - Activities
- **DOE Energy Storage Innovation, Demonstration, and Manufacturing Landscape (Interoffice Collaboration)**
- **New DOE Offices (from AMO):**
  - Industrial Efficiency and Decarbonization Office (IEDO)
  - Advanced Materials and Manufacturing Technologies Office (AMMTO)

Manufacturing and Supply Chain Innovation for Energy Storage

A strong, diverse domestic manufacturing base with integrated supply chains to support U.S. energy storage leadership

Track Focus

Accelerate scale-up of **emerging manufacturing processes**

Improve **critical materials supply chain** resilience

Address **technical barriers** in production and manufacturing

Manufacturing Challenges Across Storage Technologies

Different energy storage technologies face a range of challenges including improving manufacturability and strengthening their supply chains.

Source: ESGC Roadmap	Advance processing and recycling to diversity critical materials sourcing	Lower manufacturing cost			Improve performance				Accelerate manufacturing scale up/scale out	Standardize systems design and testing protocols to streamline integration of innovations
		Membranes	Anode, cathode, electrolyte, & chemistries	Containment structures & materials	Electrolyzers	Advanced storage materials	Bipolar plates	Heat exchangers		
Li-based batteries	●		●					●	●	
Flow batteries	●	●	●	●			●		●	●
Other battery chemistries (e.g., Na-ion)	●	●	●			●			●	●
Mechanical energy storage (e.g., pumped water, compressed air, etc.)						●			●	●
Chemical energy storage	●	●	●		●	●	●		●	
Thermal energy storage				●		●		●	●	●

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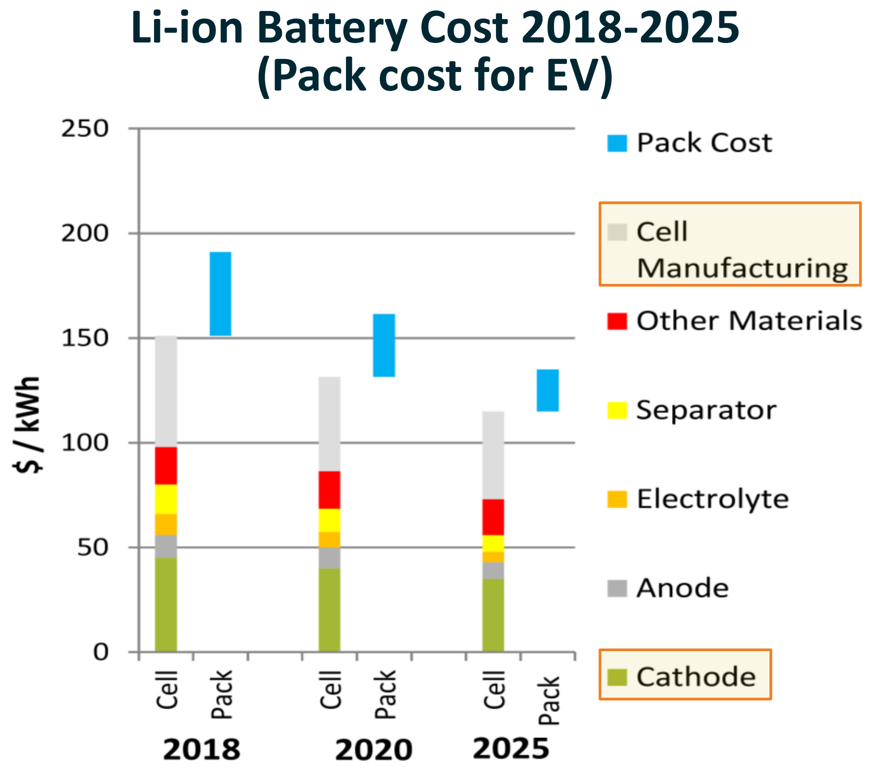
Source: *Energy Storage Grand Challenge Roadmap– December 2020*

Manufacturing Challenges Across Storage Technologies

Where to Focus on for Cost Reduction?
Advanced manufacturing is key for reduced cost.

Ex. Li-ion battery

- **“Cell manufacturing”** and “cathode” account for the two largest cost segments in LiB pack production.
- For 2025, Avicenne Energy estimates both segments will cost ~30% of a $135/kWh pack.



(For production > 100,000 packs/year)

From AVICENNE ENERGY 2019 ADEME-Bpifrance Battery Storage Meeting , Paris, France, May 28, 2019

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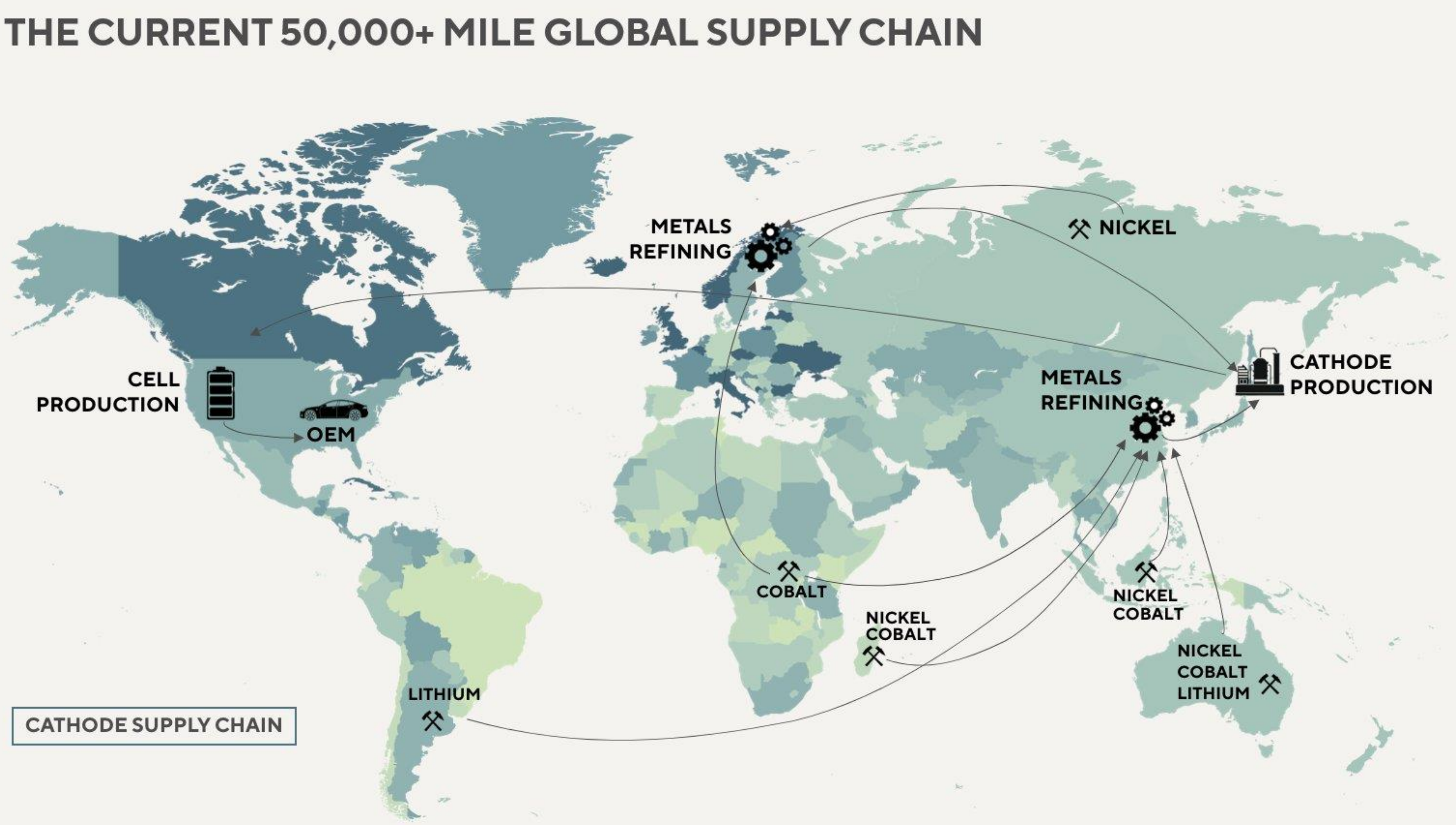
Supply Chain Challenges

The Battery community emphasizes potential supply chain risks.

Ex. Li-ion battery cathode supply chain

Source: Redwood Materials Twitter (9/21/2022)



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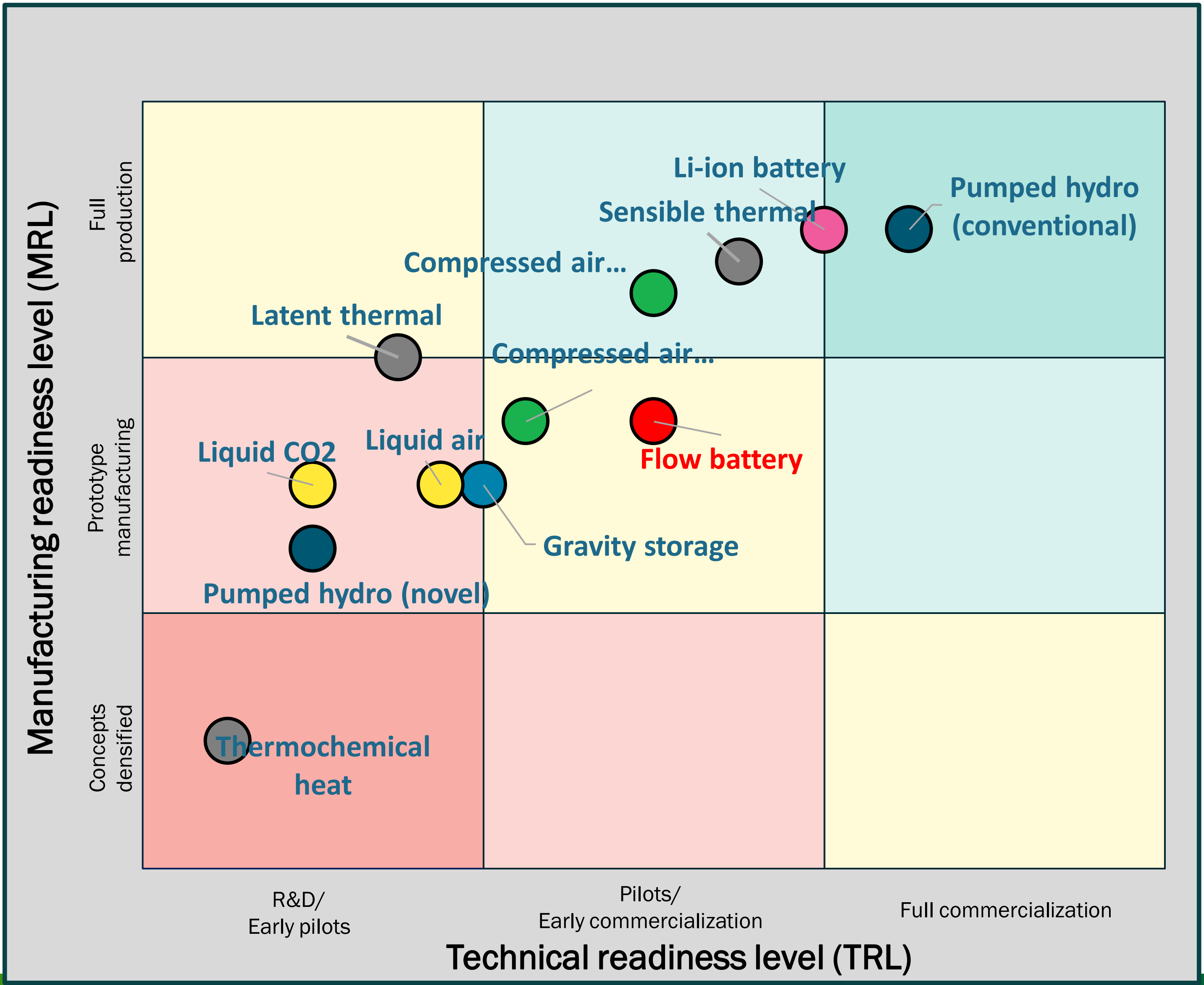
• Flow Batteries: Technology and Manufacturing Maturity Comparison



- Flow batteries form a fairly mature technology group with some on-going evolutionary design improvements.
- However, manufacturing is still inefficient and expensive.

Source: Y. Zhou, "Beyond Lithium-Ion: Long-Duration Storage Technologies, Technology Deep Dive, BloombergNEF, Department of Energy, and International Energy Agency.

Note that different studies might place technical, manufacturing, and market maturity at different places.

• Key DOE Flow Battery Collaborations

Key DOE Flow Battery Collaborations – Technology Advances for Large-Scale Energy Storage

AMO
- New chemistries and designs
- Innovative mfg. capabilities, technologies, and practices
- Accelerated, cost effective scale-up
- Streamlined & secure domestic supply chains

OE
- Predictable and robust systems and components
- Grid use cases and testing protocols
- Safe and reliable large-scale deployment
- Enable systems integration

AMO/OE Flow Battery FOA

Goal: accelerate innovation & deployment by addressing the entire ecosystem:

Upstream → Midstream → Downstream →

- **Raw Material Extraction**
- **Materials Processing** – Increase domestic processing
- **Component Manufacture** – Optimize component design for scale-up
- **Product Assembly** – Enhance system methodology and assembly processes
- **Product Use Phase** – Validate performance at scale (DOE National Labs)
- **End of Life** – Perform accelerated life-time testing

ENERGY earthshots U.S. DEPARTMENT OF ENERGY

Industrial Heat Shot

Develop cost competitive industrial heat decarbonization technologies with **at least 85% lower greenhouse gas emissions by 2035**

>85% Lower Emissions

2035

Timed with 2035 Clean Grid Goal.

3 Pathways to Decarbonize Industrial Heat

Reduce the amount of heat and/or emissions from heat to make cleaner products

Generate Heat from Clean Electricity

Reduce Emissions:
electrify equipment & use clean electricity, improve energy efficiency

Examples:
resistive heating, heat pumps, microwave heating, thermal storage, etc.

Integrate Clean Heat from Alternative Sources

Reduce Emissions:
switch to low-emissions heat sources and increase thermal storage

Examples:
solar thermal, advanced nuclear, geothermal, hydrogen, some sustainable fuels

Innovative Low- or No-Heat Process Technologies

Reduce Emissions:
new chemistry and emerging biotechnology processes to reduce heat demand

Examples:
bio-based manufacturing, electrolysis, ultraviolet curing, advanced separations, etc.

