ElectraMet®

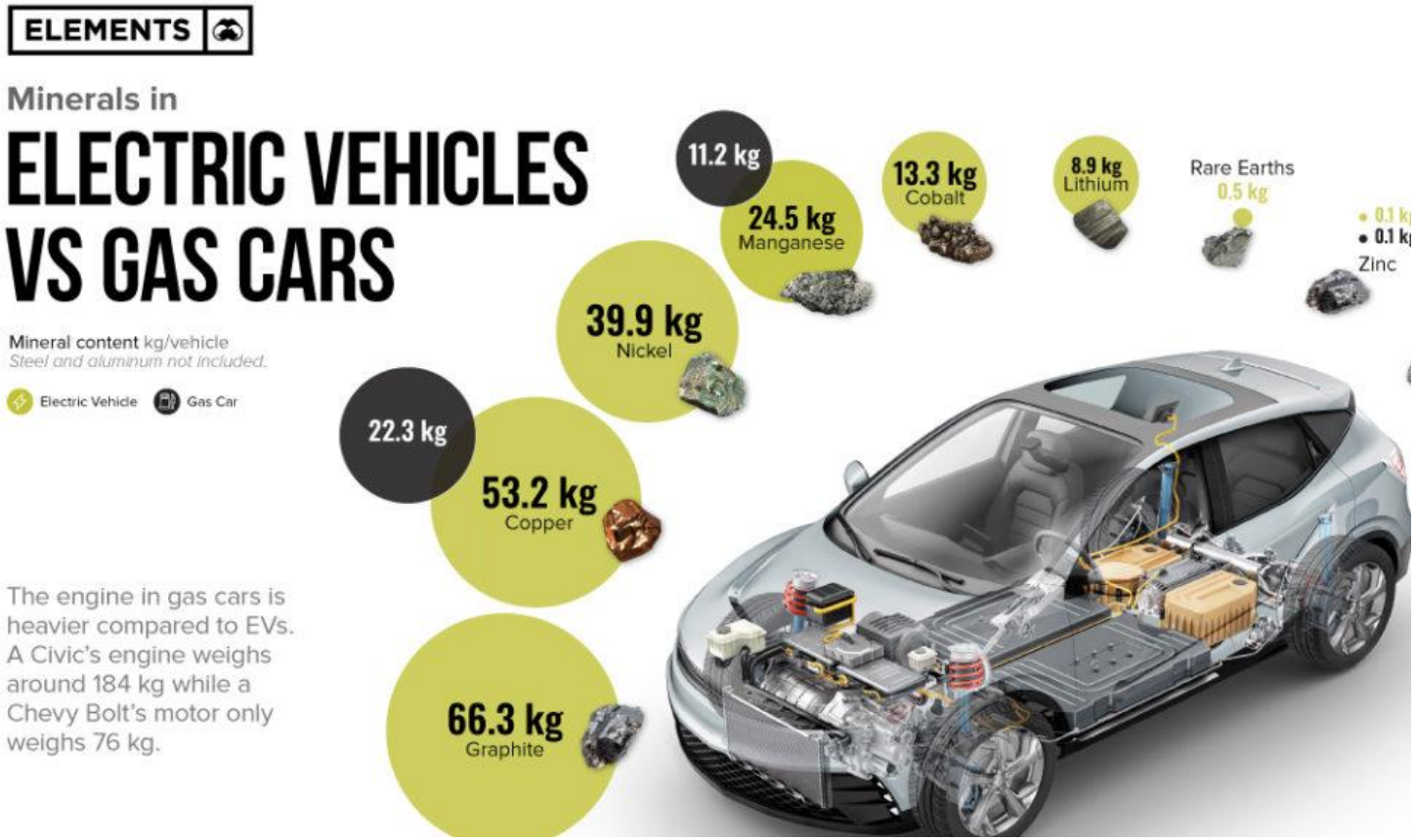
Electrochemistry that Bridges Current and Future Battery Chemistries

