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AusIMM | Southern Queensland Branch

Acknowledgement of Country

We acknowledge the Traditional Custodians of the land we are meeting on today, the ***Turrbal*** and ***Jagera*** people***.***

We also acknowledge Traditional Owners of country throughout Australia and recognize their continuing connection to land, waters and culture.

We pay our respects to their Elders past, present and emerging.

AusIMM | Southern Queensland Branch

Save the Date!

St Barbara’s Day drinks and AGM

Wed 4 Dec 2024 at the PAV BAR

Join us to celebrate St Barbara Day and the end of 2024, with drinks and hors d'oeuvres, and including our brief AGM - our final event for 2024.

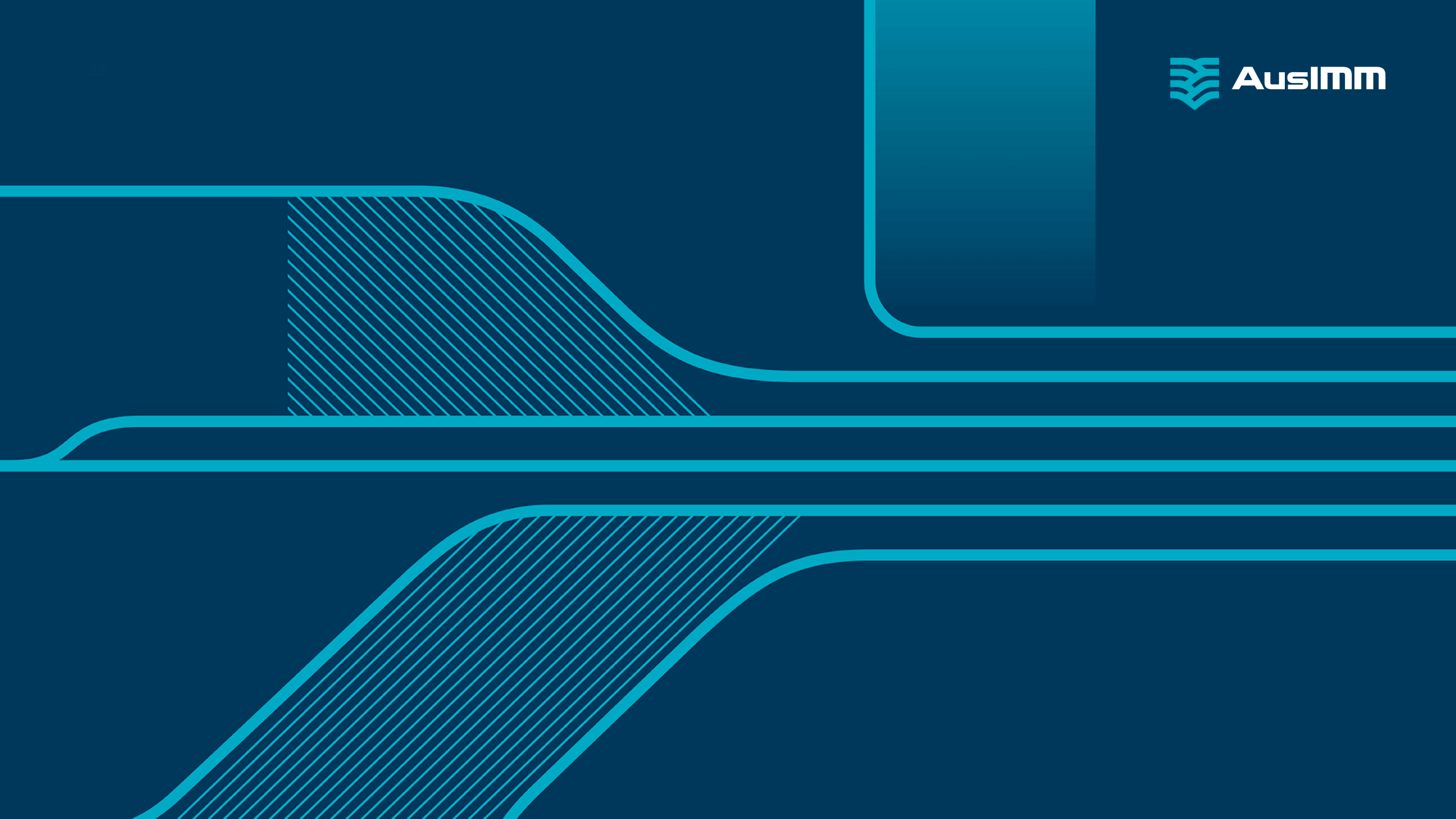
St Barbara’s Day pays tribute to the patron saint of mining and geology. This is an opportunity to celebrate the day and year, and to be involved in your local branch of the AusIMM.

Dr Andrew Newell

Manager, Metallurgy and Process Engineering– RPM Global

Metallurgical Engineer with over 45 years of experience in operating, designing, commissioning and reviewing processing operations and projects.

This experience includes base and precious metals, industrial and critical minerals as well as battery materials in the fields of minerals processing, hydrometallurgy, pyrometallurgy, plant design, process engineering and metallurgical test work.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Battery Materials - Extraction and Preparation for energy storage applications

Dr. Andrew Newell | Manager, Metallurgy and Process Engineering

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Agenda

November 2024

- RPMGlobal Overview
- Battery Materials
- Lithium
- Nickel and Cobalt
- Graphite
- Vanadium

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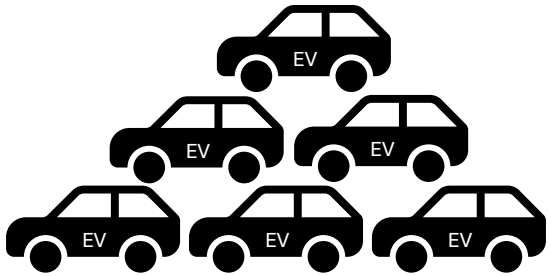
Battery Materials

Introduction

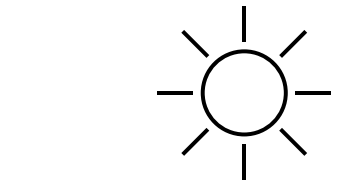
Chemicals used in rechargeable batteries, mainly Lithium-ion batteries (LiBs)

Key materials are lithium, nickel, cobalt, graphite and vanadium

Percent of total battery cost



LiB global demand being driven by rapid uptake of EVs, growing at 25-30% annually



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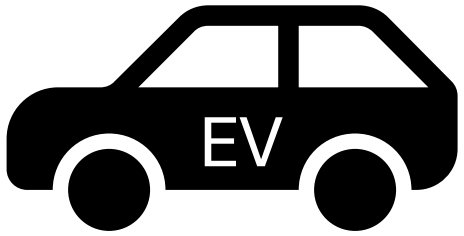
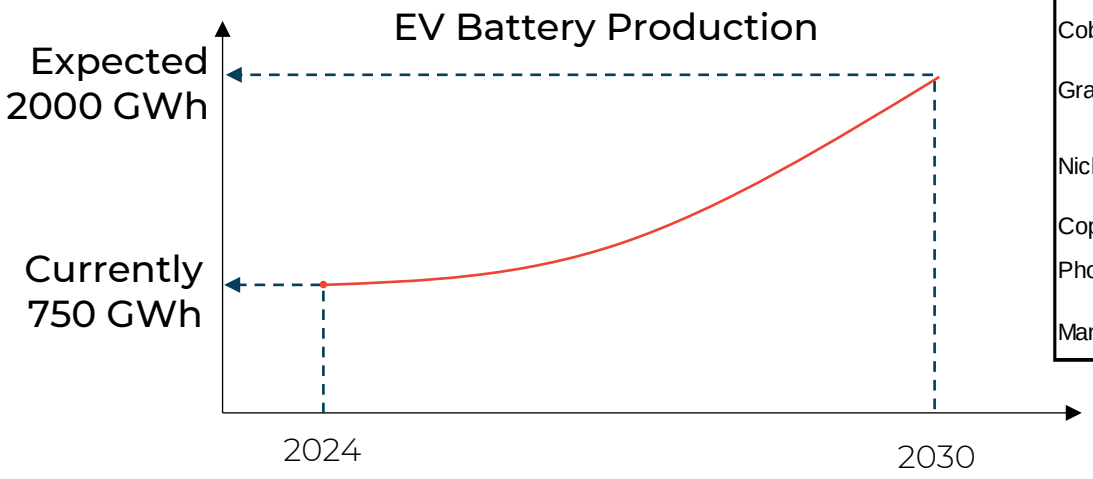
Increasing Demand of Battery Materials

Introduction



In 2022, 70% of the lithium-ion battery market was for EVs



Battery Material	EV Battery Demand (kt/a)		% of World Production		Estimated Resources (Mt)	Ratio of Resources to 2030 Demand	Role/benefit	% of LiB
	2022	2030	2022	2030				
Lithium	140	1,950-2,635	85	78-85	560	180-225	Primary cathode material	11-17
Cobalt	150	48-222	70	32-57	25	65-105	Cathode material - improved energy density & lifespan	10-20 (NMC)
Graphite		1,820-2,442		28-33	800	1,110-1,200	Anode material - coated onto copper foil	25-28
Nickel	370	507-1,128	10	13-24	350	75-90	Cathode material - higher energy density & storage density	
Copper		137-197		3.5-4.2	2,100	55-70	'Collector'	
Phosphorus		620-934		2.2-3.2	30,000	1,030-1,060	Cathode material in LFP batteries	
Manganese		293-676		1.3-2.6	17,000	660-760	Cathode material - improved stability & safety	

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Battery Materials – Four Stages

Upstream Processing

Extraction and concentration of the minerals from the ore.

