Electrochemical battery value chain (startup focused)

Value Chain	Upstream		Mid-stream		Downstream	
Business	Raw material	Material processing	Component production	Cell manufacturing	Application	★ Recycling
Market Verticals*	**Lithium**: Novalith, Cornish Lithium, RockTech Lithium **Cobalt, Nickel, Mg**: KoBold Metals, Impossible Metals **Graphite**: Green Graphite Technologies, NMG	**Lithium chemical**: Novalith, EnergyX **Cobalt, Nickel, Mg**: Jervois **Graphite & pCAM**: Urbix, greenli-ion, Ascend Elements	**Cathode**: Ascend Elements, Redwood Materials, Hengtron 珩创 **Anode**: Redwood Materials, Advano **Electrode, separator, electrolyte**: anthro, EnergyX, Piersica, Feon	**Li-ion battery**: anthro, ONE our next energy **Sodium–ion battery**: Natron Energy, Peak Energy, Altris **Solid state battery**: Factorial, QuantumScape, Group14 **Flow battery**: BioZen Batteries, Redox One	**Mobility**: Factorial, nyobolt, Volocopter **Energy Storage**: Peak Energy, ONE our next energy, Natron Energy, QuantumScape	**Recycling**: Redwood Materials, Ascend Elements, Nth Cycle, greenli-ion

*inspired by Volta Foundation Battery Report 2023

Some macros trends that are shaping the future of electrochemical batteries landscape

★ Deep dive into this next

Sustainable growth in all verticals

Sustainability doesn't stop at producing EVs with 0 running emissions. A key trend observed more frequently **further up the value chain**, low footprint technologies across mining, raw material processing, and cell material development are increasingly moving towards novel chemical processes that are low footprint, reducing negative externalities.

Key Themes:

- Sustainable mining
- Low environmental footprint
- Modular, scalable process units
- Alternative refining route

Example Venture: RockTech Lithium, NMG

Innovative chemistry has massive potential

Market is demanding batteries with lower prices and higher performance. As a result, companies are actively inventing new battery chemistries and materials.

Technological innovation is happening in every aspect; from electrodes to separators, novel chemistries are proposed for greater energy density, longer lifetime, better safety, lower footprint, lower cost, etc.

Key Themes:

- From Li metal to next gen cathodes
- Advanced recycling
- AI-accelerated material discovery
- Improved EV range and battery safety

Example Venture: ENERGYX, Feon

Battery utilization is application specific

Battery chemistries and design philosophies yields different products that meet the needs of different scenarios. For example, flow batteries are good for utility grids whereas solid state batteries are good for future of mobility.

Key for incumbent success is to **maximize strengths** of their products and focus on **finding the right market** to invest long term.

Key Themes:

- Mature battery chemistry
- Clear product-market fit
- Rapid scaling and deployment

Example Venture: PEAK ENERGY, REDOX ONE

Recycling and production ecosystem

As demand for batteries surges, recycling of metals like Li, Ni, Co is essential for mitigating environmental impact and reducing resource scarcity. In the long term, it'll play a key role in meeting market demands.

Battery recycling startups are hyper-focused on **recycling processes innovation** to increase yield, lowering emissions, and quickly plugging into existing infrastructure.

Key Themes:

- Circular supply chain
- Brine to battery
- Modular refining
- Metallurgy (hydro, electro, etc.)

Example Venture: REDWOOD MATERIALS, NTH CYCLE, ASCEND ELEMENTS, greenli-ion

Competitive landscape within battery recycling

Hydrometallurgy
This process involves using aqueous solutions to leach valuable metals from spent batteries.
Advantage: low energy consumption, high recovery rates.
Challenge: generates wastewater and harmful chemicals.

Pyrometallurgy
This process involves heating spent batteries to high temperatures to smelt the metals.
Advantage: large volume per batch, good for Co, Ni recovery.
Challenge: energy intensive, low purity of metals.

Direct Recycling
This process involves dismantling batteries and directly retrieving the active cathode and anode materials without chemically breaking them down.
Advantage: Less energy consuming, lower cost.
Challenge: Navigating battery designs, handling and sorting.