ESGC Manufacturing and Supply Chain Track

Major Activities

Subgroup 1: Analysis (Sarang Supekar and Sara Smith)

- Convening virtual seminar series
- Exploring analysis capabilities

Subgroup 2. Manufacturing for Energy Storage (Albert Lipson and Iiias Belharouk)

Manufacturing of Energy Storage (MOES) workshops

- April 29, 2022: Thermal Storage
- May 6, 2022: Flow Batteries
- May 13, 2022: Solid State Batteries

- Brought together energy storage device manufacturers with manufacturing technologies innovators in
  - Material manufacturing
  - Device fabrication
  - QC w/ AI and ML to improve cost, energy, and environmental performance
- Identified opportunities to transfer technologies
- Identified gaps, barriers, and pitfalls

Manufacturing of Energy Storage (MOES) Fridays | April 29, May 6, May 13

MOES Fridays are part of the U.S. Department of Energy (DOE) Energy Storage Grand Challenge (ESGC) Manufacturing and Supply Chain Subgroup

The workshop report will be available soon

ESGC Manufacturing and Supply Chain Track

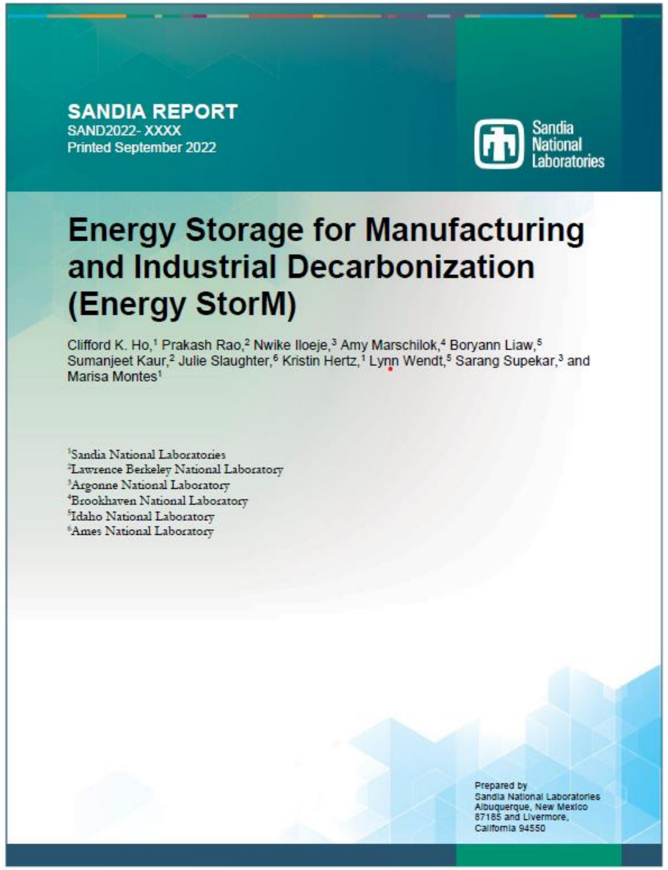
Major Activities

Subgroup 3. Energy Storage for Manufacturing (Cliff Ho and David Reed)

Energy Storage for Manufacturing and Industrial Decarbonization (Energy StorM) Workshop

- February 8 – 9, 2022
- Brought together members of industry, national laboratories, universities, government, and other stakeholders to discuss
    - Carbon-free energy and energy storage for manufacturing and industrial decarbonization.
- Addressed energy needs and challenges for different manufacturing and industrial sectors (e.g., cement/steel production, chemicals, materials synthesis)
- Covered potential role for energy storage technologies including electrochemical, thermal, and chemical energy storage
- Identified needs
    - Large, continuous on-site capacity (tens to hundreds of megawatts),
    - Compatibility with existing infrastructure, cost, and safety.
    - Analysis tools to value energy storage technologies in the context of manufacturing and industrial decarbonization

The workshop report will be available soon.



DOE Energy Storage Innovation, Demonstration, and Manufacturing Landscape

Basic Research	Applied Research and Development		Large-Scale Demonstration	Manufacturing
Basic Energy Sciences (BES) Fundamental research to understand, predict, and control the interactions of matter and energy at the electronic, atomic, and molecular levels to enable revolutionary energy storage technologies	**Vehicle Technologies Office (VTO)** Electric Vehicles • lithium ion • lithium metal • lithium sulfur • solid state	**Office of Electricity (OE)** Stationary/Grid • battery systems (lithium, sodium) • flow batteries • other long duration storage	**Office of Clean Energy Demonstrations (OCED)** **Large-scale clean energy demonstration projects in partnership with the private sector to launch or accelerate market adoption and deployment of technologies**	**Loan Program Office (LPO)** Debt financing for the commercial deployment of large-scale energy projects to support U.S. manufacturing
	Advanced Manufacturing Office (AMO) Support innovative manufacturing technology R&D focused on significantly reducing battery and energy storage cost, energy, emissions, and improve performance			

Advanced Projects Research Agency–Energy (ARPA-E)

- "Off-roadmap" Transformational R&D

Office of Manufacturing and Energy Supply Chains (MESC)

Support Scale-Up and Deployment of manufacturing infrastructure critical to the Nation's energy supply chains

AMO Plans to Become 2 Offices Beginning October 9, 2022

Industrial Efficiency & Decarbonization Office (IEDO)

- Director
  - Deputy Director
    - Energy Intensive Industries
    - Cross-Sector Technologies
    - Technical Assistance & Workforce
    - Technical Project Officers
  - Chief Engineer
  - Operations

Advanced Materials & Manufacturing Technologies Office (AMMTO)

- Director
  - Deputy Director
    - Energy Technology Manufacturing & Workforce Development
    - Next Generation Materials & Processes
    - Secure & Sustainable Materials
    - Technical Project Officers
  - Senior Advisor
  - Operations

Thank you!

Any Questions?

For additional information and to subscribe for updates:
https://www.energy.gov/eere/amo/

Office of Manufacturing and Energy Supply Chains

Energy Storage Grand Challenge Summit

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Program Manger
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September 27, 2022

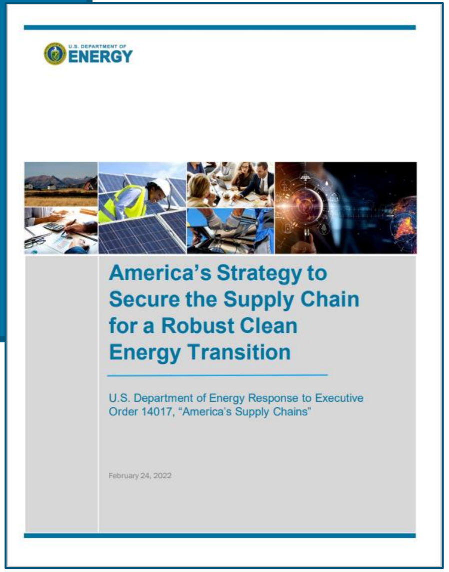
U.S. DEPARTMENT OF ENERGY

Executive Order 14017: America’s Supply Chains
(February 2021–2022)

- DOE released **14 reports on the energy sector supply chains**, including 13 issue-specific deep dive assessments and an overarching strategy report
- “America’s Strategy to Secure the Supply Chain for a Robust Clean Energy Transition” is the **first-ever comprehensive U.S. government strategy to secure our domestic energy supply chains and an Energy Sector Industrial Base**
- Lays out dozens of **critical strategies and actions** to build secure, resilient, and diverse domestic energy supply chains
- Part of a larger **whole-of-government approach** on supply chains

Deep-Dive Assessment Report Topics

- Carbon capture materials
- Electric grid including transformers and high voltage direct current
- Energy storage
- Fuel cells and electrolyzers
- Hydropower including pumped storage hydropower
- Neodymium magnets
- Nuclear energy
- Platinum group metals and other catalyst
- Semiconductors
- Solar photovoltaics
- Wind
- Commercialization and competitiveness
- Cybersecurity and digital components



https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain

DOE Optimizes Structure to Implement $62 Billion in Clean Energy Investments From Bipartisan Infrastructure Law *(February 2022)*

"The Bipartisan Infrastructure Law and the Energy Act of 2020 supercharge the Department of Energy to propel the U.S. economy towards cheaper, cleaner and more reliable energy. These structural changes set DOE up for success in carrying out all of our missions – and to carry them forward for the coming years and decades."

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

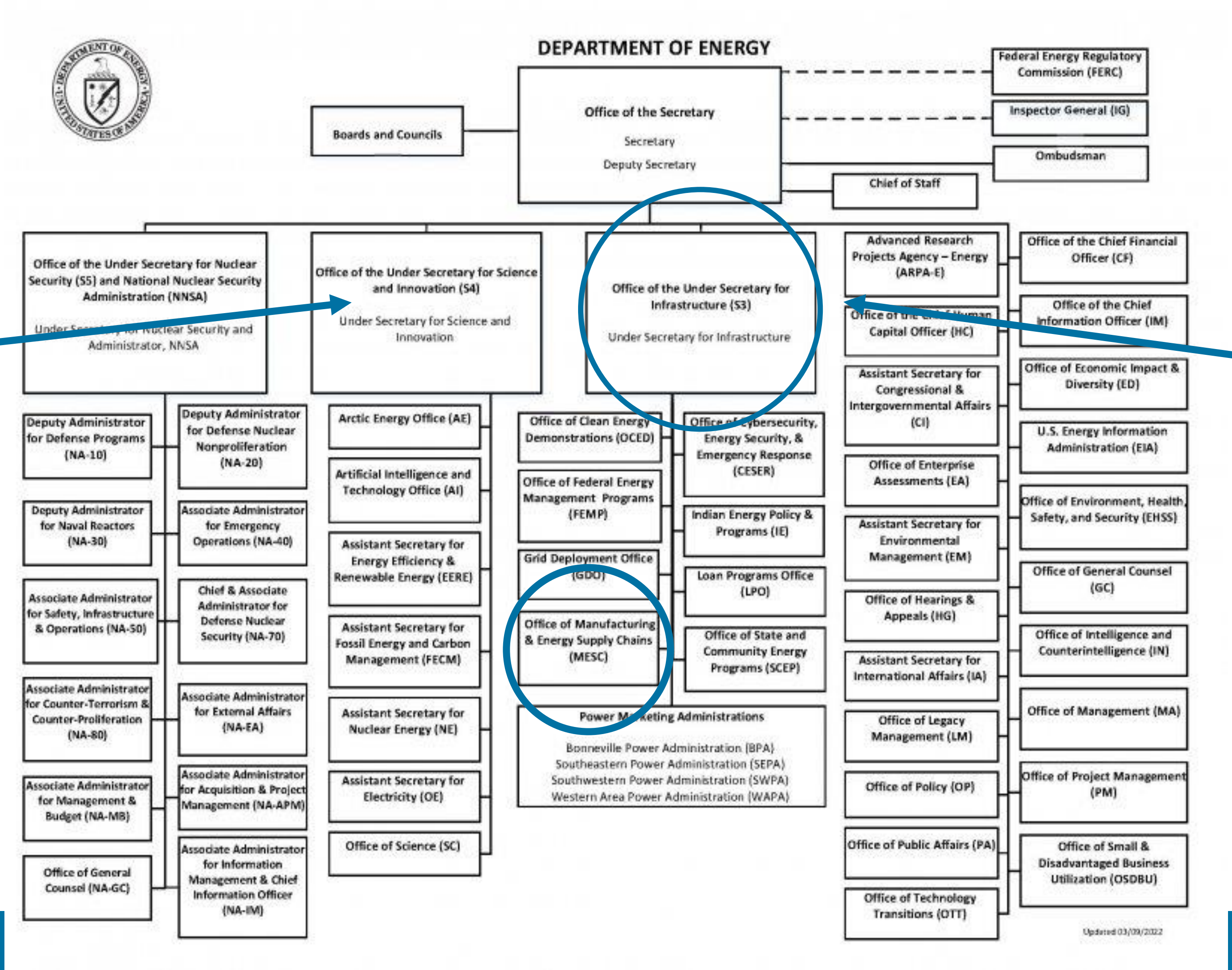
DOE's February 2022 realignment established **the Office of the Under Secretary for Infrastructure**, which will focus on deploying clean energy solutions, and included the launch of three new offices to support clean energy infrastructure deployment:

- The Grid Deployment Office to modernize and upgrade the nation's electric transmission lines and deploy cheaper, cleaner electricity across the country.
- The State and Community Energy Program to work more closely with states, localities, and communities to in the planning and deployment of decarbonization solutions.
- **The Office of Manufacturing and Energy Supply Chains to ensure the energy industrial base is supported by a clean, resilient, domestic supply chain.**

DOE's Office of Manufacturing & Energy Supply Chains, in context

Under Secretary for Science and Innovation (S4)

- Research & Development focus
- Includes EERE, OE, and SC



Under Secretary Demonstration & Deployment (S3)

- Demonstration & Deployment focus
- Includes OCED, LPO, and MESC

DOE's Office of Manufacturing & Energy Supply Chains

Responsible for **strengthening and securing manufacturing and energy supply chains** needed to modernize the nation's energy infrastructure and support a clean and equitable energy transition.

- **Catalyzing the development of an energy sector industrial base** through targeted investments that establish and secure domestic clean energy supply chains and manufacturing
- **Engaging with private-sector companies, other Federal agencies, and key stakeholders** to collect, analyze, respond to, and share data about energy supply chains to inform future decision making and investment.
- Managing programs that **develop clean domestic manufacturing and workforce capabilities**, with an emphasis on opportunities for small and medium enterprises and communities in energy transition.
- Coordinates closely with the Office of Clean Energy Demonstrations for the **management of major demonstration projects, and across all of DOE's programs on manufacturing and supply chain issues**, including with the Advanced Manufacturing Office in the Office of Energy Efficiency and Renewable Energy.

DOE’s Office of Manufacturing & Energy Supply Chains

- **<u>Facility and Workforce Assistance</u>:** Create and support partnerships between the public and private sector to address regional manufacturing and supply chain challenges and train the next generation of energy engineers
  - Industrial Assessment Centers, Expansion, and Implementation ($550M)
  - Manufacturer/Industrial/ Recycling Grants in Distressed Communities ($750M)
  - State Manufacturing Leadership ($50M BIL)
- **<u>Battery and Critical Materials</u>:** Support Scale-Up and Deployment of manufacturing infrastructure critical to the Nation’s energy supply chain
  - Battery Manufacturing, Material Processing, and Recycling (>$6B)
  - Rare Earth Element Demo Facility ($140M)
- **<u>Energy Sector Industrial Base</u>:** Assess and identify national and regional energy sector supply chain gaps and issues, and strategies to address those issues
  - Transformer and EPS Rebates ($20M)

National Blueprint for Lithium Batteries

By 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term U.S. economic competitiveness and job creation, enables decarbonization goals, and meets national security requirements.

https://www.energy.gov/eere/vehicles/articles/national-blueprint-lithium-batteries

- Minerals
- Battery Materials
- Cells/Packs
- Recycling
- Innovation

GOALS TO ACHIEVE OUR VISION

1. Secure access to raw and refined materials and discover alternates for critical minerals for commercial and defense applications
2. Support the growth of a U.S. materials processing base able to meet domestic battery manufacturing demand
3. Stimulate the U.S. electrode, cell, and pack manufacturing sector
4. Enable U.S. end of life reuse and critical materials recycling at scale and a full competitive value chain in the United States
5. Maintain and advance U.S. battery technology leadership by strongly supporting scientific R&D, STEM education, and workforce development

Inflation Reduction Act (IRA)

- Various provisions to support **domestic materials sourcing and battery production**, including credits for clean vehicles with domestic content, and other provisions that can help increase the number of vehicles that qualify and are designed to support domestic materials sourcing and battery production themselves.