Downstream Processing

Production of the battery materials from the concentrate.

Precursor Cathode Active Materials (pCAM)

Selected battery materials are combined in specific ratios and undergo a series of chemical and thermal processes.

Battery Manufacture

Assembled from pCAMs, anode material, 'collectors', spacers, electrolyte ($LiPF_6$) and casing material.

pCAM	Chemical Species	Formula	Comment
LCO	Lithium cobalt oxide	$LiCoO_2$	
NCA	Lithium nickel aluminium oxide	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$	
NMC	Lithium nickel cobalt manganese oxide	$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	NMC333-532-622-811
LMO	Lithium manganese oxide	$LiMn_2O_4$ and variants	
LFP	Lithium iron phosphate	$LiFePO_4$	
LTO	Lithium titanate	$Li_4Ti_5O_{12}$	
Li-S	Lithium sulfur		Mixture

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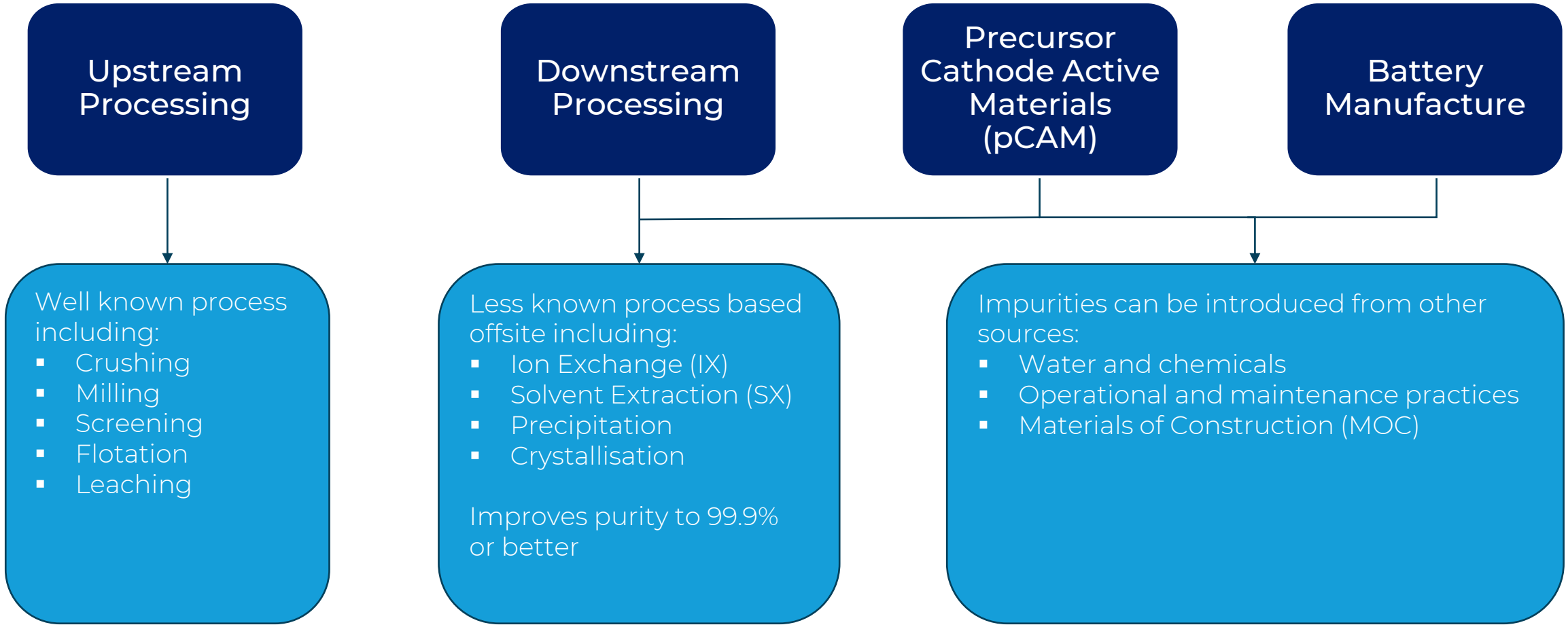
Battery Materials – Four Stages



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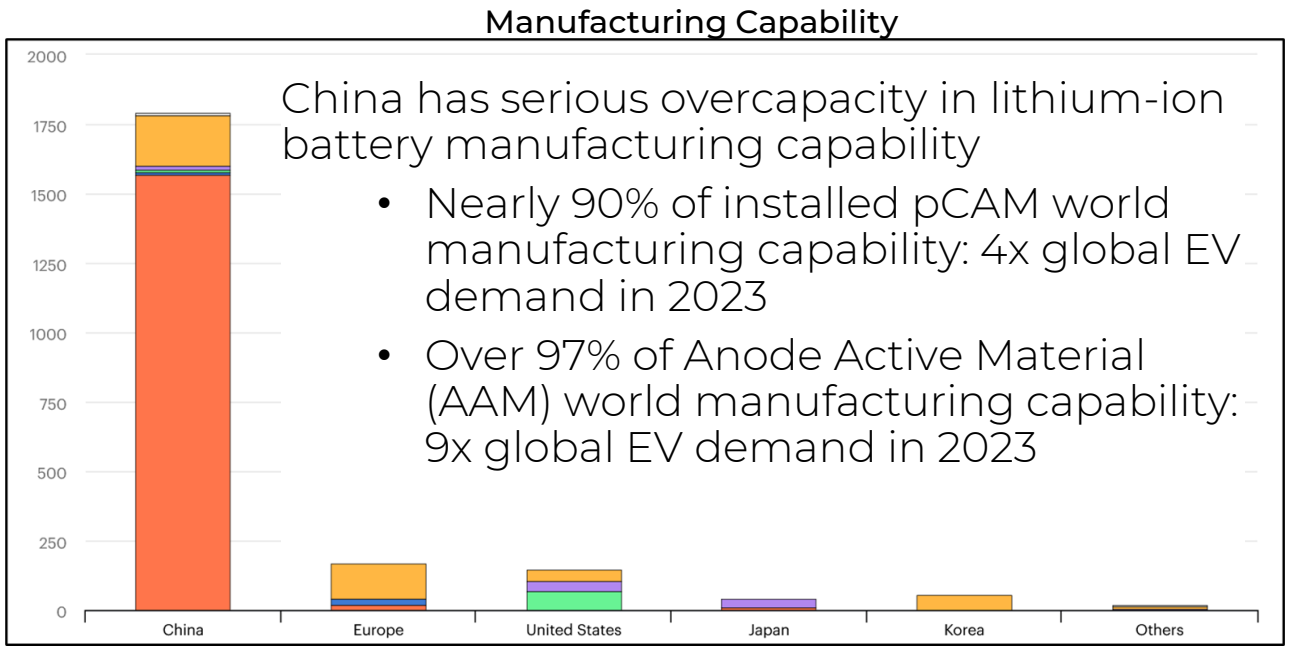
Lithium-Ion Batteries

Observations



- Lithium iron phosphate (LFP) batteries steadily replacing lithium-ion batteries based on nickel-manganese-cobalt (NMC) chemistry
- Developing new battery chemistries and making a working prototype is only the start
- The commercialisation process is long and expensive, and among other challenges, it must consider:
  - customer acceptance,
  - manufacturing processes,
  - safety,
  - application suitability,
  - recycling potential and
  - government regulations.