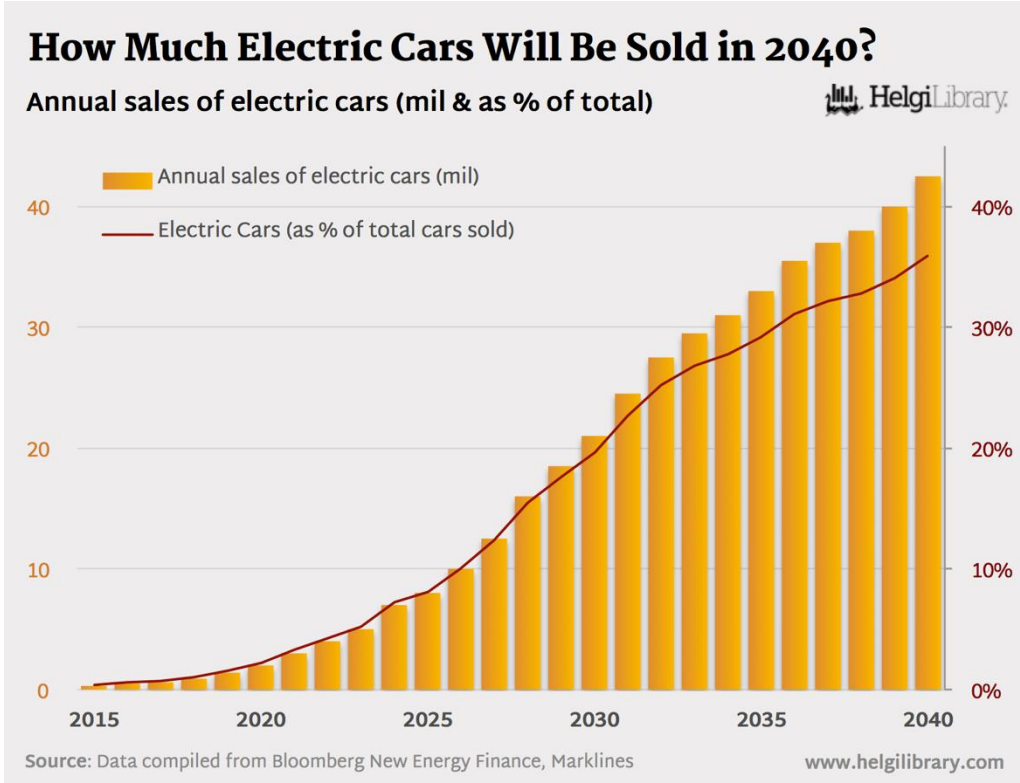


CAMERON LIPPERT, PHD | CHIEF INNOVATION OFFICER

ElectraMet™

Critical Metals are Crucial for Electrification





No Single Battery Chemistry Winner – Specifics Matter

LFP — MAINSTREAM
Low cost • Safe • Long life
Entry & mid-range EVs
~160 Wh/kg

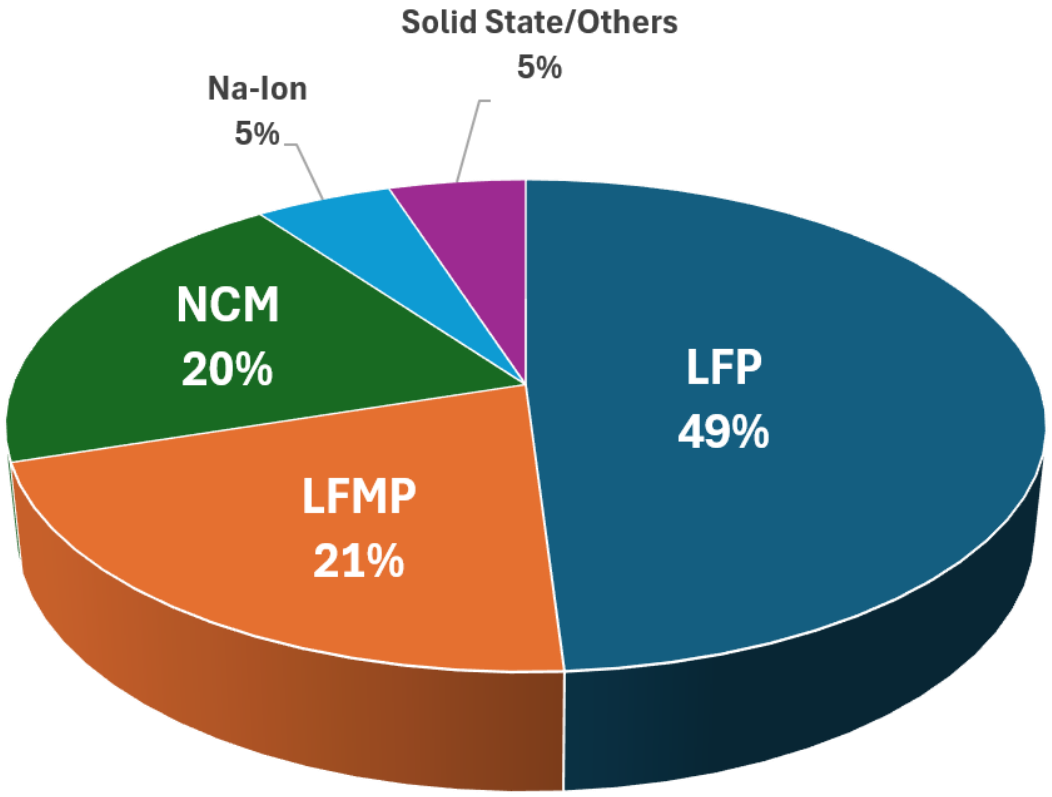
LMFP — RISING
LFP safety + 15–20% more energy
Next step for mid-segment
~200 Wh/kg