- **Grants**:
  - **$2 billion in Domestic Manufacturing Conversion Grants** to support the transition of domestic manufacturing facilities to manufacture EVs, hybrids, and hydrogen fuel cell vehicles
  - **$3 billion as credit subsidies for Advanced Technology Vehicle Manufacturing** through DOE's Loan Programs Office.

- **Credits**:
  - A new **Advanced Manufacturing production tax credit** is created for battery components and critical minerals, along with other critical technology component categories
  - The new and expanded **Advanced Energy Project Credit** credits up to 30 percent of the qualified investment in property used in a qualifying advanced energy project.

- **Direct Purchase**: in an important market signal, **$3 billion is allocated for the United States Postal Service** to purchase zero-emission electric vehicles and install charging infrastructure.

Thank you

Visit
energy.gov/MESC

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ENERGY

Strengthening and securing energy supply chains to modernize the nation’s energy infrastructure and support the clean energy transition

BREAKTHROUGH MULTI-DAY ENERGY STORAGE,

Billy Woodford
Co-founder & Chief Technology Officer
September 27, 2022

Form energy

Energy Storage
For A Better World

Our team: 300+ employees across the U.S.

200k square feet of facilities across Somerville, MA; Berkeley, CA; and near Pittsburgh, PA

Our leadership

Decades of experience in energy storage, 100's of MWs deployed, and over $1 billion of equity raised

CHARLOTTE BEARD
SVP, Finance

- VP of Tile Inc; Director of Energy Products Finance for Tesla
- B.S Accounting, Defiance College

SARAH BRAY
VP, Communications

- Founder, Innovant Public Relations; VP, Clean Line Energy; Sr. Manager, EDPR
- B.B.A., University of St. Thomas

YET-MING CHIANG
Chief Science Officer

- MIT Professor, Founder of 6 companies
- S.B Materials Science, Engineering, MIT

MARCO FERRARA
SVP, Analytics/BD

- VP IHI (ESWare)
- Ph.D. Nuclear Engineering, MIT

MATEO JARAMILLO
Chief Executive Officer

- Founder Tesla Energy, Tesla VP
- A.B. Economics, Harvard

RJ JOHNSON
SVP, Commercial Operations

- Head of Energy Operations, Tesla; VP of Origination, NextEra; US Army
- MBA, University of Chicago

ZAC JUDKINS
VP, Product Development

- VP of Products for SunPower
- M.S Materials Science, Engineering, MIT

BRIAN LEWIS
Deputy General Counsel

- Director & AGC, Facebook; Assistant U.S. Attorney, Oakland
- A.B., Princeton; J.D., Georgetown

NIDHI THAKAR
VP, Policy & Regulatory

- Sr. Director, Portland General Electric; CA PUC; U.S. DOE
- A.B., University of Maryland, J.D., Lewis & Clark Law School

SOZI TULANTE
General Counsel

- Partner, Dechert LLP; Solicitor, City of Philadelphia; Assistant U.S. Attorney
- A.B., Harvard; J.D., Harvard

TED WILEY
President & Chief Operating Officer

- Co-founder Aquion; US Army
- MBA, Harvard

WILLIAM WOODFORD
Chief Technology Officer

- Director R&D 24M
- Ph.D Engineering, MIT

Form energy

Our investors: long-term, impact-oriented

$367M in Venture Capital to Date

TEMASEK

TPG RISE CLIMATE

ArcelorMittal

ENERGY IMPACT PARTNERS

Breakthrough Energy VENTURES

Prelude VENTURES

COATUE

MACQUARIE

THE ENGINE Built by MIT

NGP ENERGY TECHNOLOGY PARTNERS III

Eni

CAPRICORN INVESTMENTGROUP

The Challenge

The electrical grid needs to fundamentally transform to meet today's challenges

Extreme weather conditions have become more frequent and disruptive

Power supply is becoming tighter

Intermittent resources need firming up

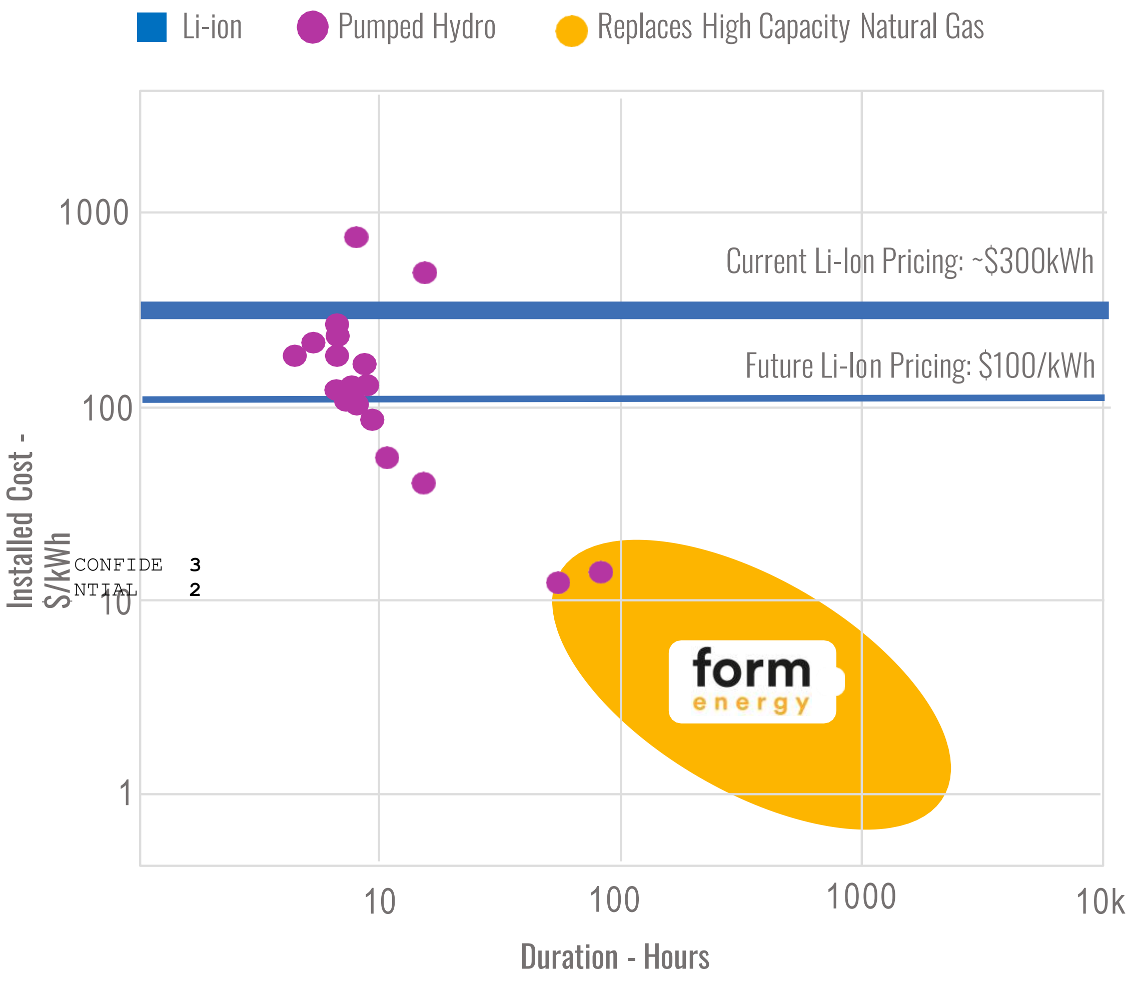
Increased transmission congestion and long interconnection queues

5

What kind of storage would it take to replace high capacity factor natural gas?

- For renewable generation to replace energy functions of natural gas/coal on the grid, **new storage solutions must be >24 hours duration AND 10-100X cheaper than lithium ion.**

- Pumped hydro is longest duration/lowest cost today



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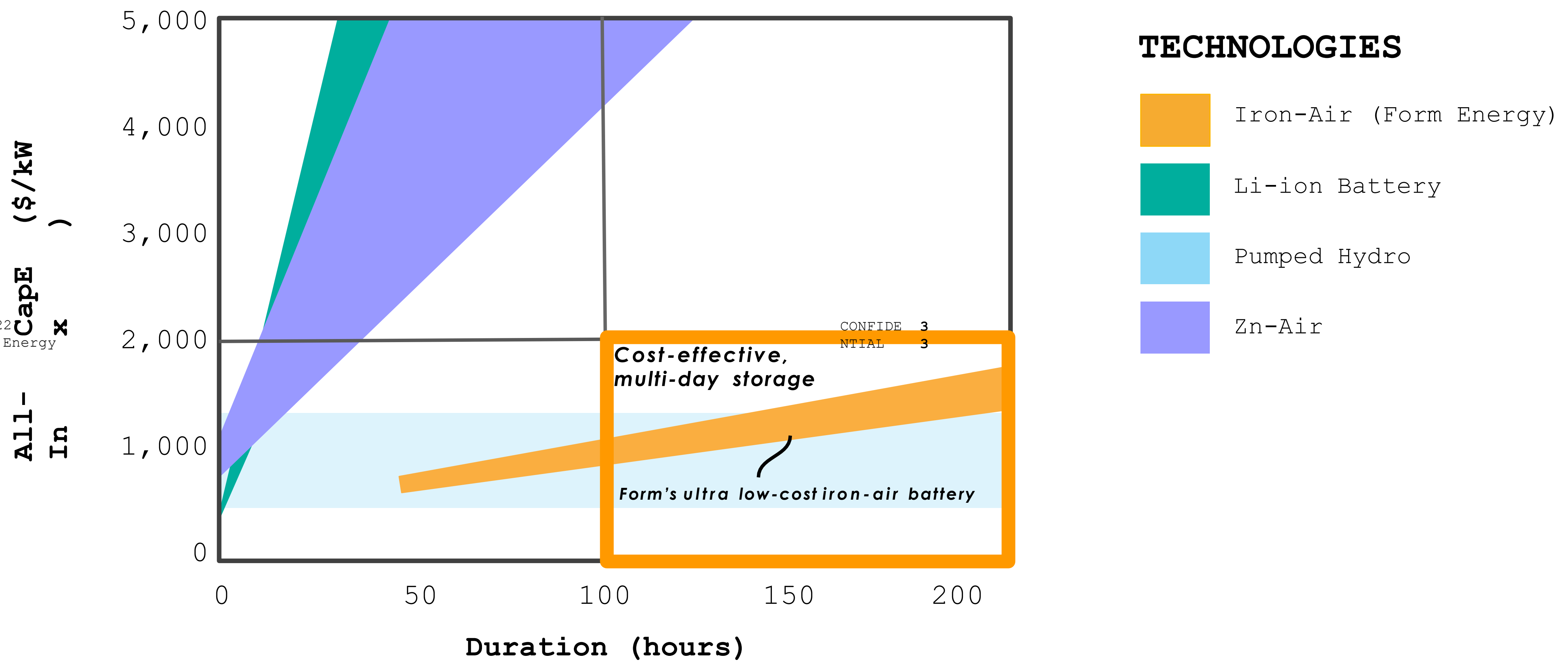
New storage solutions must be 10x longer duration & 10x cheaper

Form's multi-day storage is uniquely positioned to displace fossil generation



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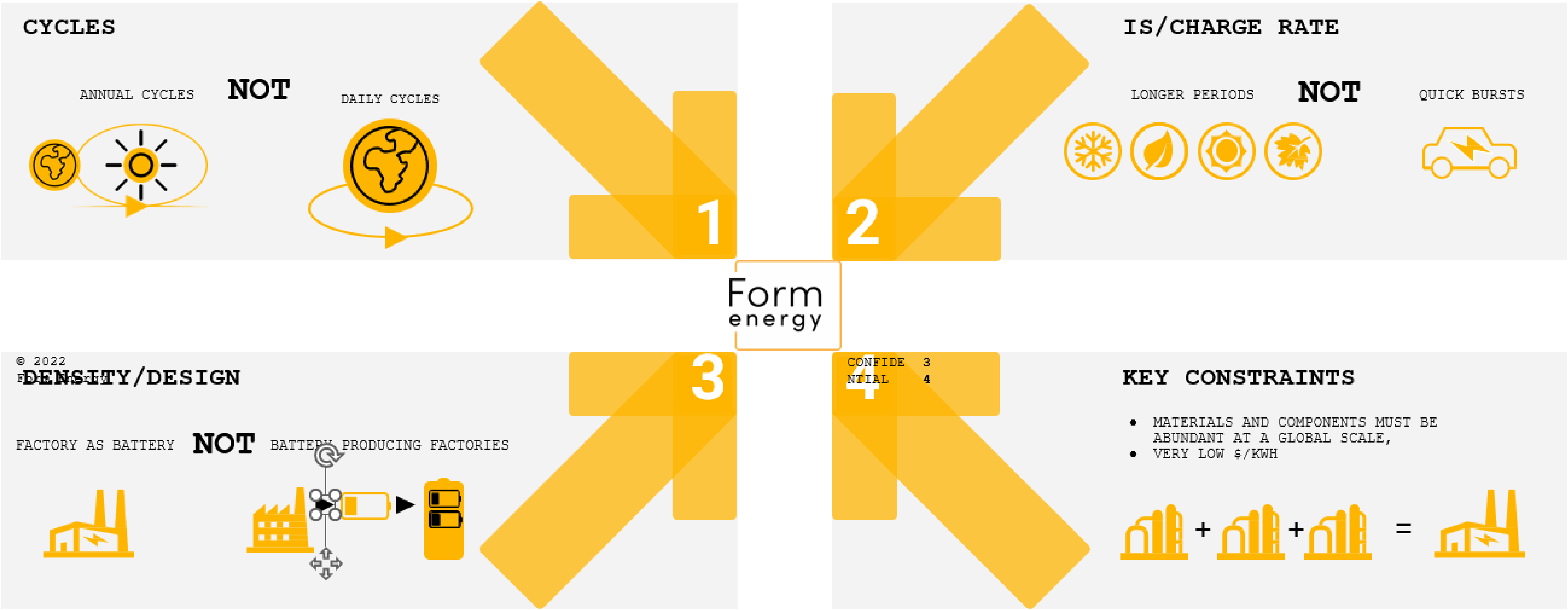
But what kind of storage exactly is Form Energy developing?