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Lithium

Lithium Primary Sources

Pegmatites

- Typically coarse-grained rocks
- Spodumene ($LiAlSi_2O_6$ - 8.03% Li_2O or 3.73% Li)
- World-wide distribution
- Mixture of large and small deposits
- Typical grades – 1% to 2% Li_2O (0.46-0.92% Li)

Salars

- Brines 'rich' in lithium
- Chile, Argentina and Bolivia dominate resources
- Typical grades 300-1,500ppm

Other Sources

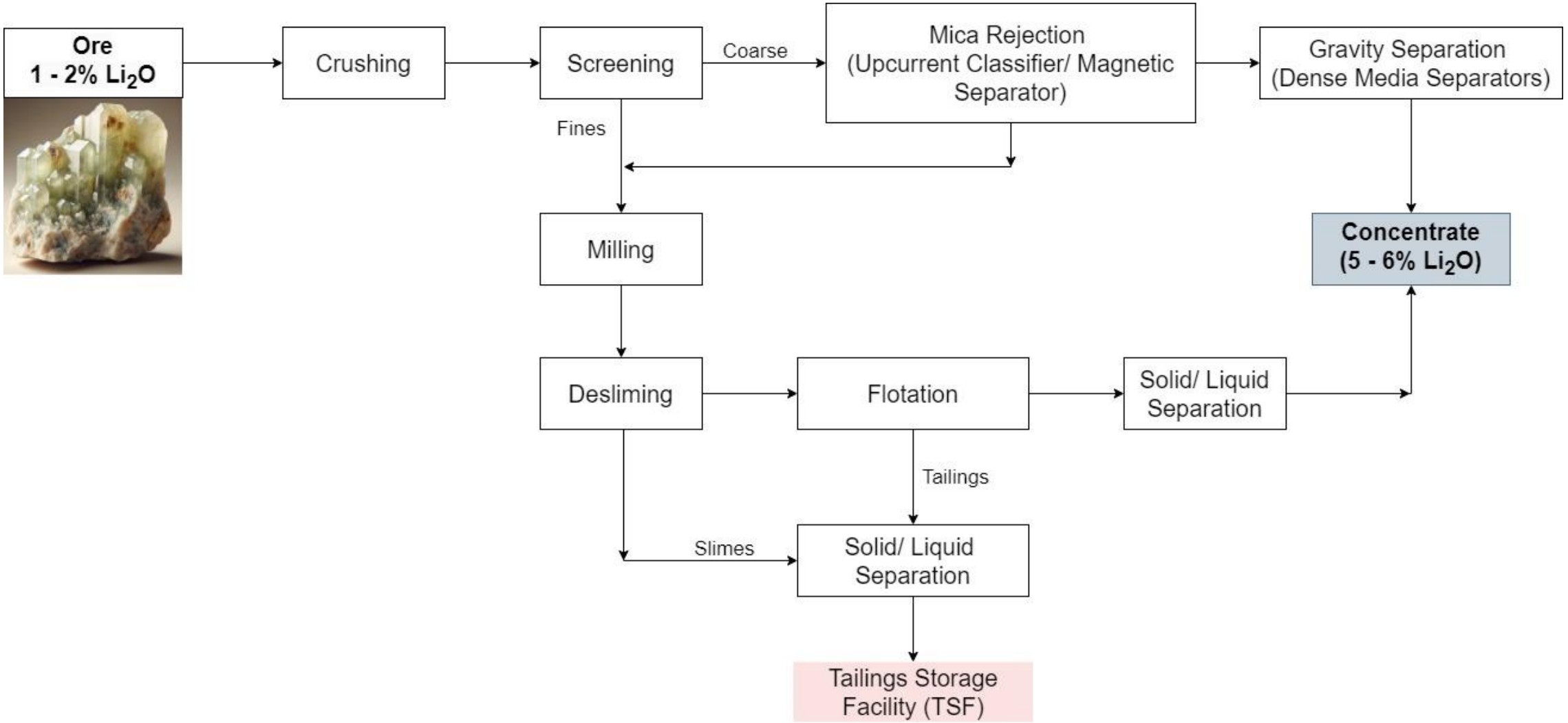
- Geothermal brines
- 'Fossil' salars
- 'Clay' deposits

Micronised Battery Grade Lithium Carbonate Specification

Element / Species	Concentration
Li_2CO_3	≥99.5%
H_2O	≤0.5%
Sulphate (SO_4)	≤0.1%
Sodium (Na)	≤0.05%
Calcium (Ca)	≤0.04%
Acid Insoluble Matter	≤0.02%
Potassium (K)	≤0.01%
Chloride (Cl)	≤0.01%
Aluminium (Al)	<10ppm
Nickel (Ni)	<6ppm
Copper (Cu)	<5ppm
Iron (Fe)	<5ppm
Zinc (Zn)	<5ppm
D100 micron	40
D90 micron	13
D50 micron	4-6

Lithium – Spodumene

Upstream Flowsheet



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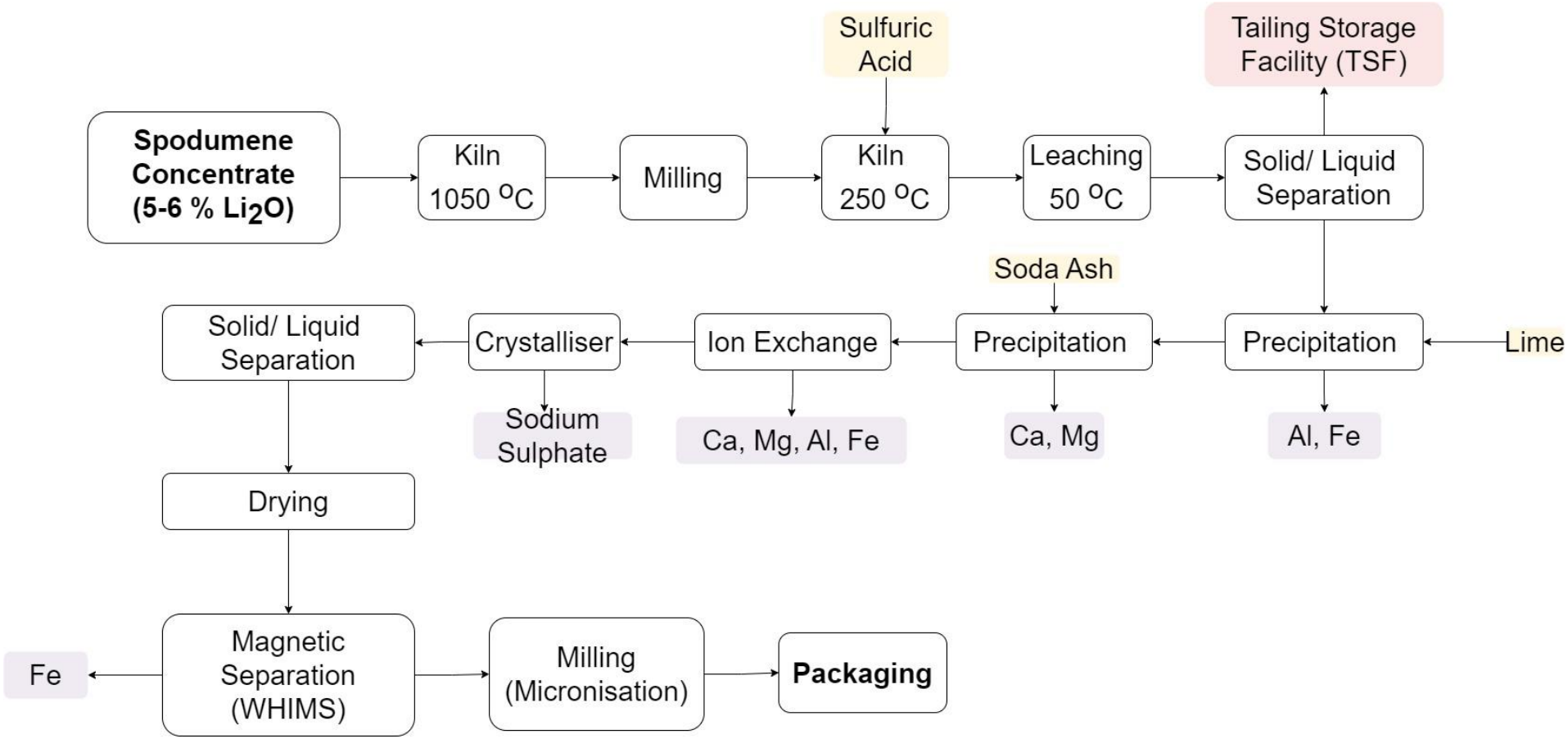
Lithium - Spodumene