NMC / NCA — PREMIUM
Highest energy density, long range
Premium & performance EVs
~270 Wh/kg

Sodium-ion — EARLY
No lithium • Strong in the cold
City cars & two-wheelers
~140 Wh/kg

Solid-state — FUTURE
Higher density • Faster charge • Safer
Pilot lines now, scale late decade+
400+ Wh/kg

Predicted Battery Chemistry In Use (2030)

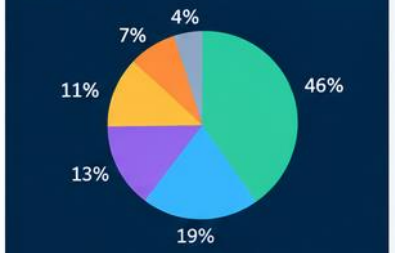


IRENA, Critical Materials: Batteries for Electric Vehicles

Different Chemistries will Require Different Strategies

LFP

Lithium iron phosphate ($LiFePO_4$)



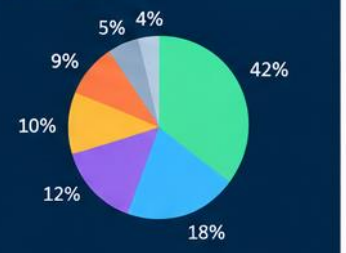
	Mass (kg)	Value (USD)
Lithium (Li)	6.0	$91
Iron (Fe)	48.0	$48
Phosphorus (P)	27.0	$27
Graphite (C)	66.0	$50
Aluminum (Al)	44.0	$132
Copper (Cu)	26.0	$377
Steel	26.0	$26

Total Material Value

$690 (~$11.5/kWh)

LMFP

Lithium manganese iron phosphate ($LiMn_{0.5}Fe_{0.5}PO_4$)



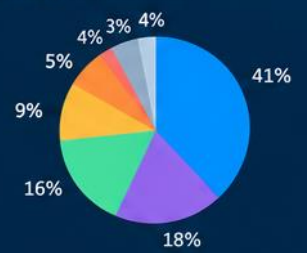
	Mass (kg)	Value (USD)
Lithium (Li)	6.0	$91
Manganese (Mn)	24.0	$69
Iron (Fe)	24.0	$24
Phosphorus (P)	27.0	$27
Graphite (C)	66.0	$50
Aluminum (Al)	44.0	$132
Copper (Cu)	26.0	$377
Steel	26.0	$26

Total Material Value

$728 (~$12.1/kWh)

NMC 811

Nickeli manganese cobalt ($LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$)



	Mass (kg)	Value (USD)
Nickel (Ni)	39.0	$604
Manganese (Mn)	5.0	$14
Cobalt (Co)	5.0	$184
Lithium (Li)	6.0	$91
Graphite (C)	45.0	$34
Aluminum (Al)	30.0	$90
Copper (Cu)	20.0	$289
Other (steel, etc.)	20.0	$20

Total Material Value

$1,307 (~$21.8/kWh)

Sodium-ion

Prussian white ($Na_2Fe[Fe(CN)_6]$) + hard carbon anode



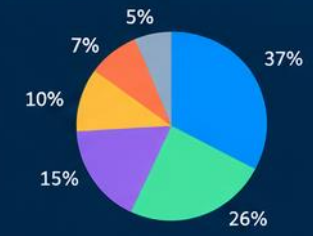
	Mass (kg)	Value (USD)
Sodium (Na)	11.0	$70
Iron (Fe)	30.0	$30
Carbon (hard)	48.0	$36
Aluminum (Al)	26.0	$78
Copper (Cu)	20.0	$289
Other (binder, etc.)	30.0	$18

Total Material Value

$179 (~$3.0/kWh)

Solid-state

NMC 811 cathode + lithium metal anode (with solid electrolyte)



	Mass (kg)	Value (USD)
Nickel (Ni)	39.0	$604
Manganese (Mn)	5.0	$14
Cobalt (Co)	5.0	$184
Lithium (Li)	17.0	$259
Graphite (C)	0.0	$0
Aluminum (Al)	30.0	$90
Copper (Cu)	20.0	$289
Other (solid electrolyte, etc.)	26.0	$78

Total Material Value

$1,502 (~$25.0/kWh)

HIGH VALUE, LOWER RISK

NMC & solid-state have high-value metals (Ni, Co, Cu, Li), making them more economically attractive to recycle.