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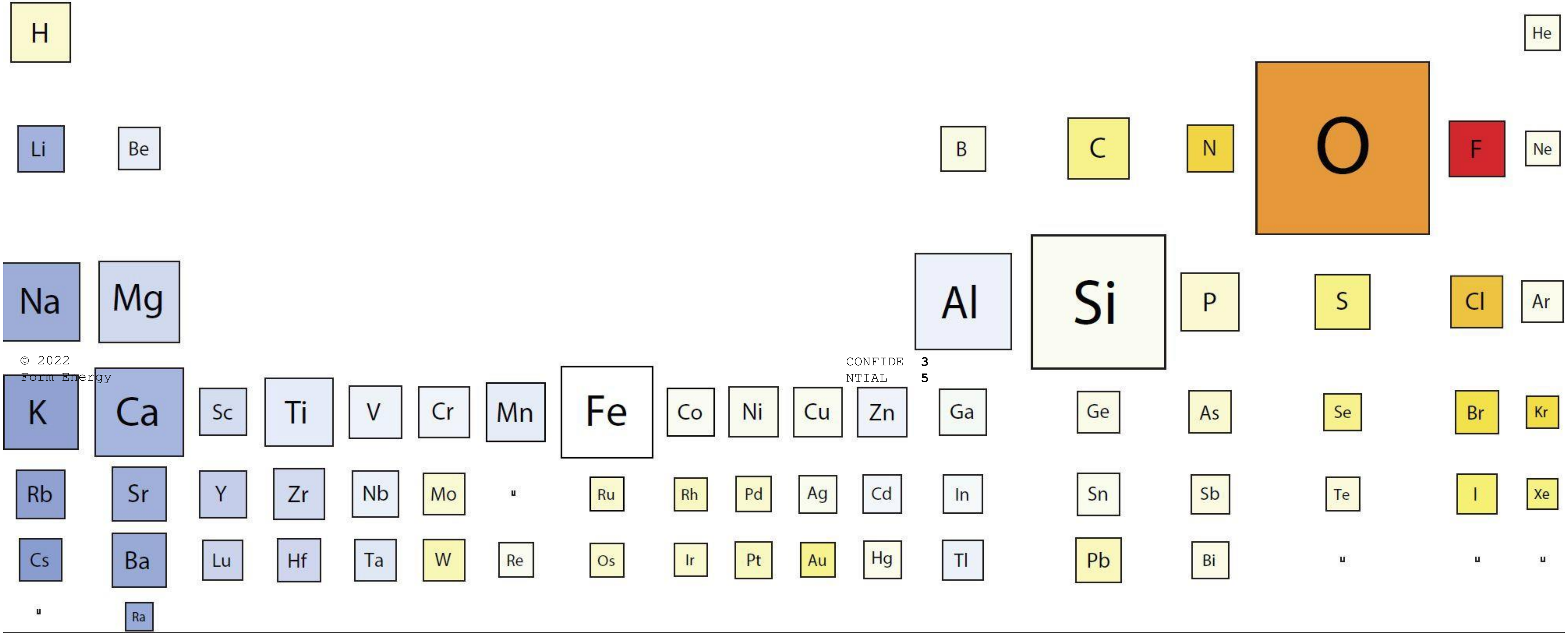
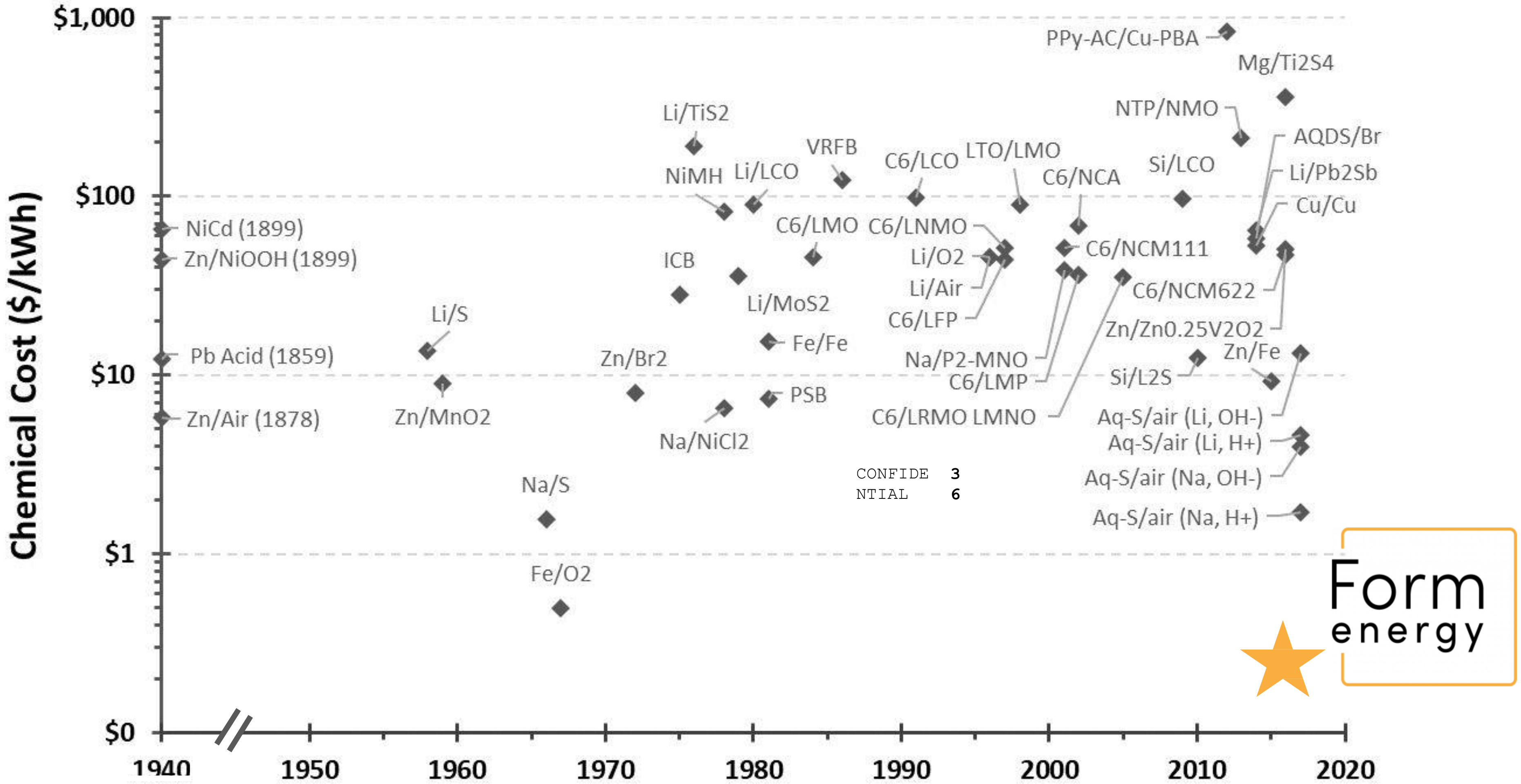
The Elements (Scaled by log – Crustal Abundance)



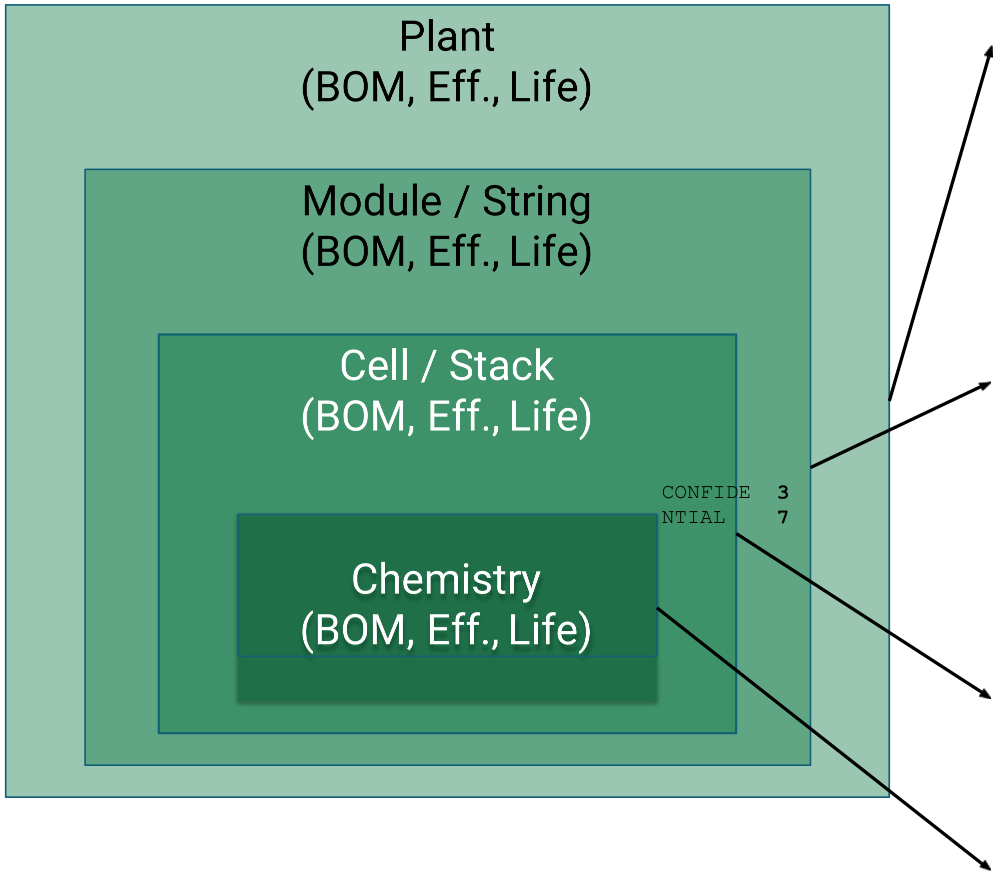
Form's iron-air battery has the lowest-cost entitlement



Li et al., Joule, 2017 JCESR | Joint Center for Energy Storage Research

Techno-economic analysis: cells to plants

Low-cost chemistry is necessary but not sufficient.



- Land
- Works (Electrical, Civil)
- Interconnection
- Development Fee
- End-of-life

- HVAC
- Blowers
- Bus bars
- Safely infrastructure
- Controls
- Mechanical enclosure
- Gas treatment / scrubbing

- Mechanical design
- Air electrode switching
- Air handling
- Current collection

- Anode
- Cathode
- Electrolyte

Rechargeable iron-air is the best technology for multi-day storage

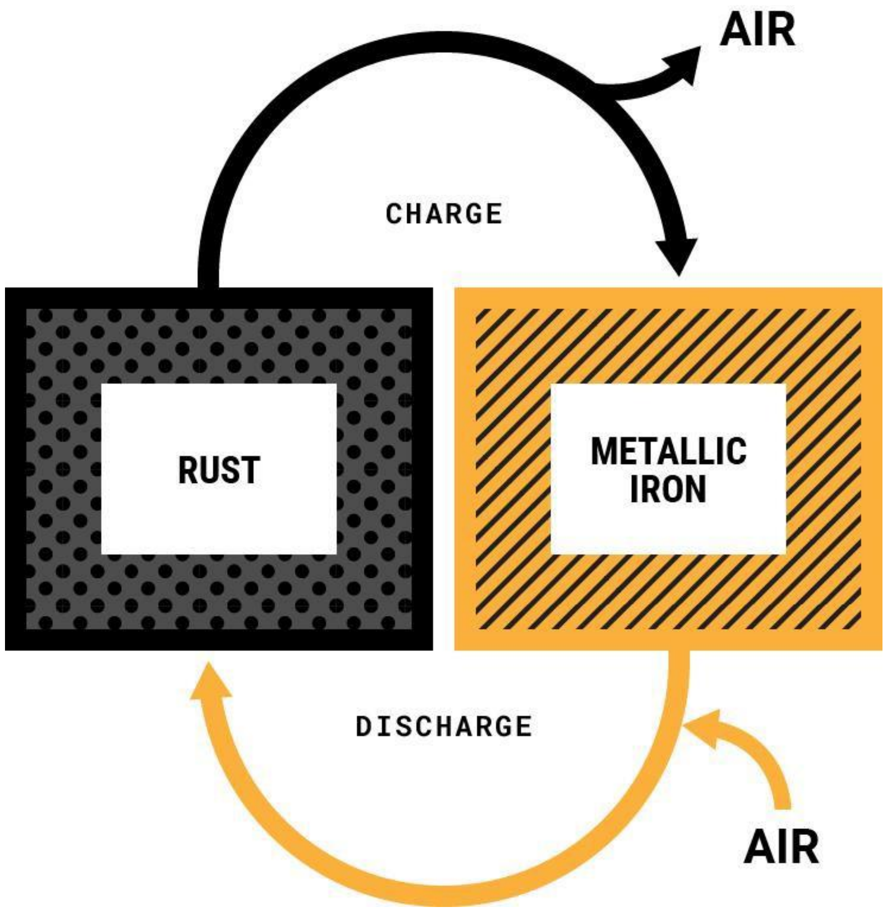
COST
Lowest cost rechargeable battery chemistry.
Less than 1/10th the cost of lithium-ion batteries

SAFETY
Non-flammable aqueous electrolyte. No risk of thermal runaway. No heavy metals.

SCALE
Uses materials available at the global scale needed for a zero carbon economy. High recyclability.

RELIABLE
100+ hr duration required to make wind, water and solar reliable year round, anywhere in the world.