Downstream Flowsheet



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Lithium - Salar

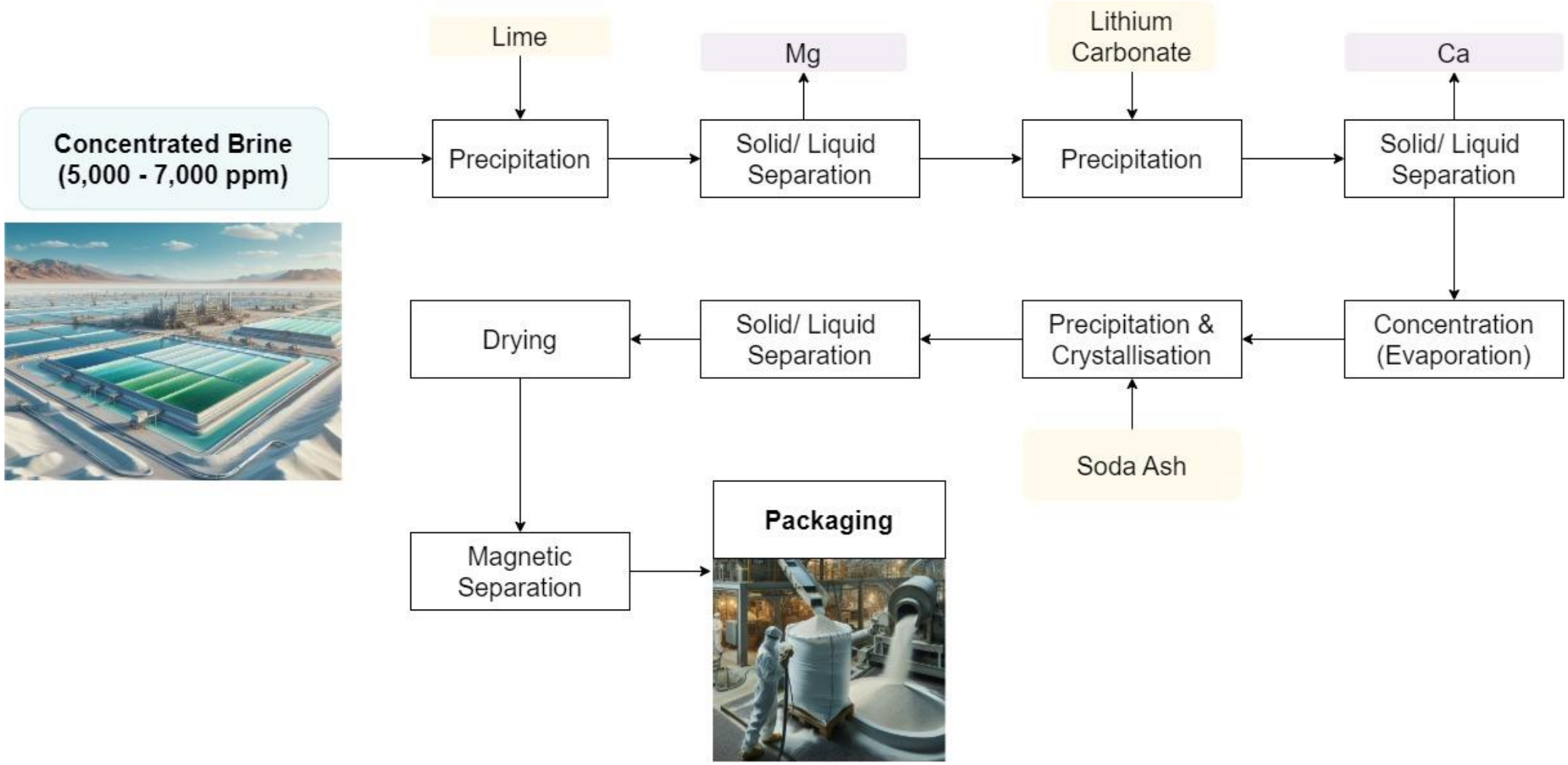
Upstream Flowsheet

- Series of evaporation ponds, where sodium, magnesium and potassium salts crystallise and precipitate out as the solubility limit of each salt is reached
  - Evaporation achieved by sun, wind and altitude
  - Very large footprint
- When the lithium concentration reaches around 5,000-7,000ppm (g/L), the solution is ready for harvesting i.e. lithium recovery

Source : SQM, Chile

Lithium - Salar

Downstream Flowsheet



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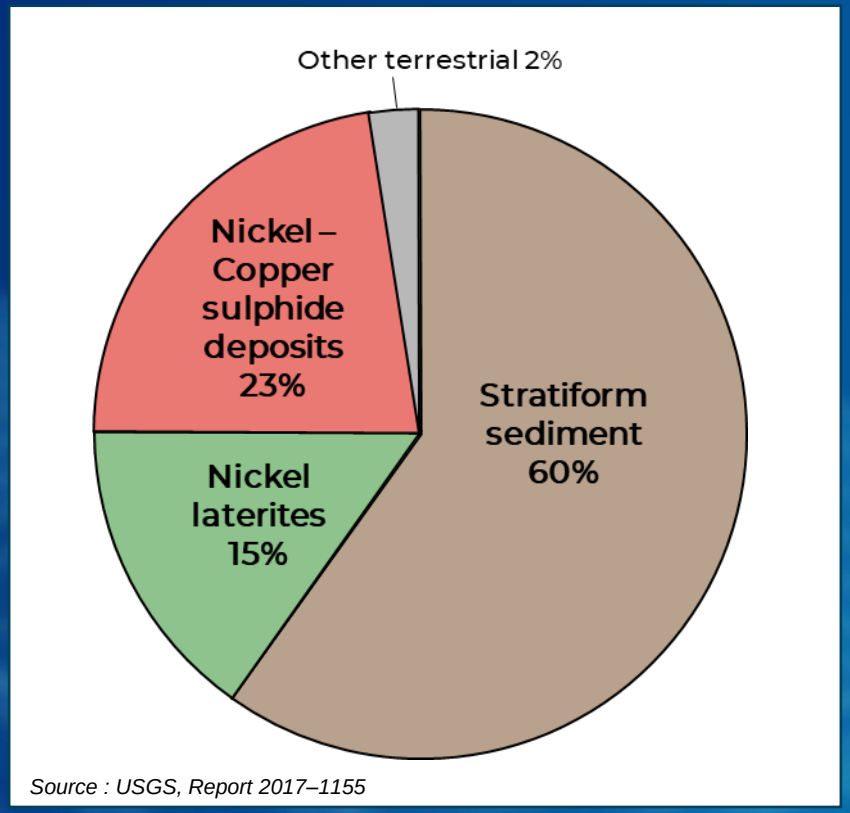
Nickel and Cobalt

Nickel and Cobalt Sources

Cobalt is a by-product of either nickel or copper



Source : USGS, Report 2017–1155

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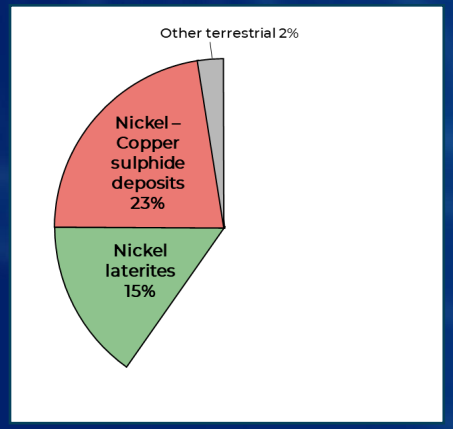

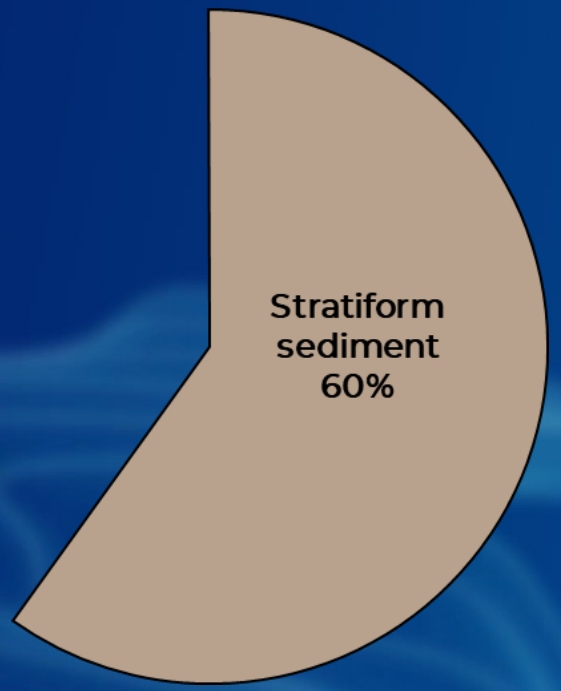

- DRC
- Large deposits
- Typical grades – 2 to 5% Cu, 0.2-0.3% Co
- Upstream processing involves leaching and after the copper is removed (SX), cobalt downstream processing similar to that for nickel-cobalt downstream processing