Electrometallurgy
This process involves depositing valuable metals from a solution onto a cathode in an electrolytic cell setting.
Advantage: Can be tuned to recover specific metals.
Challenge: Requires precise control of reaction conditions.

Investments

Investors are pouring billions into battery recycling technology, with incumbents and startup disruptors racing to making the recycling of EV/storage batteries more economical and cleaner. This space holds great return potential in the next decade as our economy's fuel shifts from fossil fuels to lithium and other battery metals.

Company	Investment Planned	Note
REDWOOD MATERIALS	$1,000 Million	**Redwood** Materials raises over $1 billion to focus on collection of end-of-life batteries, increasing refining capability. Redwood receives conditional commitment for $2B Department of Energy loan for battery materials with recycled content.
ASCEND ELEMENTS	$542 Million	**Ascend Elements** (previously Battery Resourcers) raises $542 million to build North America's first cathode precursor (pCAM) facility, utilizing recycled material, on a 140-acre site in Hopkinsville, Kentucky.
Li-Cycle	$375 Million	**Li-Cycle** receives conditional commitment for $375 million loan from the U.S. Department of Energy ATVM Program.
Cirba Solutions	$282 Million	**Cirba Solutions** & U.S. Department of Energy to expand Lithium-Ion Battery recycling operations in Ohio. The more than $200 million expansion is aided in part by an over $82 million Department of Energy (DOE) grant.
AQUA METALS	$5 Million	**Aqua Metals** and Yulho (a South Korean storage solution and battery materials company) form a strategic partnership. Yulho invests $5 million in Aqua Metals, and Aqua Metals grants Yulho a license to deploy Aqua Metals' AquaRefining technology in Asia and Europe.
ABTC AMERICAN BATTERY TECHNOLOGY COMPANY	$60 Million	**ABTC** receives $10 million DOE grant for the development of new lithium-ion battery recycling technologies. **ABTC** also secured up to $50 million investment to support commercial-scale battery material construction projects including Lithium-Ion battery recycling.

Source: Volta Foundation Battery Report

Market Dynamics & Hypothesis to Win

Market Dynamics (source: Volta Foundation)

Large Number Of Competitors

- There is a small window opportunity for new entrants, with over 30 recycling projects already announced in the EU.
- Cell manufacturers, auto OEMs, and traditional recyclers are all seeking to lead the energy transition and capture margin.

Alternatives At End Of Life

- Second life applications delay the time at which batteries can be recycled.
- Disparate hazardous waste regulations across markets can landfill disposal, especially for battery chemistries that use lower value materials.

High Barriers To Entry

- Current technologies require high opex and capex.
- Economies of scale are required to compete in new markets.
- There may be no sustainability premium.
- Uncertainty due to challenges with scale-up and variable scrap rate from cell and cathode manufacturers.
- Recycling technologies recover different materials at different costs.

Bargaining Power Of Buyers

- Refined materials markets are dominated by a few players, typically cathode manufacturers or integrated cell manufacturers.
- Refining companies need long term offtake agreements to recoup capex, giving buyers higher bargaining power.

Bargaining Power Of Suppliers

- The highest volume of feedstock currently comes from the cell scrap of cell manufacturers, a highly concentrated market with a lot of bargaining power.
- Cell manufacturing is concentrated regionally and often colocated with suppliers to reduce transportation cost.

Additional risks:

Fluctuation in raw material prices

Supply chain complexity (feedstock, battery life cycle, etc.)

Initial hypothesis on how to win:

- Technology route to drastically cut down cost to increase margins
- Economic of scale to capture market share

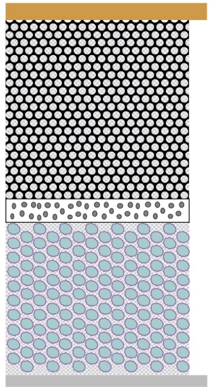
Battery Recycling Process Flow (the grand scheme)

Retired Power Batteries → Second-Life Utilization → Energy storage, FTM/BTM

Retired Power Batteries → Recycling → See below

Step 1: Physical Separation

Discharge & Shredding



- Plastic, papers
- Black mass: cathode & anode materials
- Cu, Al metal foils
- Electrolyte (Li rich)
- Steel Canisters

Separation using density, magnetism, froth floatation, etc.)