LFP & SODIUM: CHALLENGING ECONOMICS

Lower value metals (Fe, Mn, Na) and less critical materials make LFP and sodium-ion harder to recycle profitably.

DIFFERENT CHEMISTRIES. DIFFERENT MODELS.

Recycling isn't one-size-fits-all. Each chemistry requires a tailored approach — from metal recovery to offtake and processing strategy.

Different Chemistries will Require Different Strategies

Lithium First Approach

MAXIMIZE VALUE. MINIMIZE COMPLEXITY.

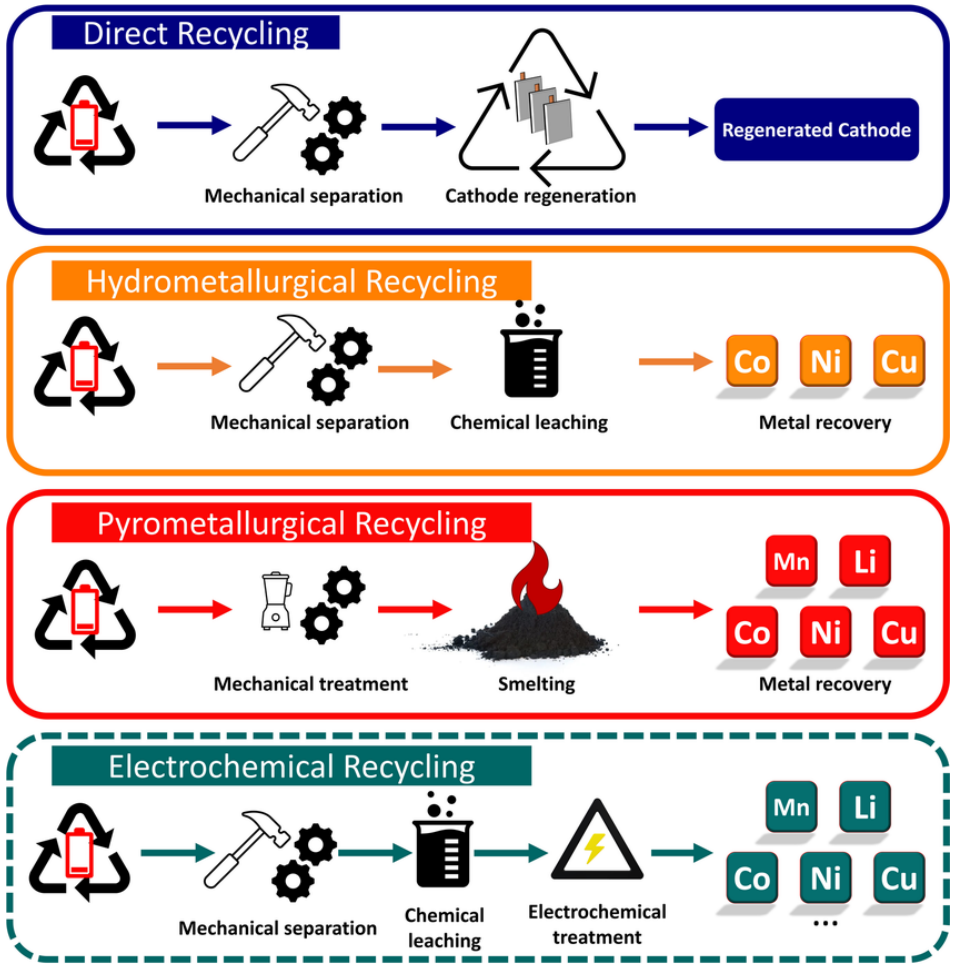
End-of-Life Batteries → Black Mass (mixed metals)

Lithium
- ✓ Easiest to recover
- ✓ Highest value
- ✓ Drives economics

→ Lithium Processing (proprietary or commercial) → Lithium Product (e.g., lithium carbonate or hydroxide)

Remaining Metals
- ✓ Commodity value
- ✓ Sell as-is
- ✓ No processing needed
- ✓ No capital infrastructure

→ Sell to Smelters & Offtakers (e.g., copper, nickel, cobalt, manganese) → Commodity Metals (market-based pricing)



Why Is an Adaptive Process Needed?