Reversible Rust Battery



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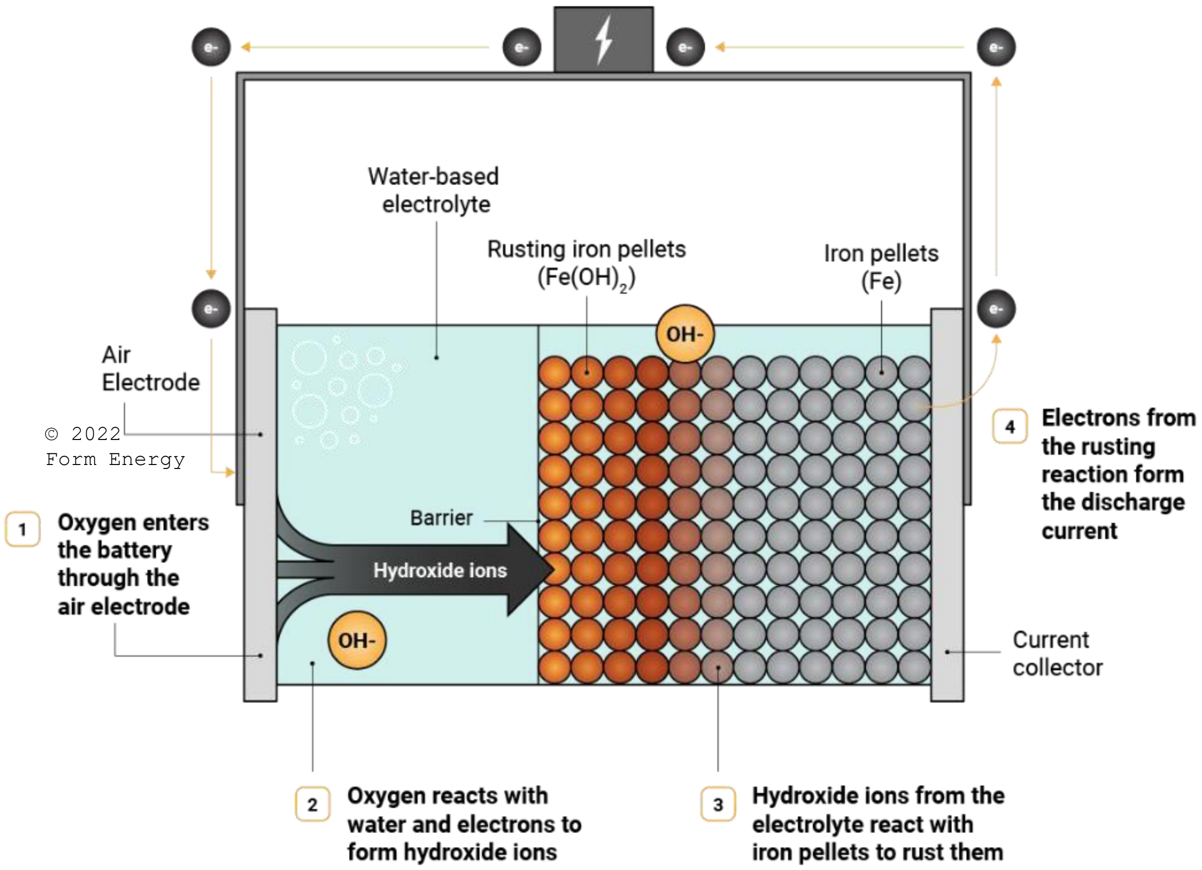
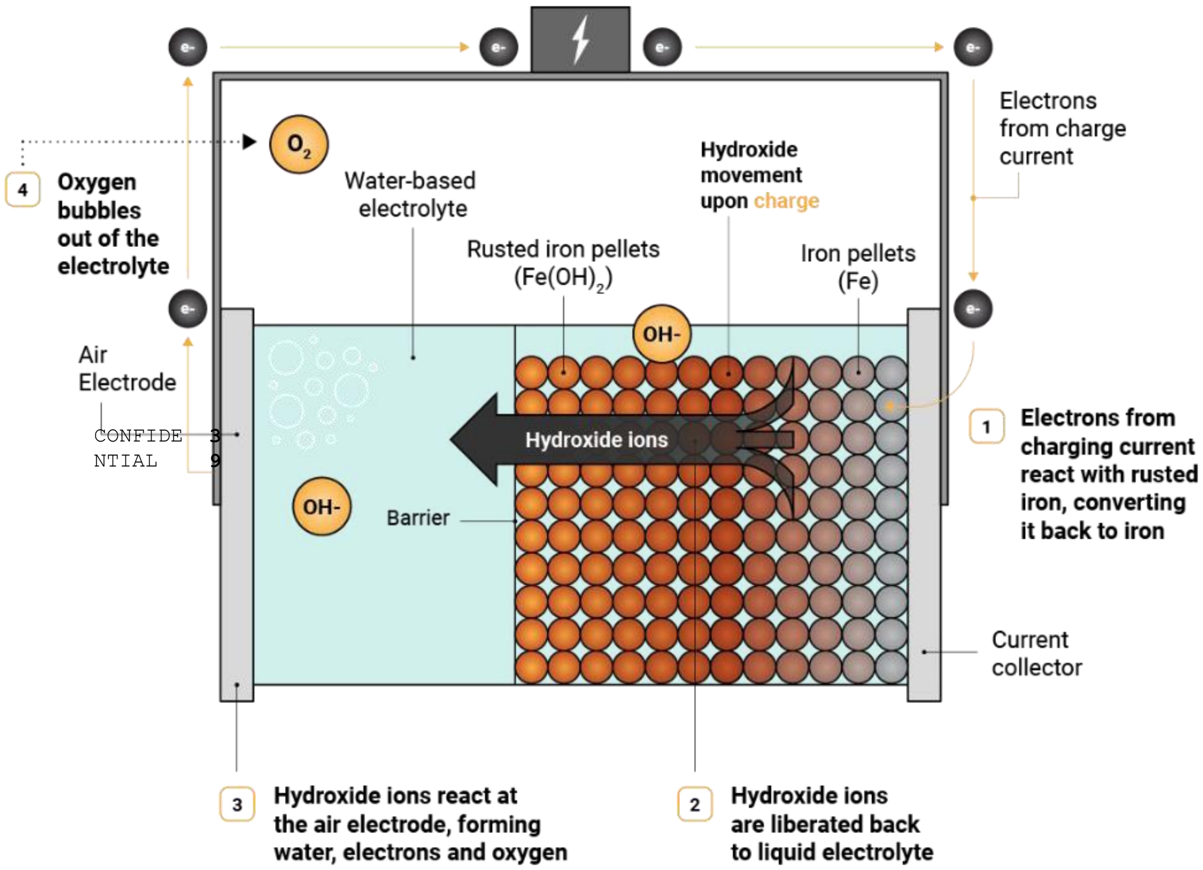
Iron-air principle of operation: “reversible rust”

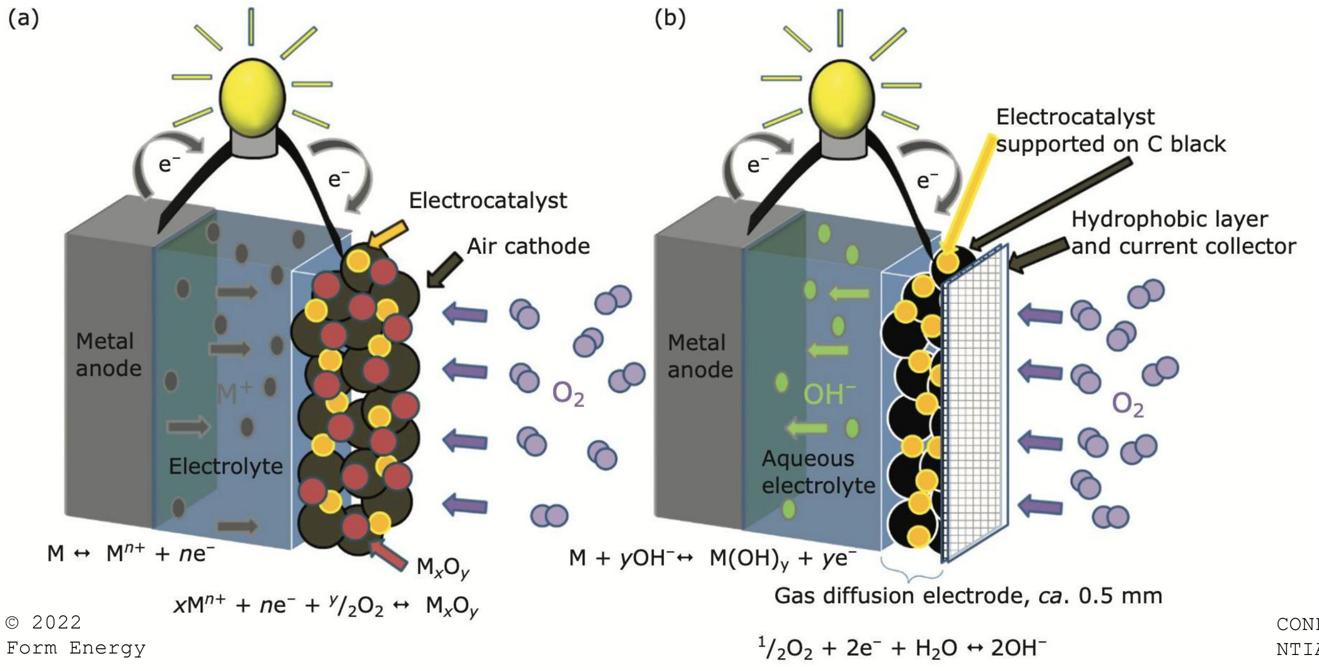
Discharge



Charge



Aqueous inorganic-air batteries



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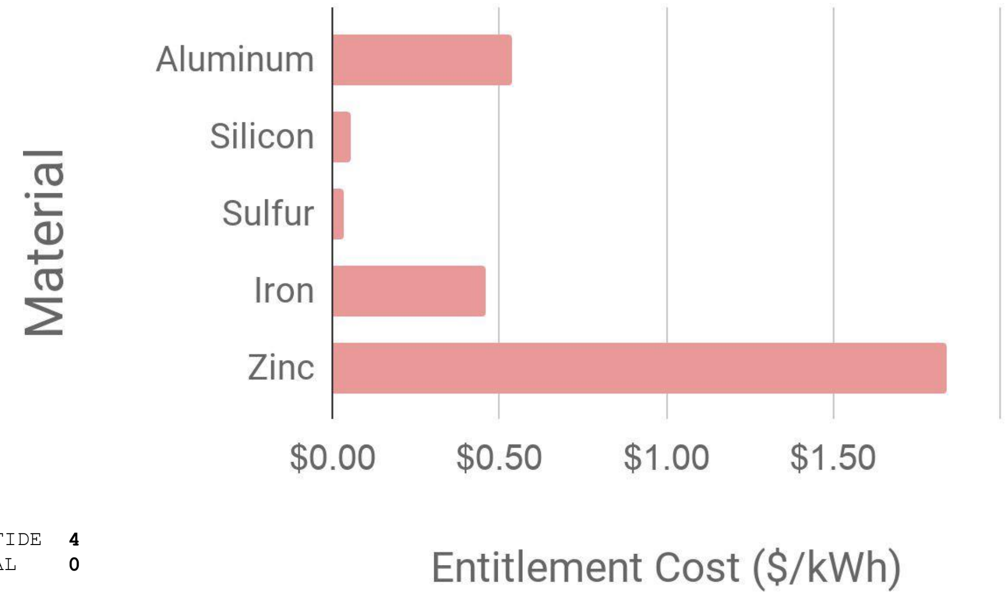
Hardwick and de León, "Rechargeable Multi-Valent Metal-Air Batteries," *Johnson Matthey Technol. Rev.*, 2018, **62**, (2), 134–149



Compare to ~10 $/kWh for Pb-acid

Advantages

- Low-cost
- Globally available, highly abundant reagents
- Inherent safety

Challenges

- Round Trip Efficiency
- Air Electrode Lifetime
- Balance of System/Plant

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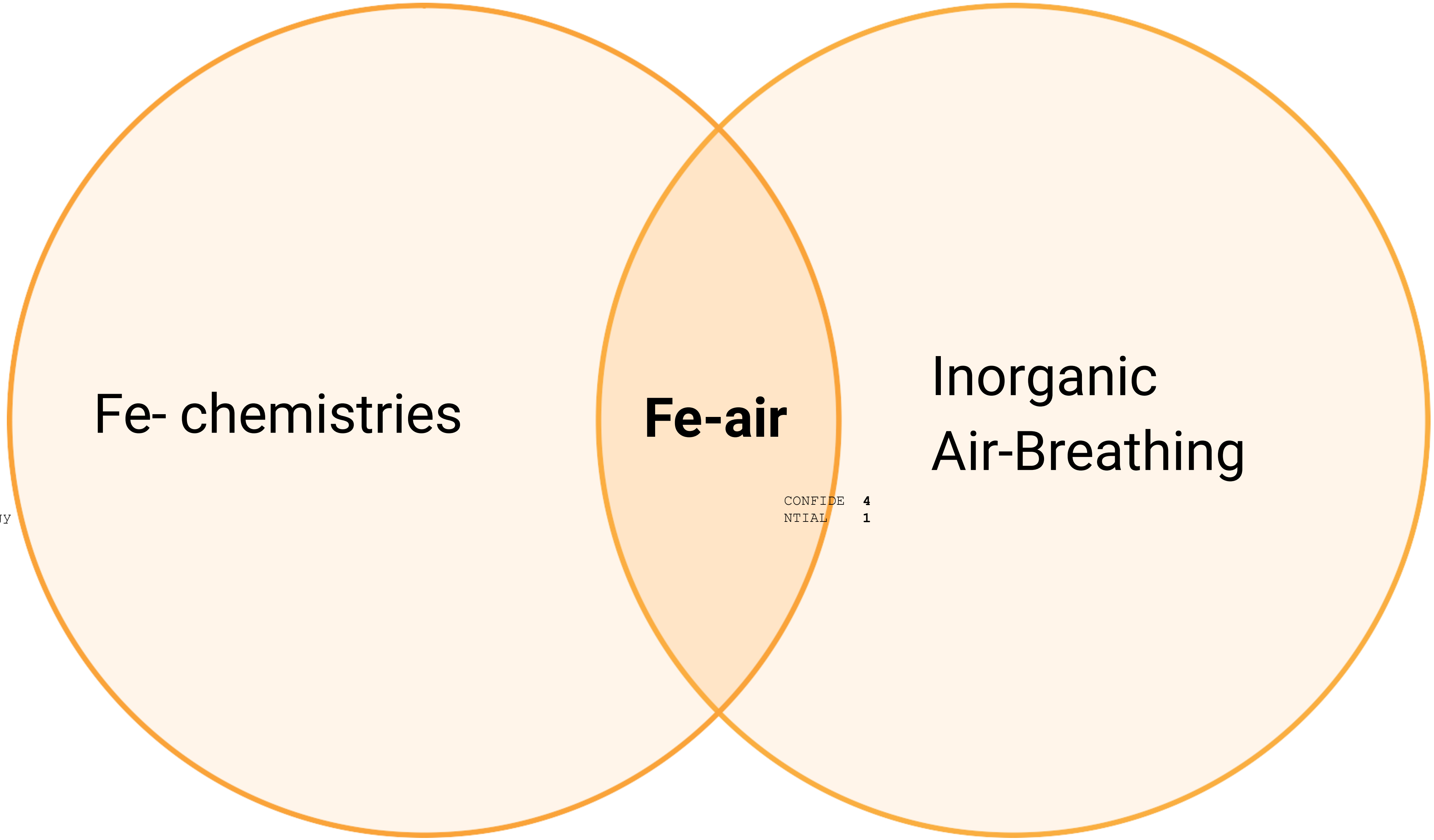

Fe- chemistries
Fe-air
Inorganic
Air-Breathing

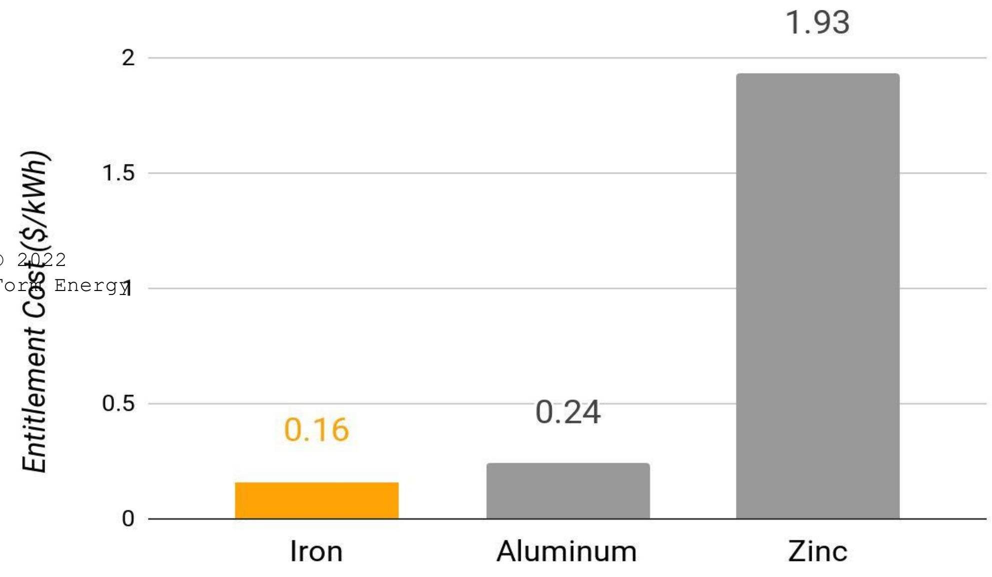
Thank you!

Form energy

Why not other metals?