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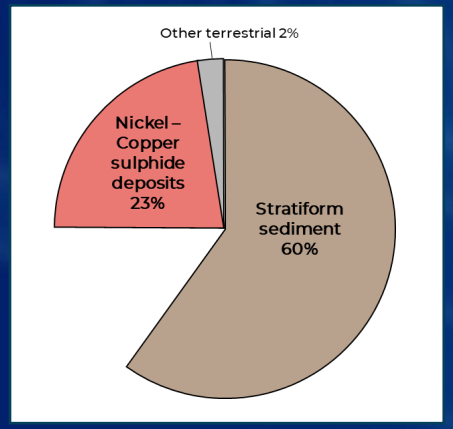
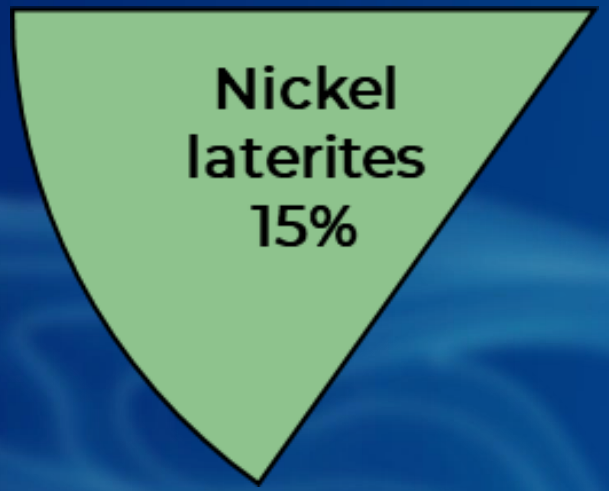
Nickel and Cobalt Sources

Cobalt is a by-product of either nickel or copper





- Indonesia, New Caledonia, Philippines, Cuba and Australia
- Limonite (HPAL feed) and saprolite (RKEF feed)
- Typical grades 0.66-2.4% Ni, 0.01-0.05% Co

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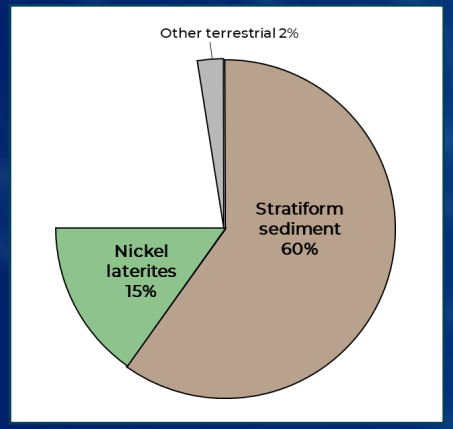
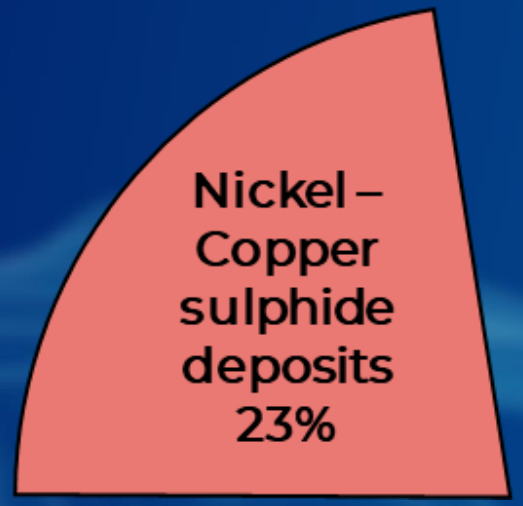
Nickel and Cobalt Sources

Cobalt is a by-product of either nickel or copper





- Russia, Australia, Canada, Brazil
- Typical grades – 1-3.0% Ni, 0.03-0.3% Co
- Upstream processing – comminution, flotation followed by downstream smelting, leaching and purification through IX, SX, precipitation and crystallisation

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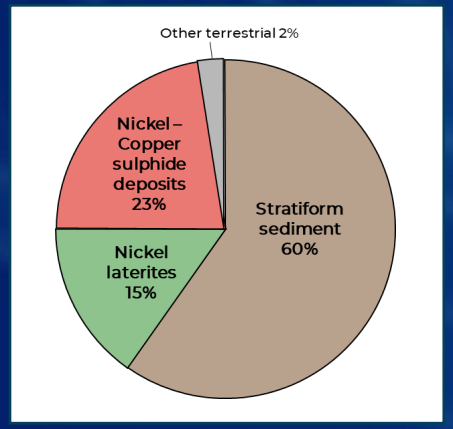
Nickel and Cobalt Sources

Cobalt is a by-product of either nickel or copper

- Largest accumulation of cobalt (as well as nickel and manganese) are submarine nodules
- Production tightly tied to the main output elements
- DRC produced 74% of the world's cobalt production in 2023
- Of which 71% of cobalt production was used in lithium-ion batteries (45% in EVs)

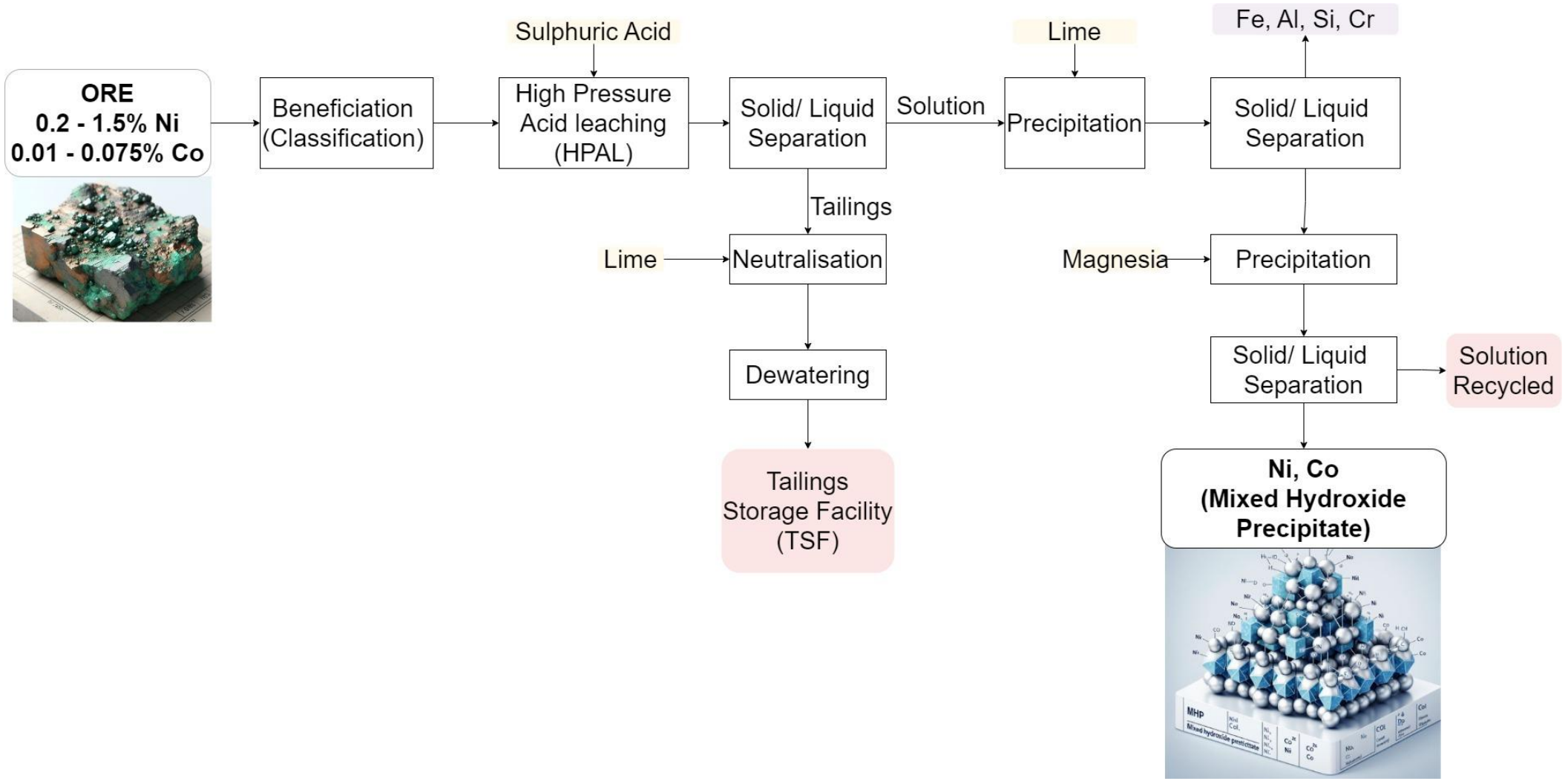


Nickel sulphate hexahydrate ($NiSO_4.6H_2O$ – 22.30% Ni) battery grade specification
(≥99.99% based on trace metal elements (<100ppm))