Step 2: Black Mass Processing

Technology Solutions*

- Hydrometallurgy
- Pyrometallurgy
- Others (electrometallurgy, bio-methods, etc.)

This is the core "moat" of a battery recycling startup.

The key is either:

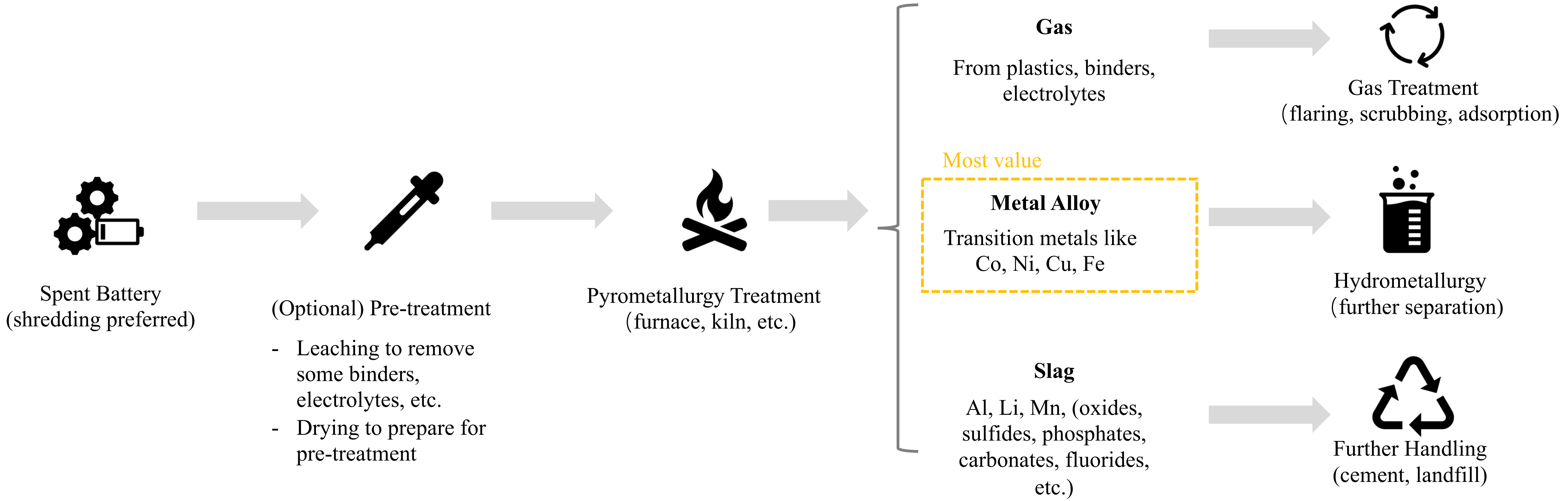
1. **Economy of scale**
2. **Drastically lower cost**

*Direct recycling will not shred battery material but preserve cathode structure in spent cells.

Technology – Pyrometallurgy

Definition: Pyrometallurgy uses **a high temperature furnace to reduce the component metal oxides** to an alloy of Cu, Co, Fe, and Ni. The process is commercially demonstrated and is advantageous for consumer LIBs due to its versatility. It is best for recovering high-value transition metals such as Cobalt and Nickle.