Entitlement cost (Raw materials cost floor)

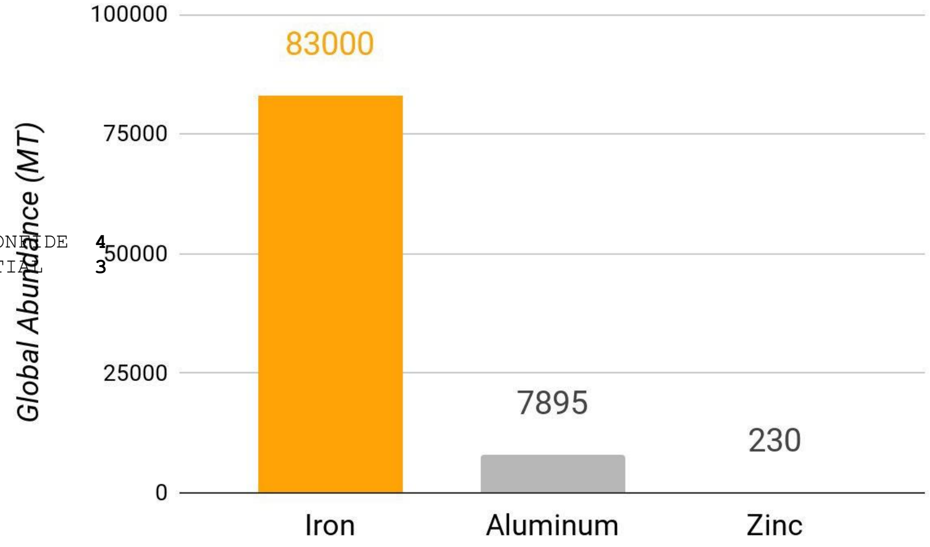
Iron has an advantageous combination of cell voltage, raw metals cost ($/kg) and specific capacity (Ah/kg) - leading to a low entitlement cost ($/kWh) for iron-air ESS



Why not aluminum? It's not reversible!

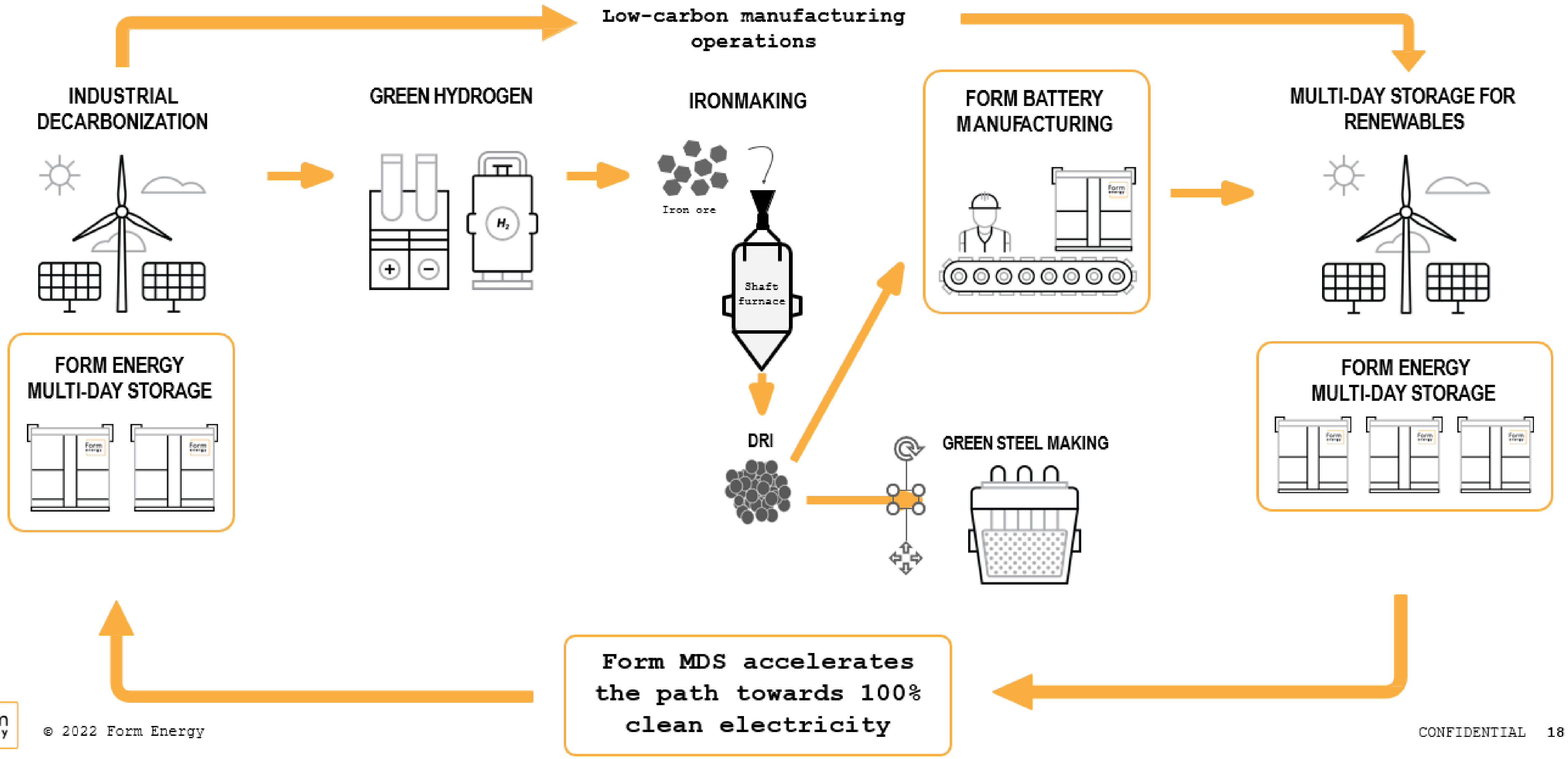
Proven reserve of material

There is a great deal of iron available globally and it is the 2nd most mined mineral (after coal) - iron-air can meet the TWh-scale demands of a 100% renewable grid



Source: USGS Mineral Commodity Summaries - Fe Al Zn
USGS defines "reserve" as materials that are discovered, recoverable, and commercial.

Domestic multi-day storage production spurs innovation, and decarbonization across industries



Supply Chain Challenges for Energy Storage

Eric Gratz, Ph.D.

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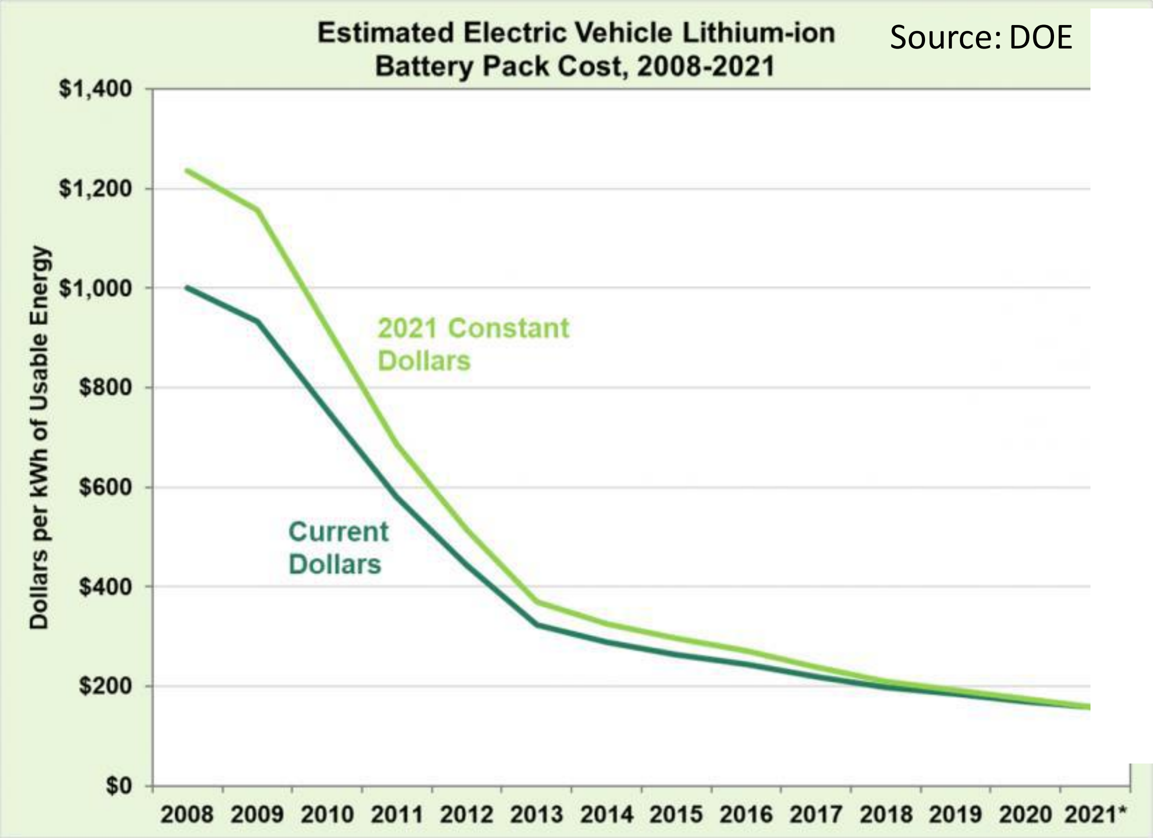
We were winning…



Source: NREL

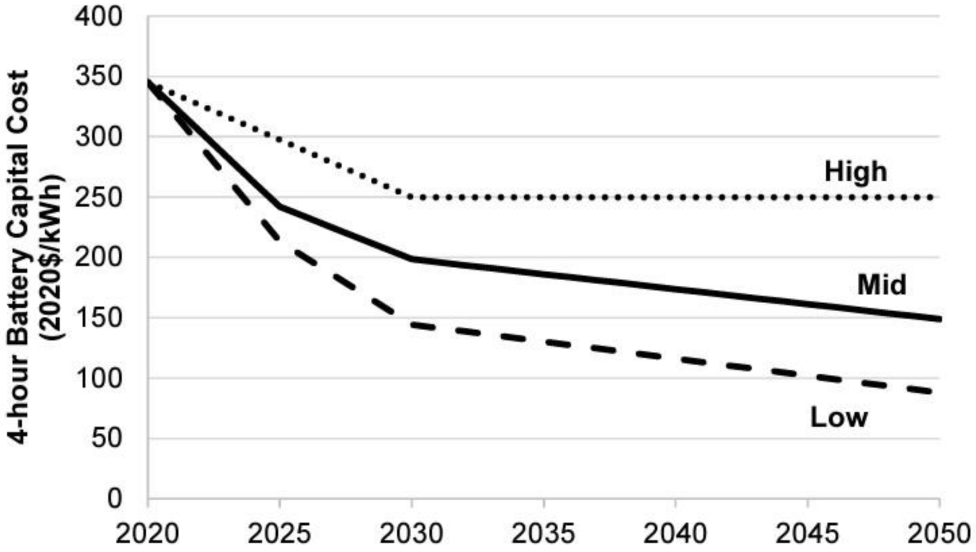


Figure 2. Battery cost projections for 4-hour lithium ion systems.

- With over wins on the way more dense electrodes, dry coating, etc

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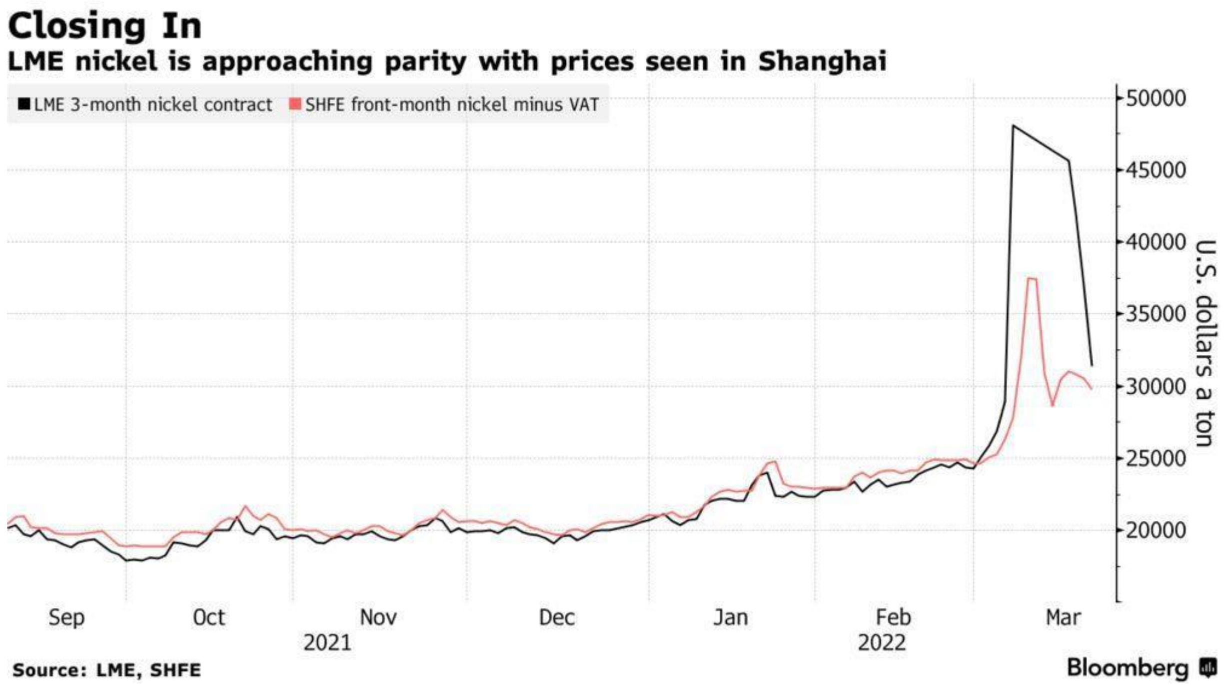
Until the supply crunch!!!



Source: BNEF

Source: USGS

- Raw materials cost have changed the economics

Why?

Permitting, planning and construction time

Gigafactory = 3-4 years

Mine = 10+ years

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How to solve this?