Element	Concentration (%)
Nickel (Ni)	22.20 – 22.30
Cobalt (Co)	< 0.0010
Magnesium (Mg)	< 0.0010
Sodium (Na)	< 0.0050
Calcium (Ca)	< 0.0005
Iron (Fe)	< 0.0010
Copper (Cu)	< 0.0005
Zinc (Zn)	< 0.0005
Manganese (Mn)	< 0.0010
Cadmium (Cd)	< 0.0005
Lead (Pb)	< 0.0010
Chromium (Cr)	< 0.0010
Acid Insolubles	< 0.0050

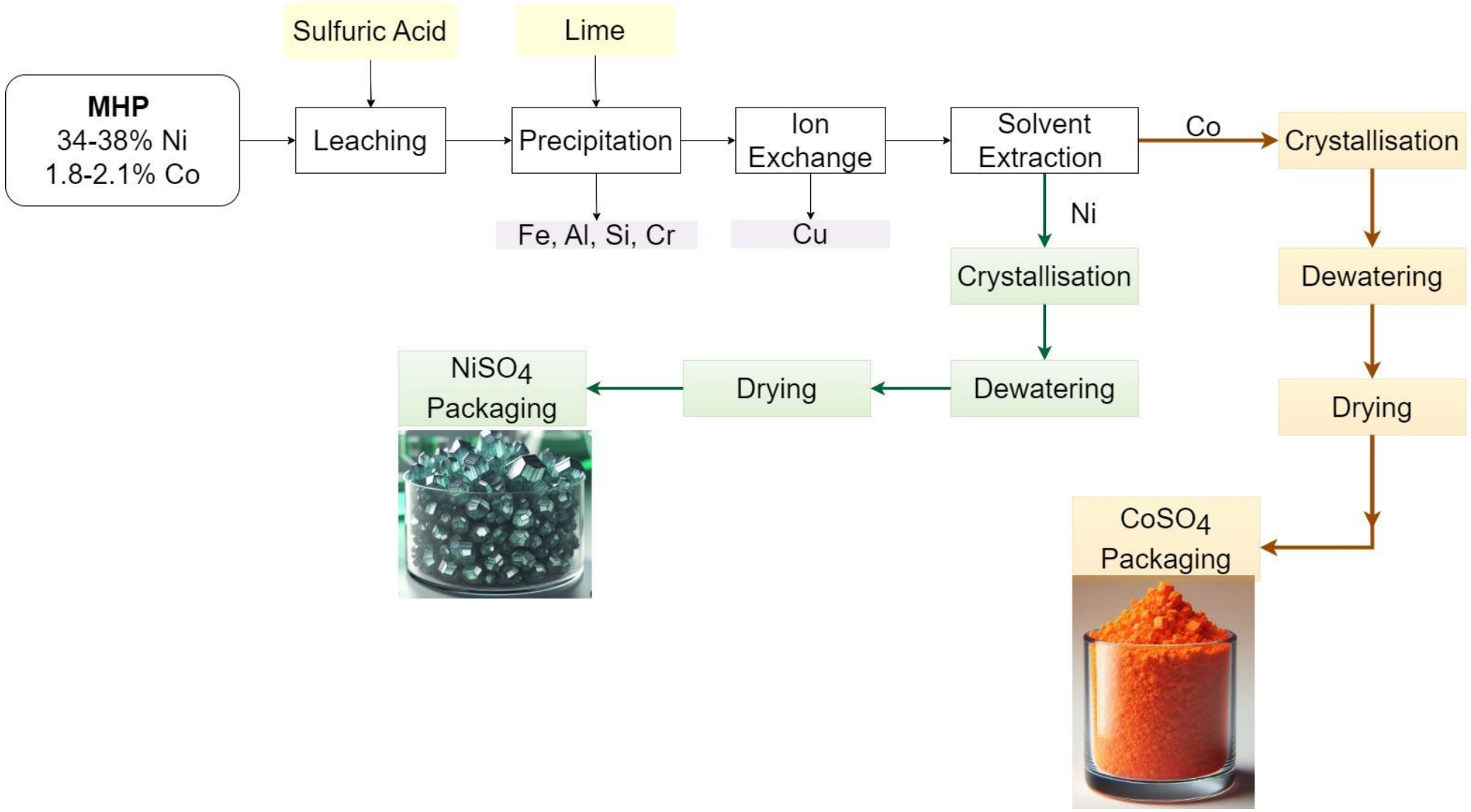
Nickel and Cobalt - Laterite

Upstream flowsheet



Nickel and Cobalt - Laterite

Downstream flowsheet



Graphite

Graphite

- World resources exceeds 800 million tonnes
- Typical feed grades are 5% to 12% Cg
- China has the largest reserves and is the largest producer
- Graphite typically forms as flakes in metamorphic rocks such as schists, marble and gneisses
- Larger flakes have greater purity (and thus need less downstream processing)
- Synthetic graphite, although more expensive, dominates usage in lithium-ion batteries

Coated, Micronised & Spheroidised Graphite Battery Specification

Element / Species	Concentration
Graphite	≥99.95%
Silicon (Si)	<35ppm
Iron (Fe)	<30ppm
Sulphur (S)	<6ppm
Ash	<0.15%
H_2O	<0.03%
D90 micron	28-32
D50 micron	17-19
D10 micron	8-12
Tap density	1.2 g/cm^3
Specific Surface Area (BET)	3-5 m^2/g
First discharge capacity	>365 mAh
First discharge effiicency	95%

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Graphite

Upstream Flowsheet

Crushing

Rod Mill

Rougher/ Scavenger Flotation

Tailings

Solid/ Liquid Separation

Tailing Storage Facility (TSF)