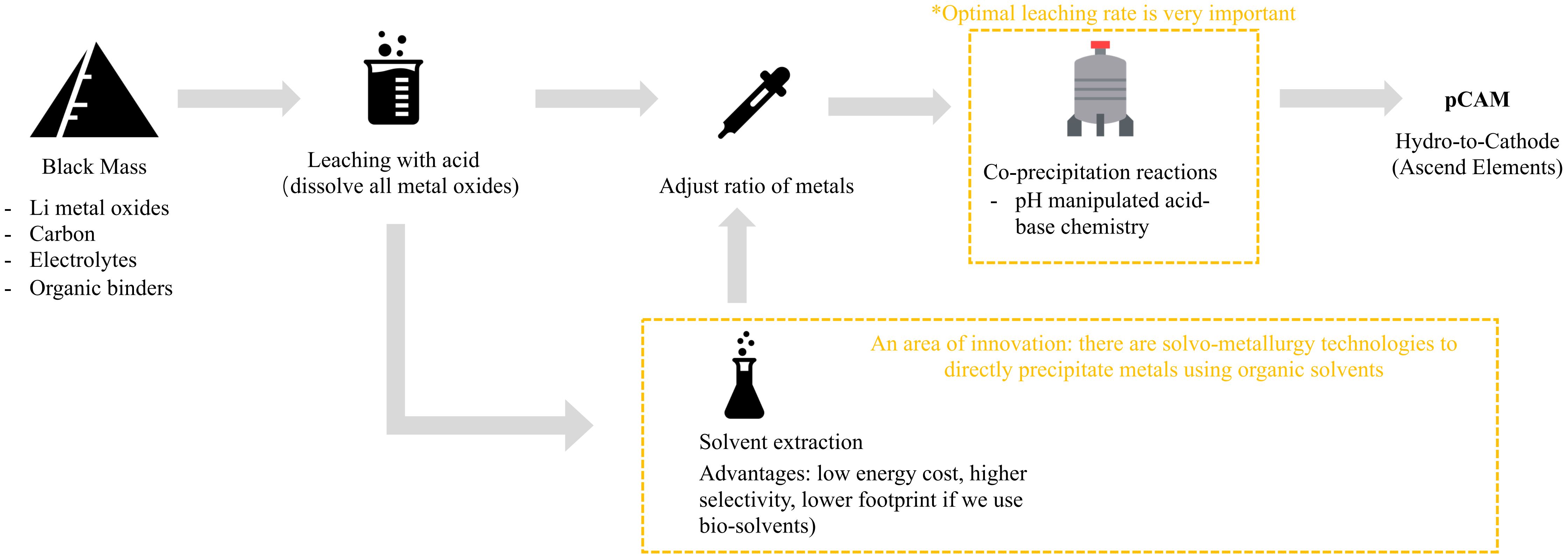
Advantage: versatility, good for general consumer LIBs (imperfectly sorted feedstocks) large volume per batch, good for Co, Ni recovery. Can be sued with whole cells or modules without the need for passivation/shredding.
Challenge: energy intensive, high environmental footprint, few metals recovered.



Technology – Hydrometallurgy

Definition: Hydrometallurgy involves using **aqueous solutions** (e.g., H2SO4 and H2O2) **to leach desired metals** from cathode material. Once leached, metals can be **precipitated by precise control of pH** of the leached solution. This process can recover a wider range of metals (especially Li) compared to pyrometallurgy.