Volatile Metal Prices



High Risk Exposure

Electrochemistry enables versatility in product choice to match market needs

Surprise Contaminants



Impurities Decrease Value

Electrochemistry enables tunability to target different impurities

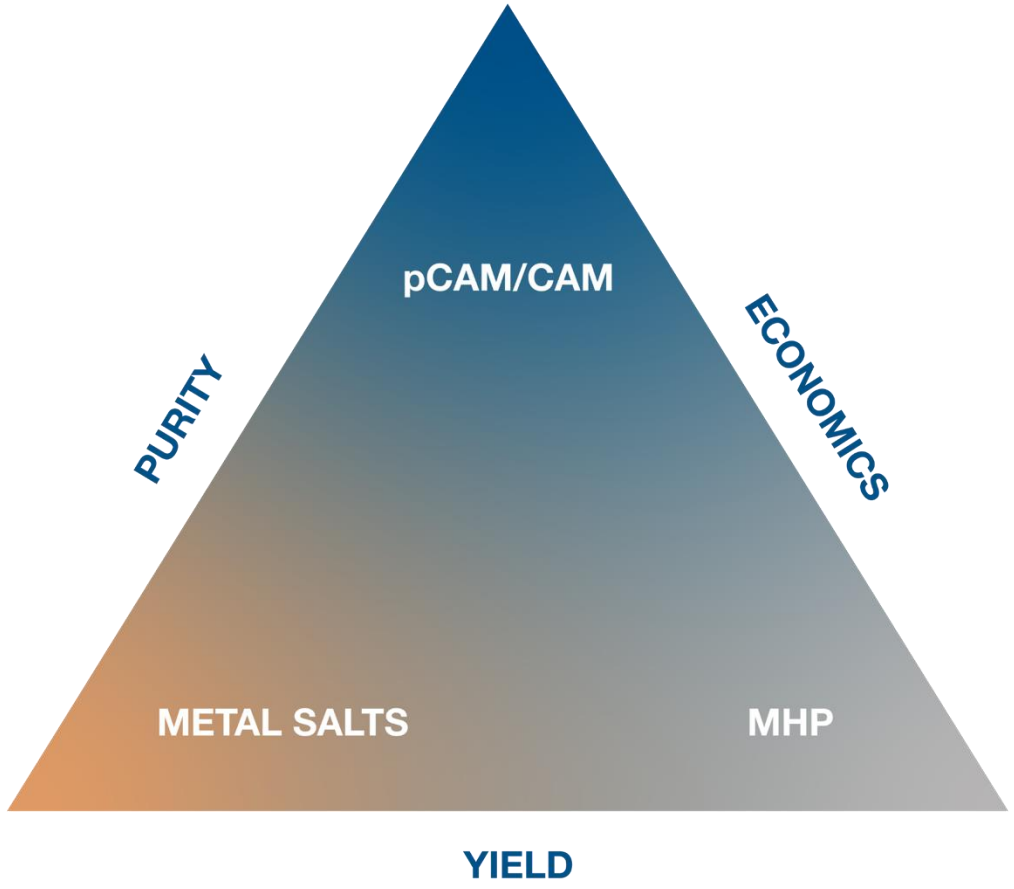
Glauber's Salt



Costly Waste Stream

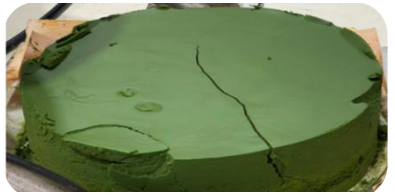
Electrochemistry can convert a waste stream into a value stream