Concentrate

Tailings

Regrind 1

Cleaner 1

Regrind 2

Cleaner 2

Regrind 3

Cleaner 3

Concentrate

Concentrate

Tailings

Concentrate

-180 µm

-300 / +180 µm

+300 µm

Screening

Drying

Dewatering

Concentrate

Cleaner 5

Concentrate

Cleaner 4

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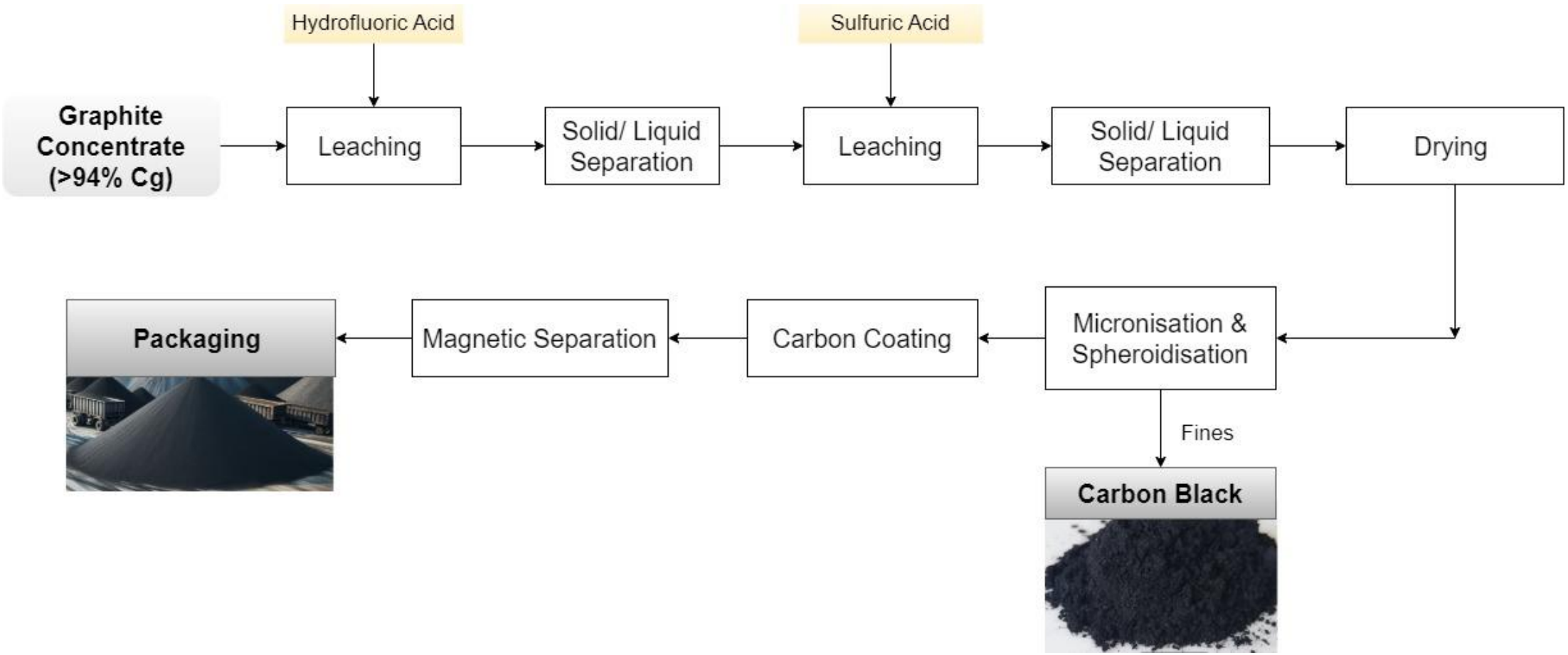
Graphite

Downstream Flowsheet



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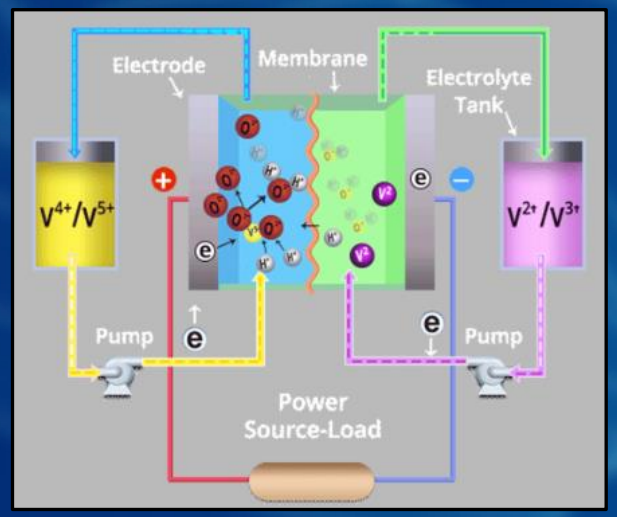
Vanadium

Vanadium

Primary Sources

- Mainly vanadiferous titanomagnetite (VTM) deposits and marine sediments/oil shales (Julia Creek)
- Largest reserves are in China, Russia, Australia and South Africa
- Largest producers are China, Russia, South Africa, Brazil
- Typical grades 0.3-1.5% V_2O_5
- Upstream processing of VTM ores involves comminution and magnetic separation
- Downstream processing involves roasting with salt, leaching, silica removal, precipitation (AMV), drying and calcination (V_2O_5)

Vanadium is being used in 'stationary' batteries (Vanadium Redox Flow Battery - VRFB) that takes advantage of the fact that the vanadium ion has four valency states viz., +2, +3, +4 and +5.



Vanadium VRFB Battery Grade Specification

Element / Species	Concentration
Vanadium (V_2O_5)	≥99.6%
Molybdenum (Mo)	<0.025%
Iron (Fe)	<0.02%
Sodium (Na)	<0.01%
Silicon (Si)	<0.01%
Potassium (K)	<0.01%
D100 micron	850

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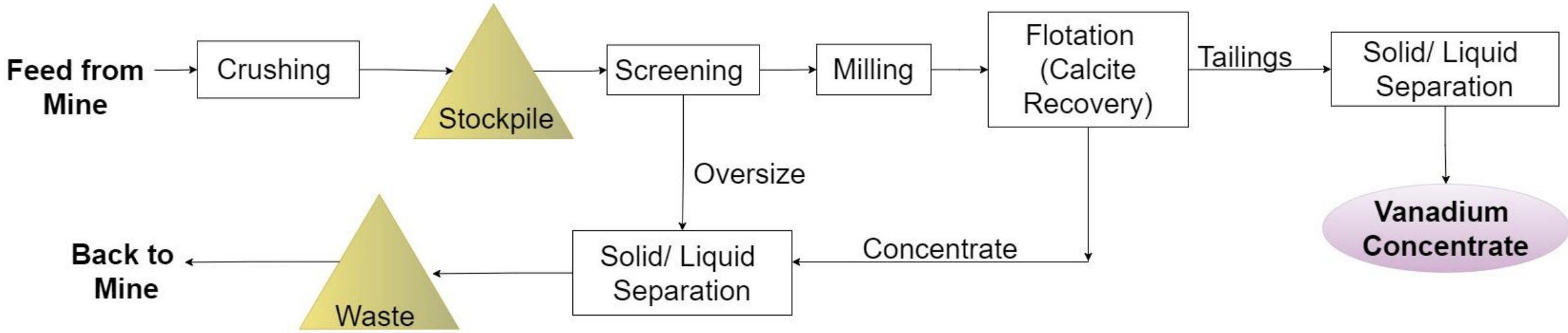
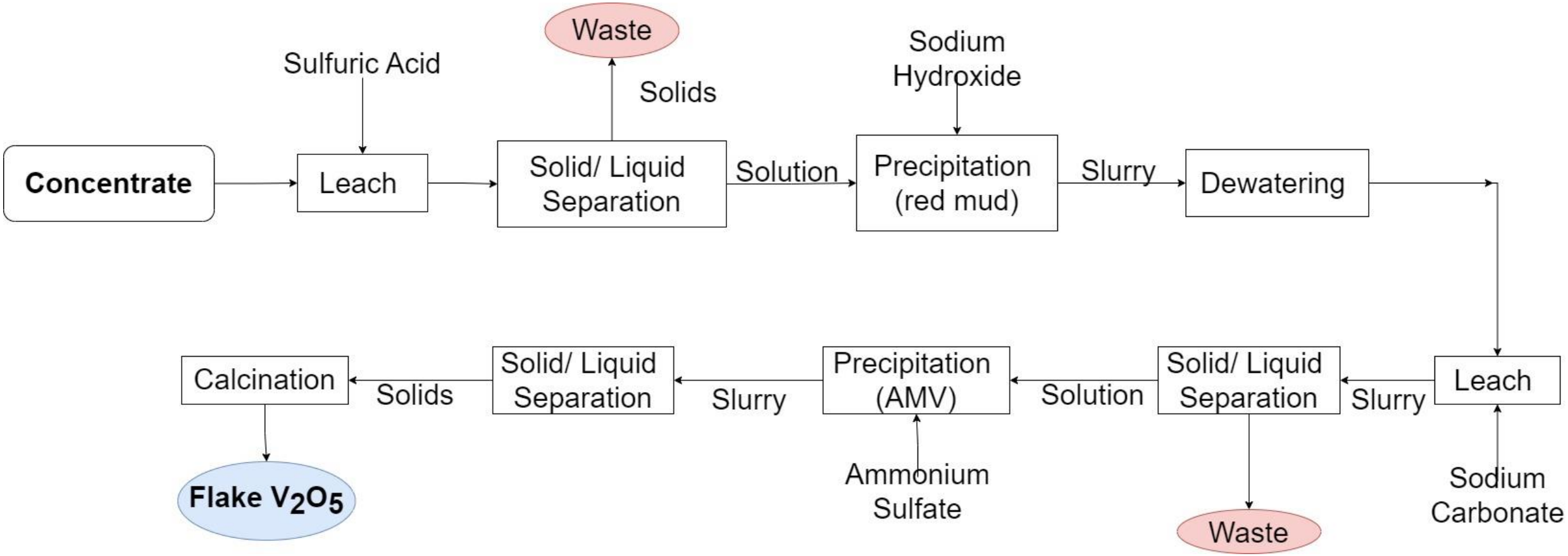
Vanadium Stage

Upstream flowsheet – Julia Creek



Vanadium Stage

Downstream Flowsheet – Julia Creek



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Thank you

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Shelly Sidell

Business Developer Manager for ESG– RPM Global

With over a decade of experience in business development within mining, oil and gas, and construction.