Technologies that break the current raw materials paradigm

1. New lithium streams
2. New methods of lithium processing
3. Environmentally friendly materials processing

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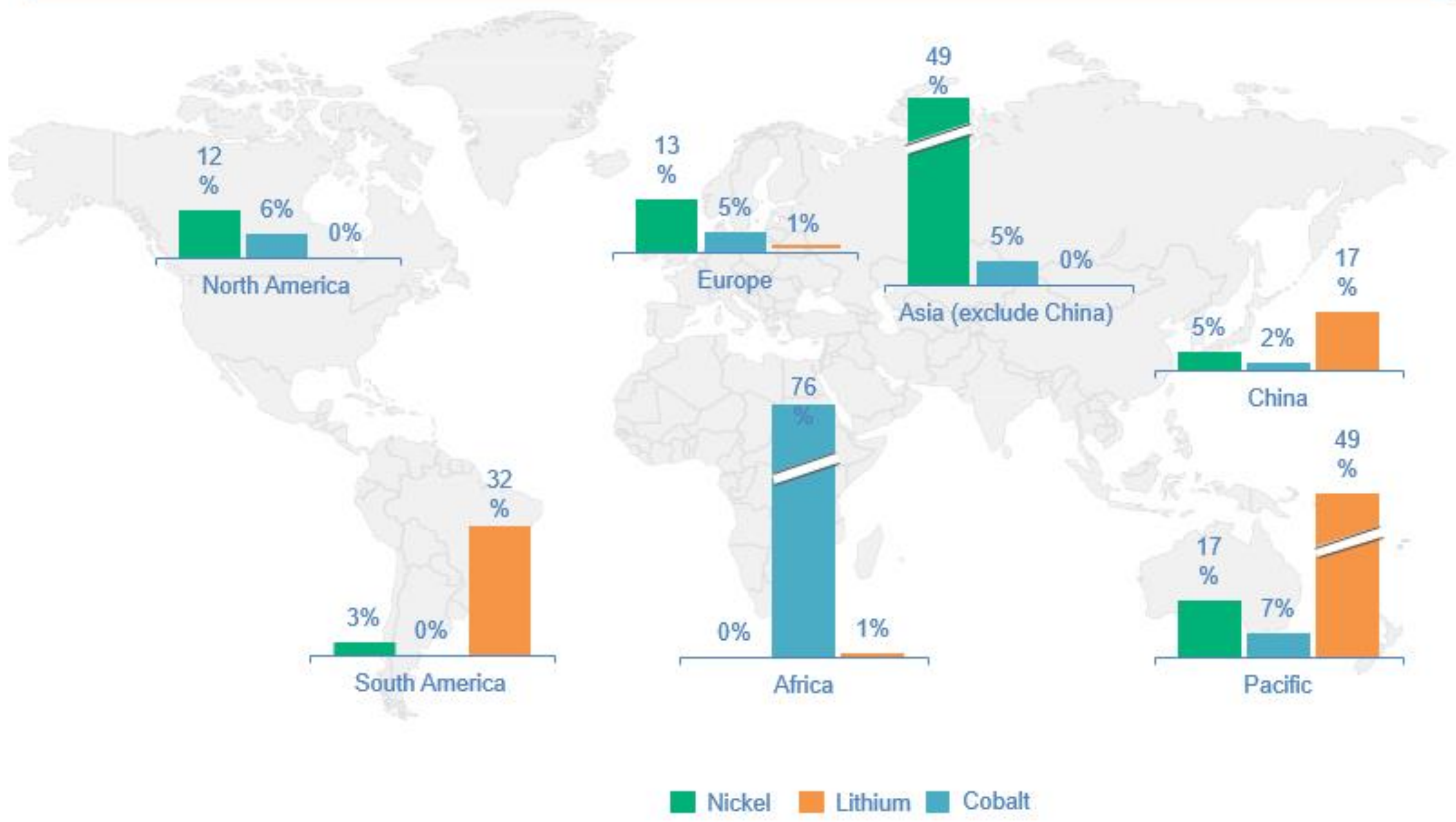
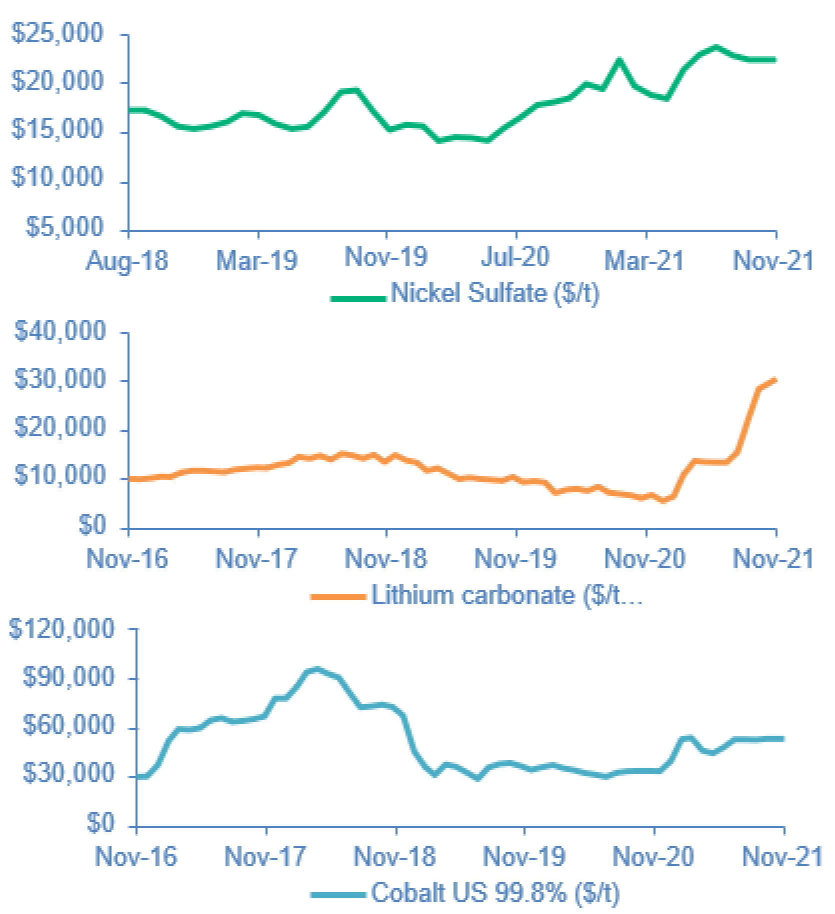
Battery raw materials in politically risky or less sustainable locations

Virgin raw materials supply, 2020 (% share of global)[a]

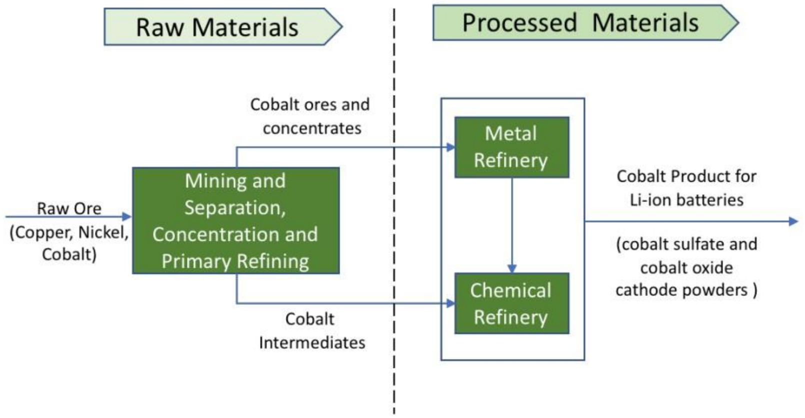


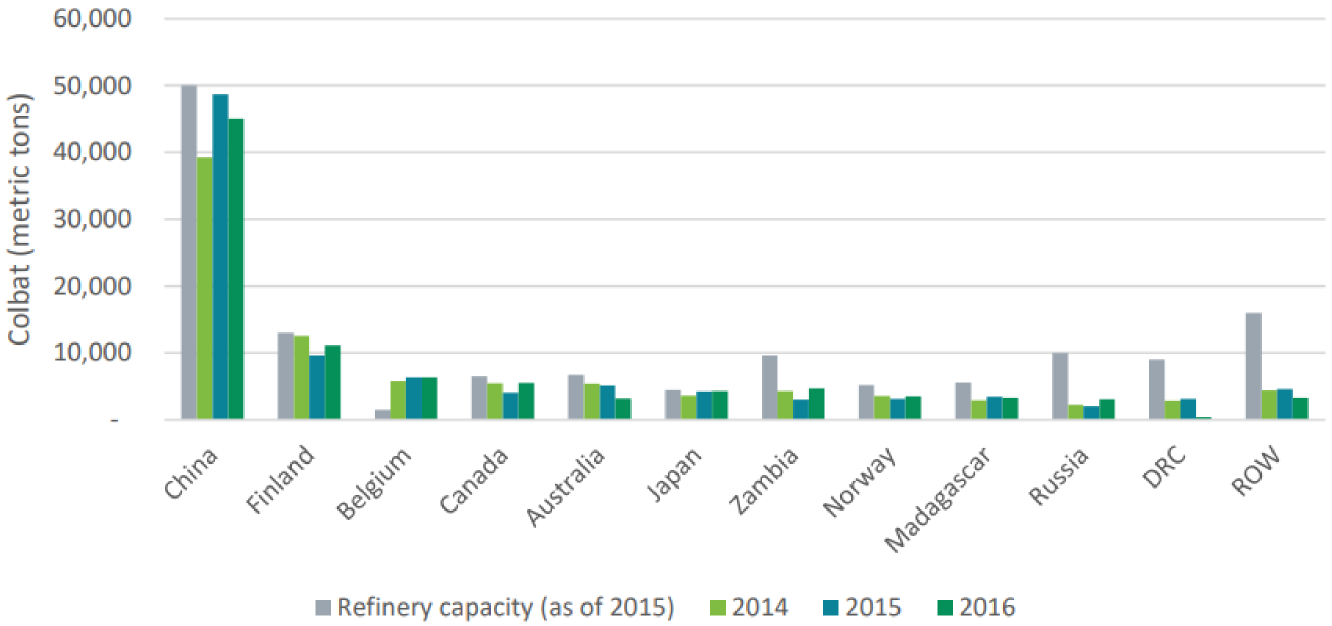
(a) China shown separately. Excludes data of countries either due to small amount or proprietary data
Source: United States Geological Survey, Roland Berger, CRU, Broker research

Historical pricing trends



Battery material refining





Material refining is similar technology to solvent extraction practice on ores

- Market dominated by Chinese players

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EV growth

Figure 1: Lithium-ion battery supply chain rankings, 2020 and expected in 2025

Country	2020 rank	Raw material	Cell & component	Environ.	RII	Demand	2025 rank	Raw material	Cell & component	Environ.	RII	Demand
China	1	1	1	16	11	1	1	1	1	15(▲1)	11	1
Japan	2	12	2	6	7	6	2	8(▲4)	3(▼1)	7(▼1)	7	8(▼2)
S. Korea	3	17	2	9	5	2	8(▼5)	16(▲1)	2	13(▼4)	5	9(▼7)
Canada	4	4	10	4	10	11	5(▼1)	3(▲1)	12(▼2)	4	10	6(▲5)
Germany	4	17	6	12	2	2	6(▼2)	22(▼5)	6	9(▲3)	2	3(▼1)
U.S.	6	15	4	13	6	2	3(▲3)	13(▲2)	3(▲1)	7(▲6)	6	2
U.K.	7	17	6	9	4	6	8(▼1)	17	8(▼2)	10(▼1)	4	4(▲2)
Finland	8	11	13	5	3	13	7(▲1)	10(▲1)	8(▲5)	6(▼1)	3	17(▼4)
France	8	17	13	1	9	5	10(▼2)	17	12(▲1)	1	9	5
Sweden	10	22	13	3	1	8	4(▲6)	17(▲5)	7(▲6)	3	1	7(▲1)
Australia	11	2	13	21	12	8	11	2	12(▲1)	19(▲2)	12	11(▼3)
Brazil	12	3	13	2	24	23	12	7(▼4)	18(▼5)	2	24	15(▲8)
Poland	12	22	5	11	13	14	13(▼1)	22	5	12(▼1)	13	19(▼5)
Hungary	12	22	6	8	14	15	15(▼3)	22	8(▼2)	11(▼3)	14	18(▼3)
Czech Rep.	15	17	10	17	8	17	16(▼1)	17	12(▼2)	17	8	21(▼4)
India	16	9	13	19	18	11	16	13(▼4)	18(▼5)	21(▼2)	18	10(▲1)
Chile	17	6	13	18	16	20	14(▲3)	4(▲2)	12(▲1)	15(▲3)	16	23(▼3)
Vietnam	18	16	6	22	20	10	23(▼5)	17(▼1)	12(▼6)	23(▼1)	20	12(▼2)
S. Africa	19	5	13	23	17	19	20(▼1)	4(▲1)	18(▼5)	19(▲4)	17	22(▼2)
Argentina	20	12	13	6	22	24	16(▲4)	8(▲4)	18(▼5)	5(▲1)	22	25(▼1)
Indonesia	21	7	13	25	21	15	20(▲1)	4(▲3)	18(▼5)	24(▲1)	21	13(▲2)
Mexico	22	12	13	15	19	22	16(▲6)	12	18(▼5)	13(▲2)	19	16(▲6)
Thailand	23	22	10	19	15	17	22(▲1)	22	8(▲2)	21(▼2)	15	20 (▼3)
D.R.C.	24	8	13	14	25	24	25(▼1)	10(▼2)	18(▼5)	18(▼4)	25	24
Philippines	25	9	13	24	23	20	24(▲1)	13(▼4)	18(▼5)	25(▼1)	23	14(▲6)

Source: BloombergNEF. Note: "Environ." is environmental. "RII" is regulations, infrastructure and innovation. Red represents countries in the Asia-Pacific region, teal countries in Europe and Africa, and blue countries in the Americas. The symbol represents if country has moved up or down the rankings in comparison to its 2020 score, green represents up and red represents down. The number shows the number of places the country has moved.

*Manufacturing capacity T is material input

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Building out a Li infrastructure

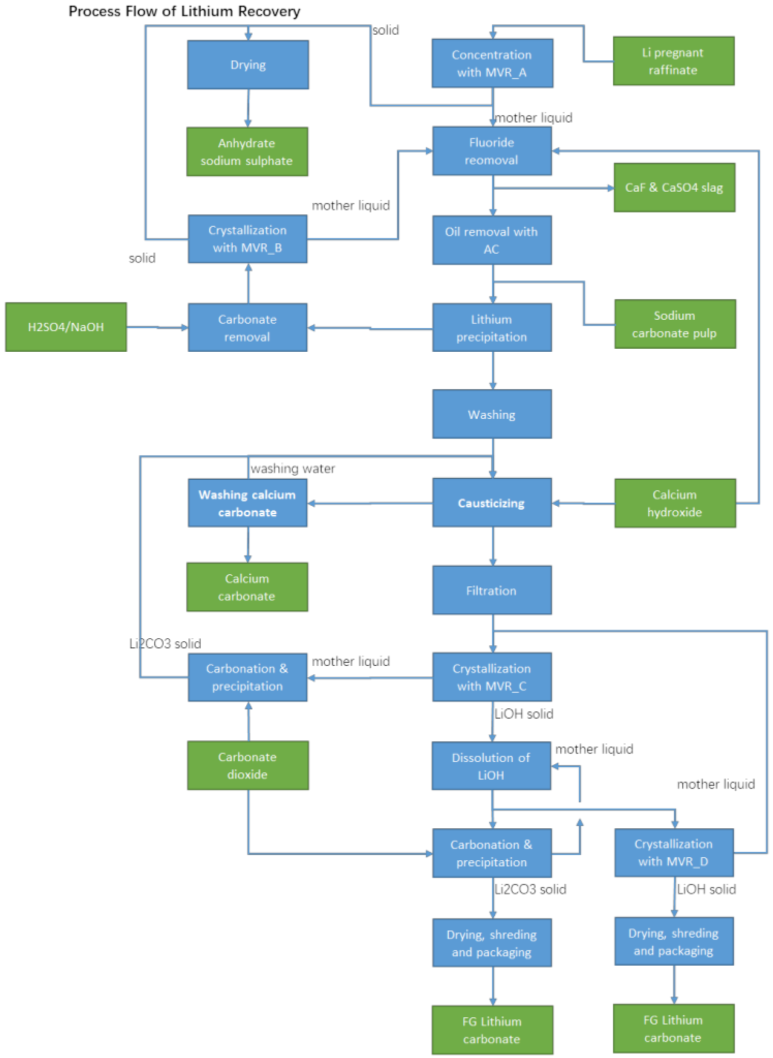
Critically important to:

1. Identify new sources of lithium
2. Develop efficient methods to purify technical and industrial grade lithium to battery grade

These are two independent things

Building out a Li infrastructure

Chinese commercial recycling process for recovery battery grade lithium carbonate after solvent extraction



Geothermal lithium

Significant untapped resource

- Permitting time drastically shorter than setting up a “new” lithium mine
- Reduced sodium sulfate output
- Drastically behind Europe, which will have geothermal in mid 2020s
- Skill set of works from fracking

Photo credit: U.S. Dept. of Energy

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Direct lithium extraction

Technology	Lithium recovery %	Maturity	Flexibility	Can handle Na	Permitting risk
Absorbents	80-99.9	Commercial	limited	yes	low
Ion Exchange	80-99.9	Pre-commerical	limited	yes	med
Solvent extraction	>99	Commercial	okay	yes	highest
Membrane separation	>>99	Pre-commerical	Very limited	Only in low concentration	med
Electrochemical separation	>90	Pre-commerical	broadest	yes	lowest

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Environmentally friendly processing

- Technologies that work in Eastern Asia will not work in North America
- Sodium sulfate production levels need to be reduced in both pCAM and lithium recovery

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Cathode is coming, but not precursor

Umicore invests $1.2 in battery materials plant in Ontario

GM Expands its North America-focused EV Supply Chain with POSCO Chemical in Canada

GM and POSCO Chemical to process cathode active material at new joint venture plant in Quebec

BASF to build cathode material plant in Québec

Tesla applies to build giant new cathode factory for battery production next to 'Gigafactory Texas'

*Manufacturing capacity T is material input

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Why no precursor?