Key Factors for a Successful Recycling Operation





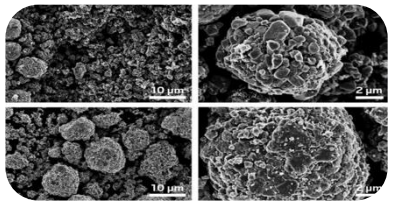
Black Mass:
~50 (up to 70%) LME



MHP:
58% Co LME
79% Ni LME

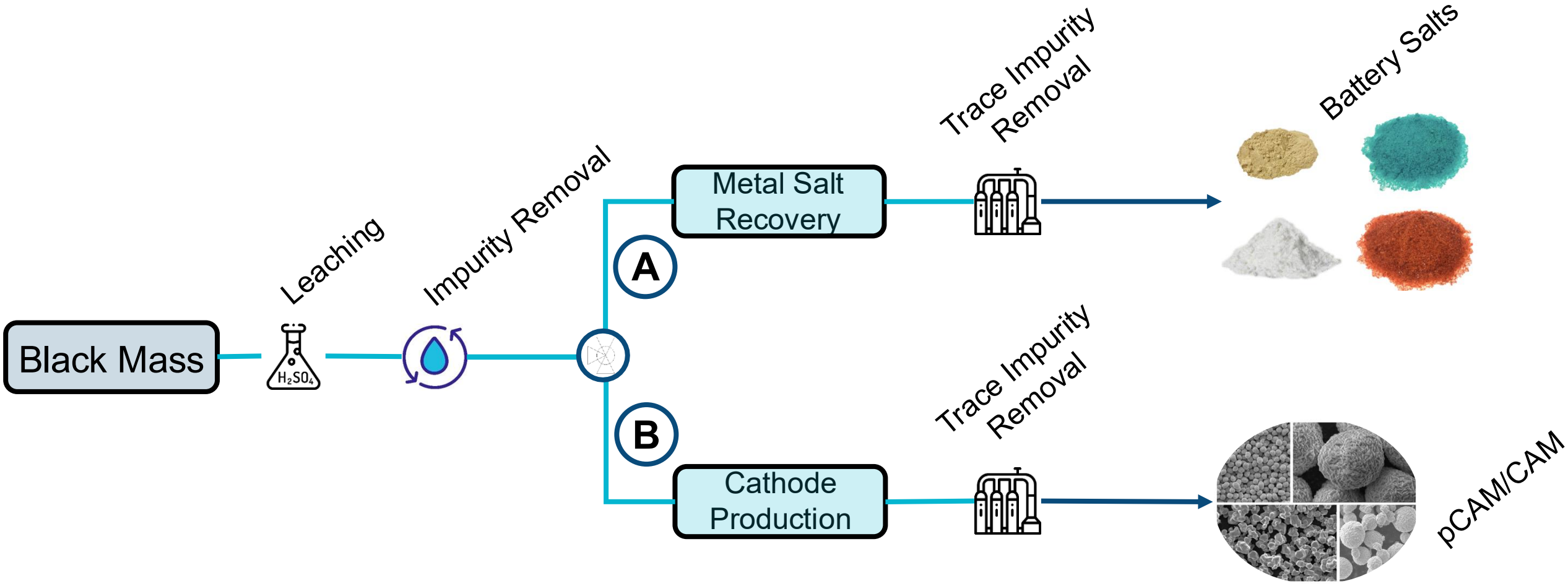


Metal Salts:
> 90% LME or 30% Premium

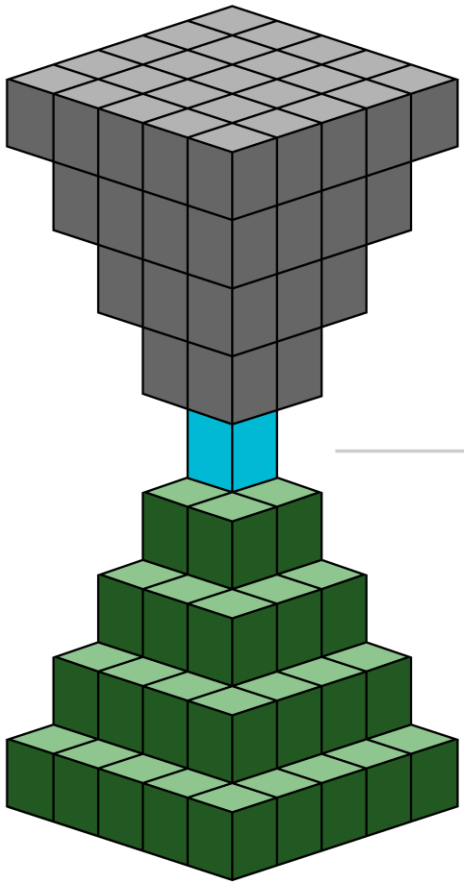


pCAM/CAM:
$ 10x

General Hydrometallurgical Process Options (NMC Focus)