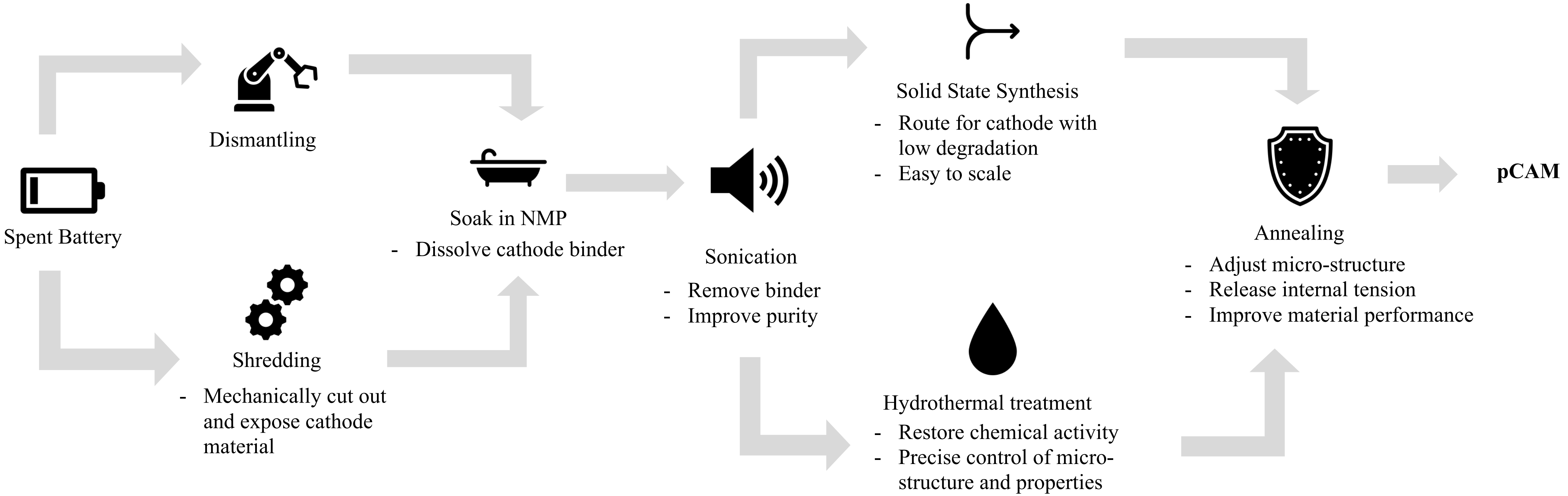
Advantage: energy efficient, high recovery rates of metals, **customizable reaction**: precipitation can be designed to directly produce pCAM material or move to supply new battery chemistries. **Challenge:** generates wastewater with harmful chemicals, require shredded black mass.



Technology – Direct Recycling

Definition: The removal of cathode and anode material of spent LIBs for reconditioning and reuse. This process preserves microscopic morphology of cathode and anode materials. Material degradation can be mitigated by replenishing Li content.

Advantage: desirable for lower value cathodes like LFP where manufacturing is the major cost, low energy costs
Challenge: handling and sorting batteries, navigating different battery designs, organic binders and cell configuration presents additional challenges



Black Mass Technology Evaluation

Comparison of different LiB recycling methods

Best ●●●●● | ●●●● | ●●● | ●● | ● Worst

	Technology readiness	Complexity	Quality of recovered material	Quantity of recovered material	Waste generation	Energy usage	Capital cost	Production cost
Pyrometallurgy	●●●●●	●●●●●	●	●●●	●●	●	●	●●●●●
Hydrometallurgy	●●●●	●●●	●●●	●●●●	●●●	●●●	●●●	●●●
Direct recycling	●●	●	●●	●●●●●	●●●●	●●●	●●●	●

	Presorting of batteries required	Cathode morphology preserved	Material suitable for direct re-use	Cobalt recovered	Nickel recovered	Copper recovered	Manganese recovered	Aluminium recovered	Lithium recovered
Pyrometallurgy	●●●●●	No	No	●●●●●	●●●●●	●●●●●	●●	No	●
Hydrometallurgy	●●●●	No	No	●●●●●	●●●●●	●●●●	●●●	●●●●●	●●●
Direct recycling	●	●●●●●	●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●

Investment consideration

Methods	Invest?	Assessment
Pyrometallurgy	Maybe in short term	The environmental footprint and energy intensive nature will eventually out-weight the benefit of versatility once other technologies become more versatile and efficient.
Hydrometallurgy	Yes	The selective nature and customizability of reactions makes this a flexible, easily controlled process with well-understood acid-base chemistry. Despite the pre-processing and complex process required, it is the technological route that holds the most promise to rapidly scale.
Direct Recycling	Maybe in long term	The low cost and simple process makes direct recycling the best at recovering cathode value. However, different battery designs increases the difficulty of direct recycling. As the market sees better standardized batteries and cell manufacturers are properly incentivized, direct recycling will be very effective technology.

Key technology due diligence questions before investing:

- How much of cathode value can be recovered for various type of battery chemistry? How does the process adjust?
  - Rationale: this question ensures the technological route can recover sufficient value from cathode to be economically desirable.
  - For example, for cobalt-rich batteries (e.g., LCO batteries), hydro- and pyrometallurgy can recover 70% of cathode value, but this number drops significantly as cobalt content decreases.
- How much does this technology cost? (how do the economics look like when raw material costs fluctuate?)