- Permitting
- Environmental risk
- Cost

- Sodium sulfate emitted to oceans in east Asia
- Limited locations that allow this in North America.
  - Only a matter of time before this issue is identified by environmental groups.

Winning CAM technologies

- LFP
- Mid nickel single crystal materials (67% of the current market)
- High Ni core shell and gradient (70% of the current market)
- **Very low cost LFP**
- Single crystal CAM with no sodium sulfate production
  - One pot processes
- Lower cost high Ni technologies that allow gradient or core shell with reduced sodium sulfate

*Manufacturing capacity T is material input

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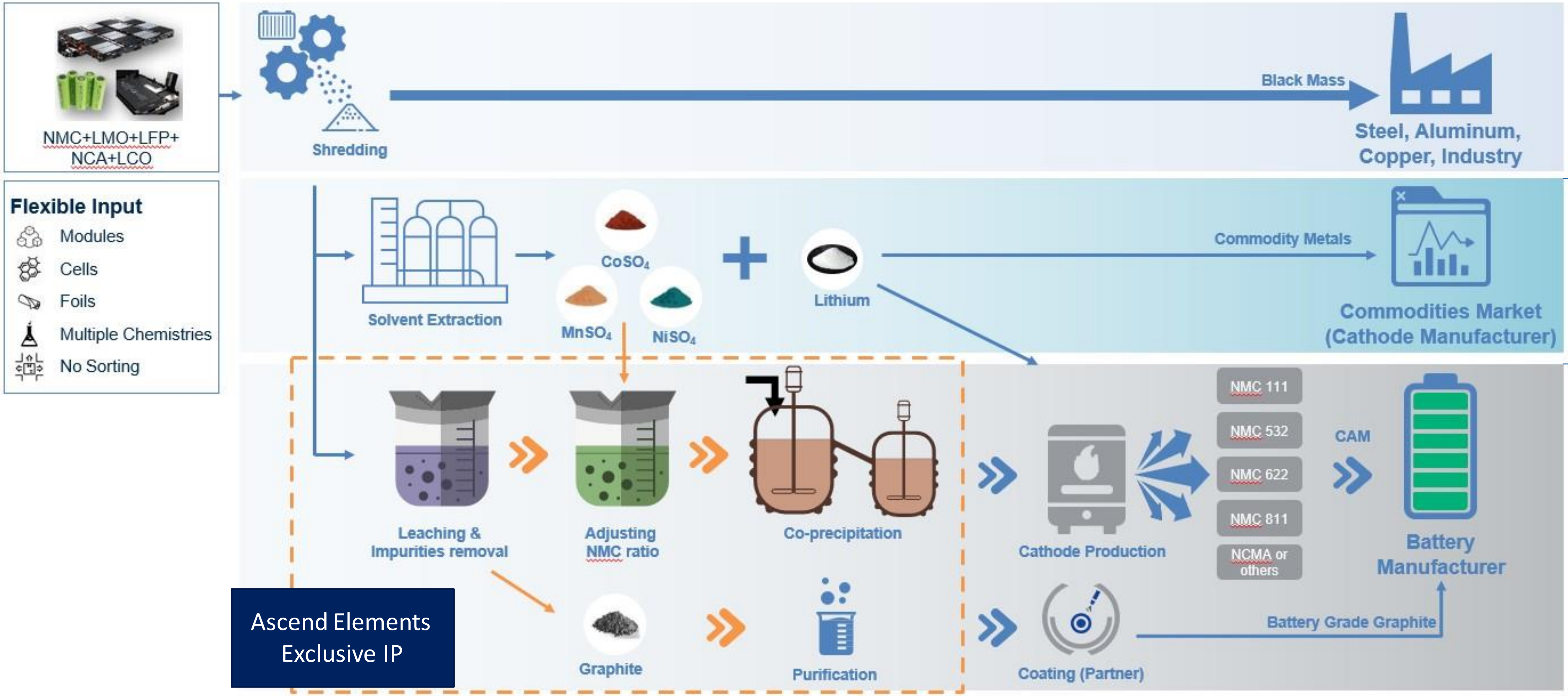
Hydro-to-Cathode™ direct precursor synthesis process



Black Mass

Metals

CAM & pCAM

Graphite

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Recycling as a solution

- Ascend Elements' technology enables EV batteries to be leveraged as a raw material source for energy storage batteries

- Hydro-to-Cathode™ process produces pCAM with 3.5x lower sodium sulfate versus traditional solvent extraction to pCAM synthesis

*Manufacturing capacity T is material input

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Recycled cathode materials enabled superior performance

- Recycling plays a significant role in alleviating shortage of raw materials and environmental problems.
- However, recycled materials are deemed inferior to commercial materials, preventing the industry from adopting recycled materials in new batteries.
- In a recent study, our upcycled cathode cell exhibited over 50% longer cycle life than the traditional cathode cell, and its power capability was increased by 88%.


IEEE Spectrum

Study: Recycled Lithium Batteries as Good as Newly Mined › Cathodes made with novel direct-recycling beat commercial materials


SCIENTIFIC AMERICAN

Lithium-ion batteries are at the heart of nearly every electric vehicle, laptop and smartphone, and they are essential to storing renewable energy in the face of the climate emergency. But all of the world's current mining operations cannot extract enough lithium and other key minerals


wbur

Mass. startup transforms old electric car batteries into better-than-new ones


Daily Mail .com

Scientists invent method to recycle environmentally-damaging lithium-ion batteries used in electric cars that sees the cells crushed into 'black dust' before being separated into valuable component metals

- Ascend Elements, in Westborough, Massachusetts, created the new process
- It shreds used batteries from phones and cars and extracts raw materials
- The process further purifies the metals 'atom-by-atom' and creates a cathode
- These cathodes can then be used by EV manufacturers to create new batteries


Joule

Recycled cathode materials enabled superior performance for lithium-ion batteries

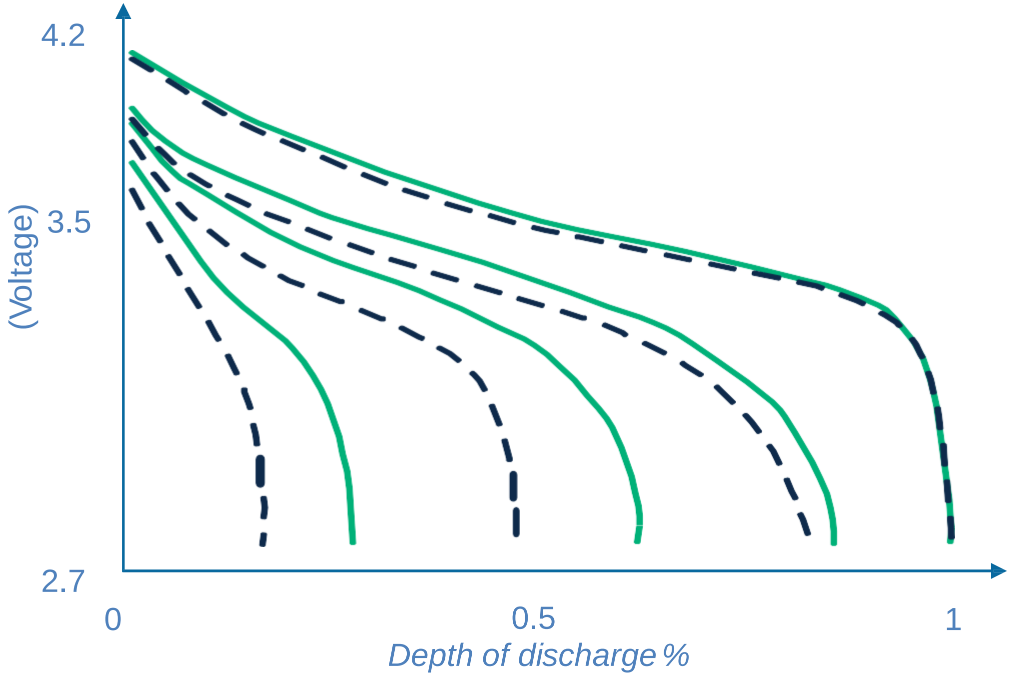
Highlights

Summary

Performance improvements overvirgin materials

Cells performance

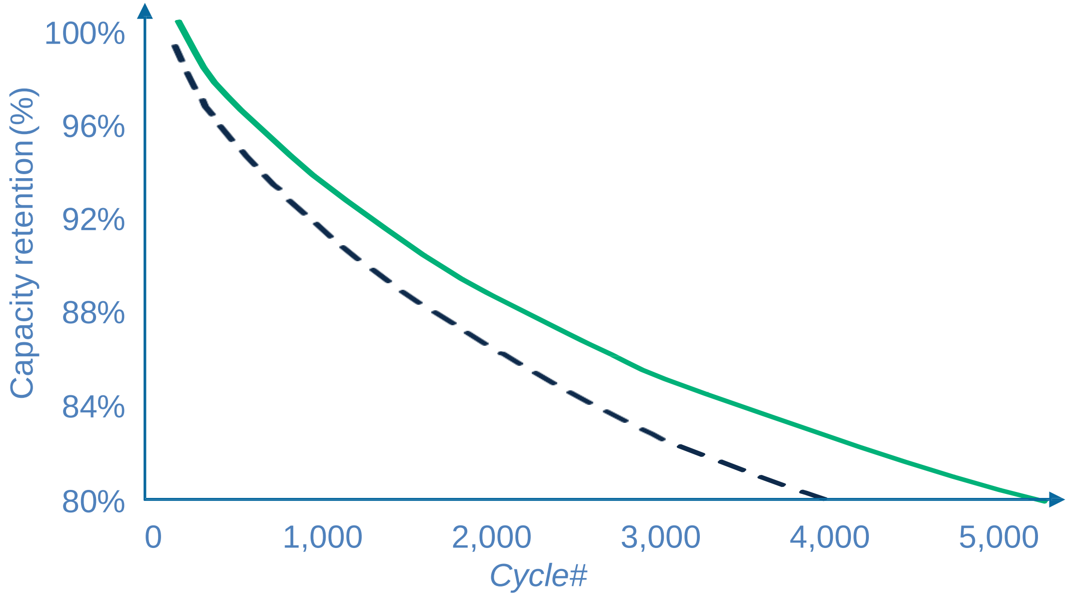
Cells made from our materials yield higher charge capacities than benchmark cells



AE cell   Benchmark cell

Cathode performance

Cathodes made from our materials reach up to 20% cycle life enhancement compared to leading commercial cathode materials



AE material   Benchmark cathode materials

(a) c-rate is the current through the battery divided by the theoretical current draw under nominal rated capacity in one hour
Source: Company information, Joule

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Apex 1Facility (Hopkinsville, Kentucky)

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Transforming black mass into high value materials via Hydro-to-Cathode™ direct precursor synthesis

Material for **250,000** EVs per year

Apex 1 facility
Up to **$1B** investment
Up to **400** high-quality jobs
Operational in **Q4 2023**

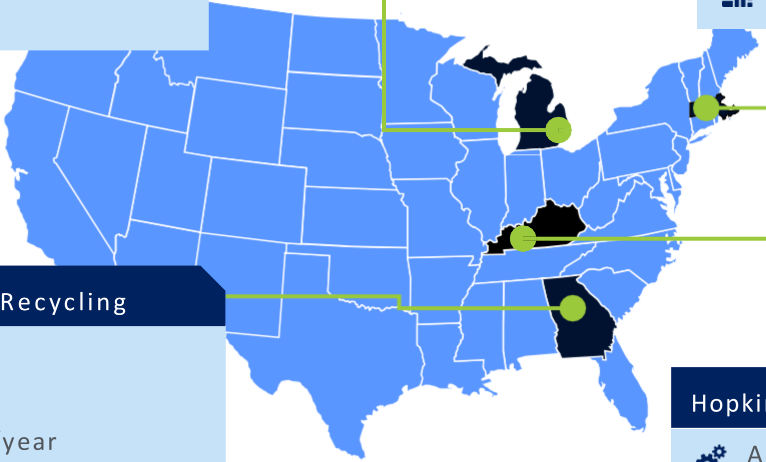
North American Operations

Novi, MI – Cathode Sintering and Battery Lab

- Cathode NMC production
- Output: NMC cathode = 12,000kg/year
- Operational
- 6,300 sq ft

Westborough, MA – HQ and Cathode Precursor

- NMC precursor production
- Output: NMC cathode precursor = 12,000kg/year
- Operational
- 16,000 sq ft



Covington, GA – **Base 1** Commercial-scale Recycling

- Shredding and metal extraction
- Intake: 30,000 tonnes/year
- - Output: Black mass = 15,000 tonnes/year
  - Output: Metals (Li, Ni, Co) = 1,200 tonnes/year
- Operational Q4 2022
- 154,000 sq ft

Hopkinsville, KY – **Apex 1** Battery Material Plant

- Active material, precursor and metal extraction
- - Output: Metals (Li, Ni, Co) = 20,000 tonnes/year
  - Output: pCAM and CAM = 20,000 tonnes/year
  - Output: Graphite = 10,000 tonnes/yr.
- Operational 2023
- 500,000 sq ft