Impurity Removal is the Key

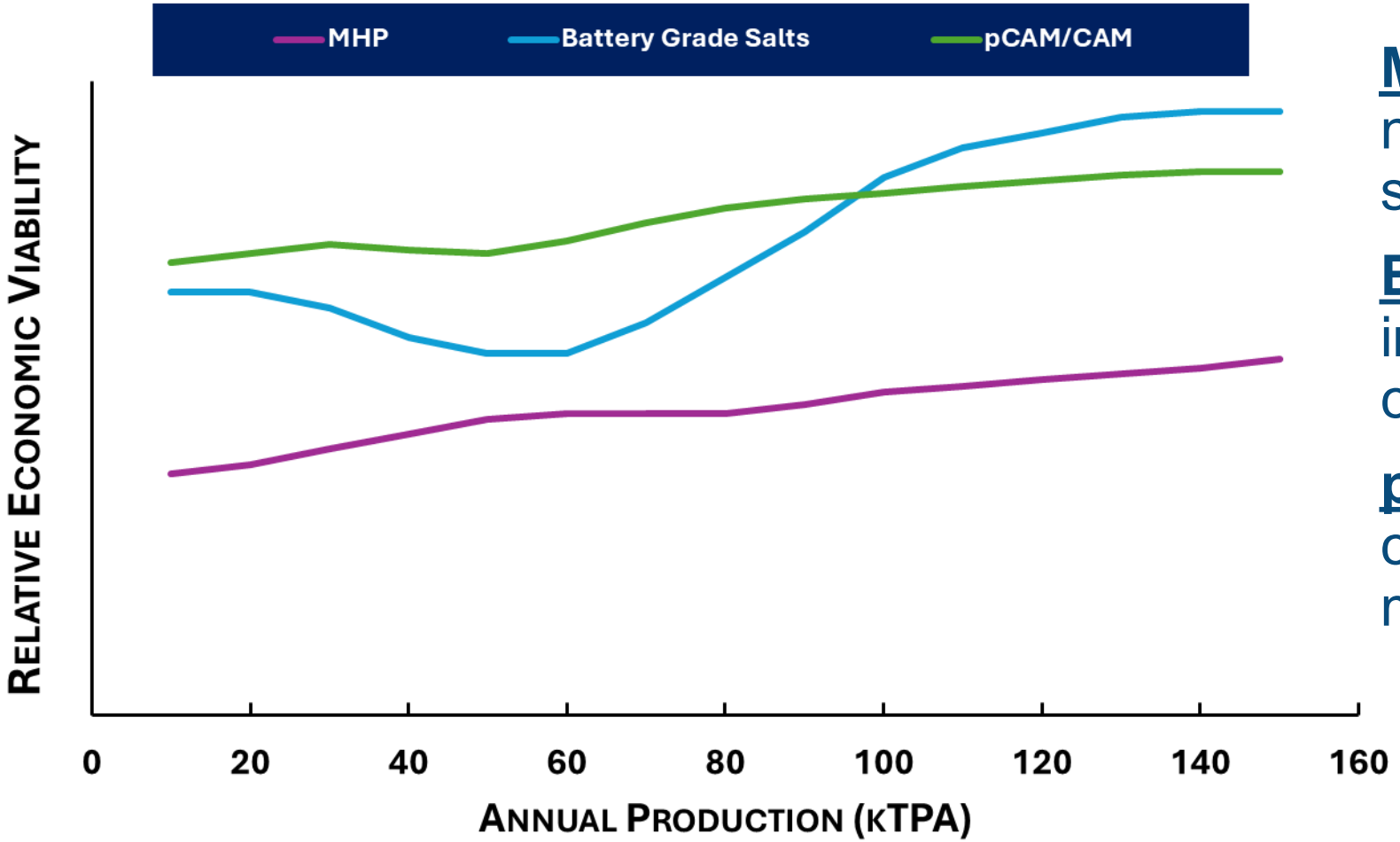


	CONTAMINATE LIMIT (ppm)											
PRECURSOR	Na	Ca	Fe	Al	Cu	Ni	Mg	Mn	Pb	Cr	Cd	K
LiOH	20	15	5	10	5	10			10	5		10
NiSO4	15	4	3	5	1		10	2	5	5	1	10
CoSO4	12	12	5	12	3	100	10	5	5	5	5	5
MnSO4	50	50	10		10		50		10			1

	CONTAMINATE LIMIT (wt%)					
PRECURSOR	Na	Ca	Fe	Cu	Zn	Cd
NMC 622	0.03		0.01	0.005		0.002
NMC 522	<0.03	<0.01	<0.005	<0.002		<0.001
NMC 811	<0.03	<0.01	<0.006	<0.002	<0.02	<0.001
NMC 111	<100 ppm	<300 ppm	<100 ppm	<20 ppm	<20 ppm	<5 ppm