Shelly aligns the company’s strategies with clients' current and future needs. Collaborating with clients to provide effective solutions that address their environmental and social requirements, helping to enhance their corporate reputation while supporting their initiatives in environmental and community matters.

RPMGLOBAL

GLOBAL CLIENT BASE

GLOBAL COMMODITY LEADERS

OVER 50 YEARS

125 COUNTRIES

21 OFFICES GLOBALLY

Mining Advisory Services

INVESTOR

- Compliance Reporting & Valuation Reports
- Technical Review for Investment & M&A
- Lenders Engineering Technical, Environmental & Social
- Expert Witness

OPERATIONAL

- Optimisation & Improvement Projects
- Strategic & Operational Mine Planning
- Mining Methods Studies & Trade Off
- Whole of Mine Emissions Reporting

RPMGLOBAL ADVISORY SERVICES

ESG

- Net Zero
- ESG Strategy Advice
- Rehabilitation & Closure
- E&S Technical Review & Due Diligence
- Environmental Impact Assessment & Approvals

MINING PROJECTS

- Study Peer Review & Audit
- Energy Aware Mine Design
- Geological & Exploration Advisory
- Mining Studies (Concept to Feasibility)

Battery and Critical Mineral Experience

RPMGlobal has completed over 100 battery and critical mineral projects spanning the globe, including work on:

	**Hardrock Lithium (spodumene)**	Western Australia, Canada, USA, Africa
	**Brine Lithium**	Chile, Argentina, Germany
	**Sulfide Cobalt & Nickel**	Western Australia, USA
	**Oxide Cobalt**	DRC
	**Laterite Nickel & Cobalt**	Australia, Indonesia, New Caledonia, Madagascar, Philippines
	**Graphite**	Australia, Tanzania, Sweden, Mozambique and South Korea
	**Rare Earth**	Australia, China, Brazil, USA

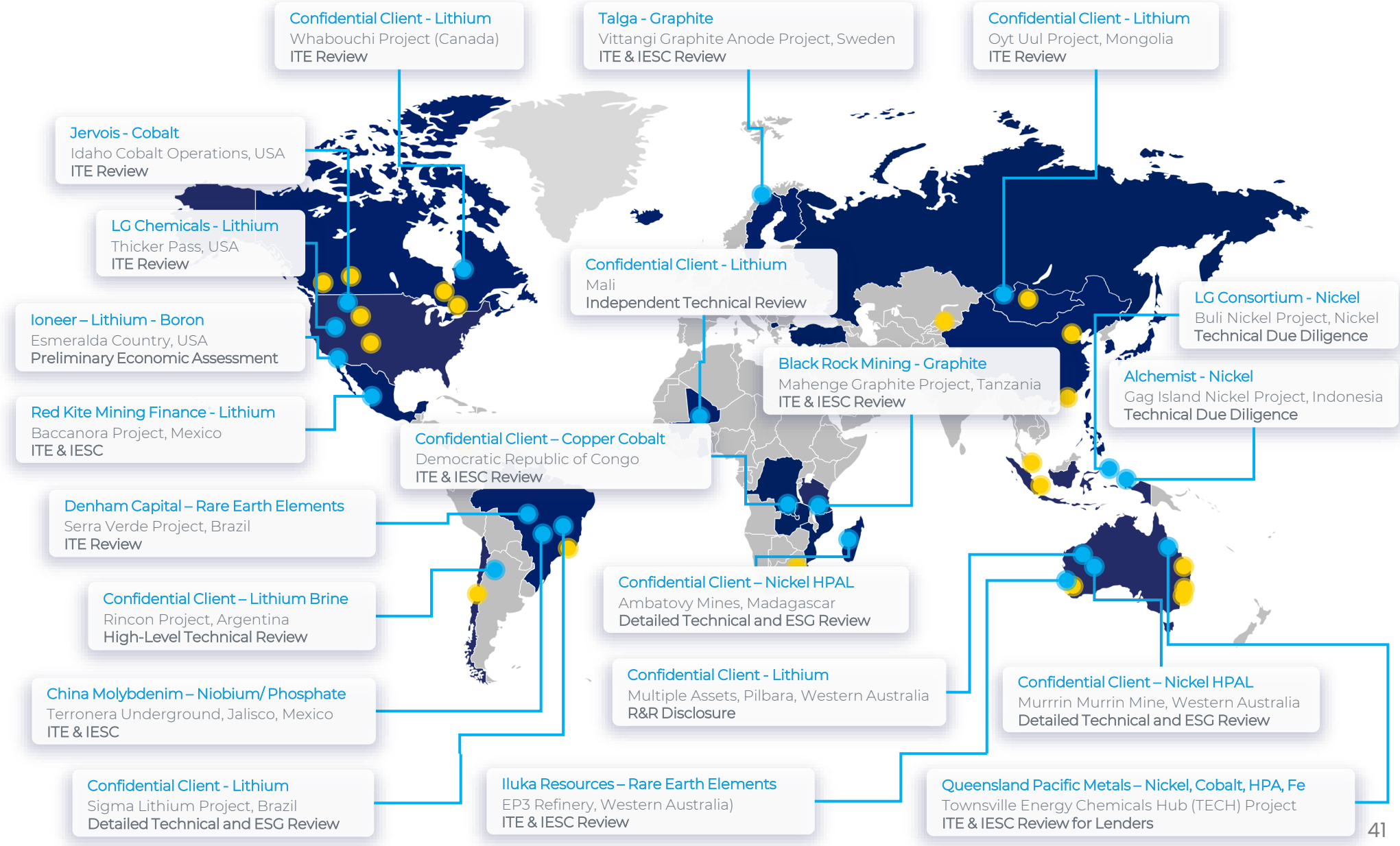
Our battery metals work includes advising battery manufacturers and OEMs for raw material supply investments upstream in the value chain and downstream through to and including battery recycling.

This work includes review of the mining operations as well as downstream refining technologies (solvent extraction, DLE, etc.) either through our internal team or partner network.

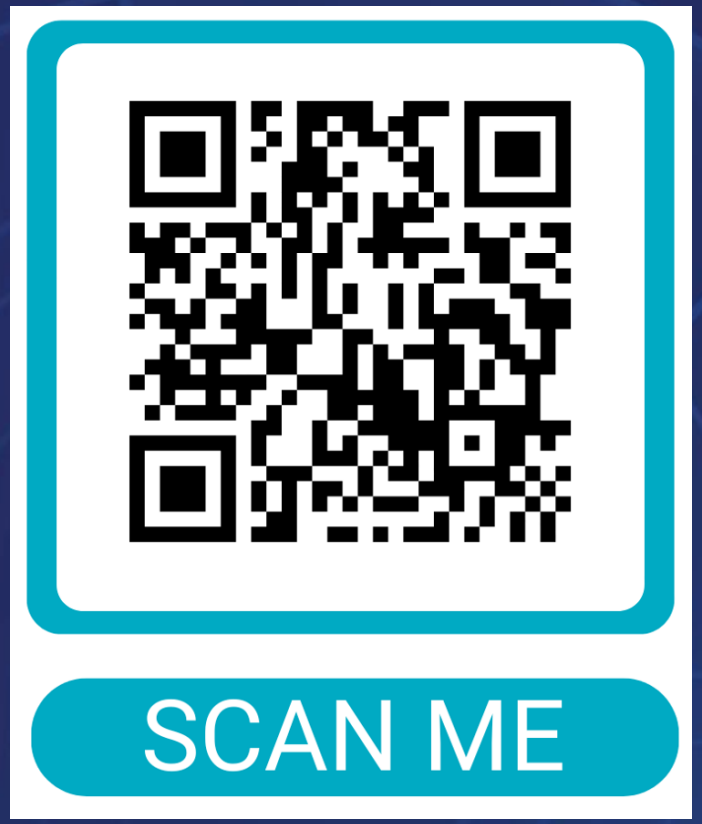
RPM Battery and Critical Minerals Overview

Some of our Battery and Critical Minerals clients

Sumitomo
posco
LG Energy Solution
SK



- Project Location
- RPMGlobal Office
- Countries where RPM has completed Battery and Critical Minerals Projects



AusIMM Survey