* Specifications sourced from Livent, iSkyChem, Sigma-Aldrich, MSE Supplies, CoreMax

Maximizing Outcomes Through Product & Scale Synergy

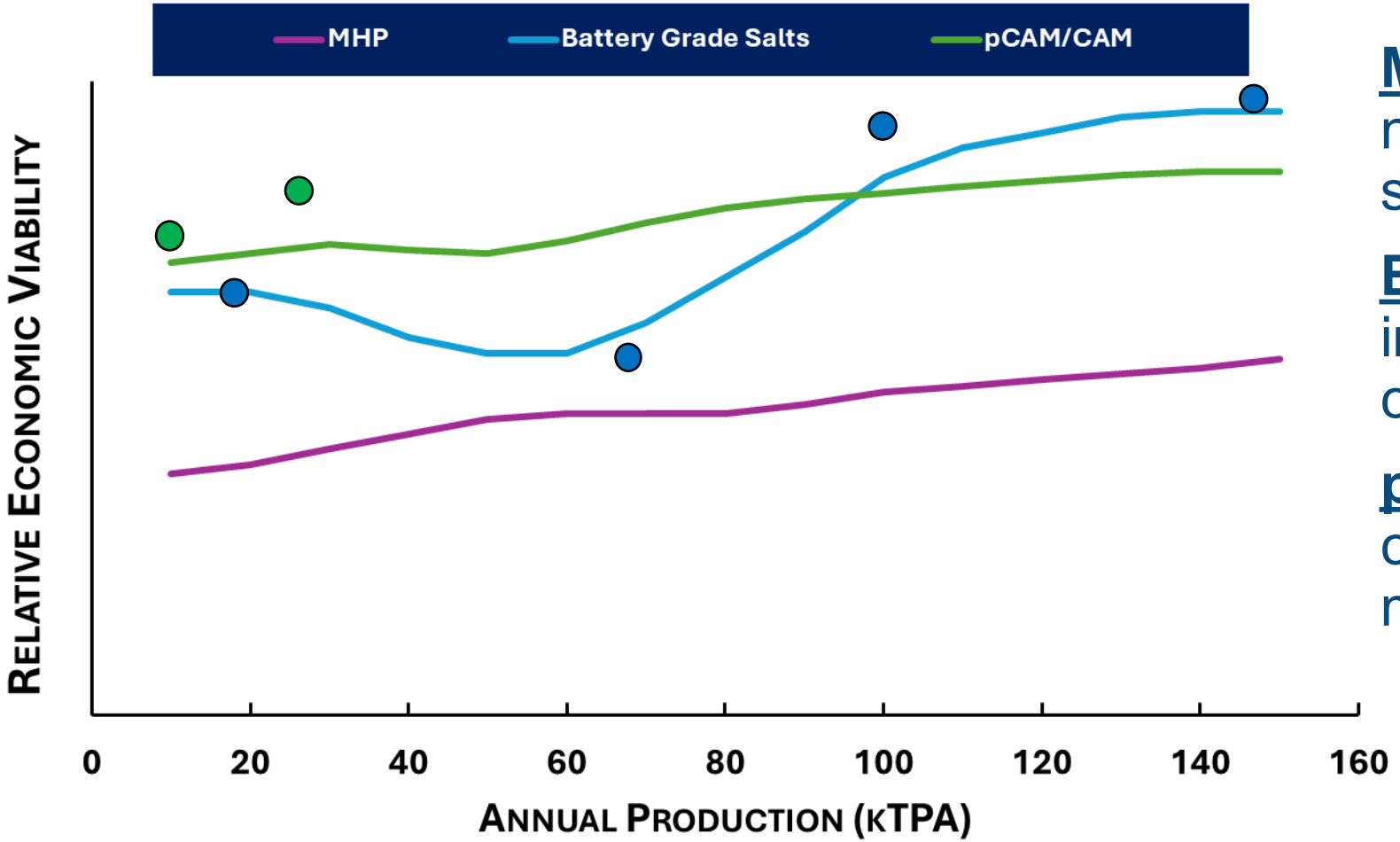


MHP – Low-value commodity needing scale; early revenue source

Battery Salts – Requires scale; impurities/reprocessing increase costs

pCAM/CAM – High-value, but challenging to control purity & morphology

Maximizing Outcomes Through Product & Scale Synergy



MHP – Low-value commodity needing scale; early revenue source

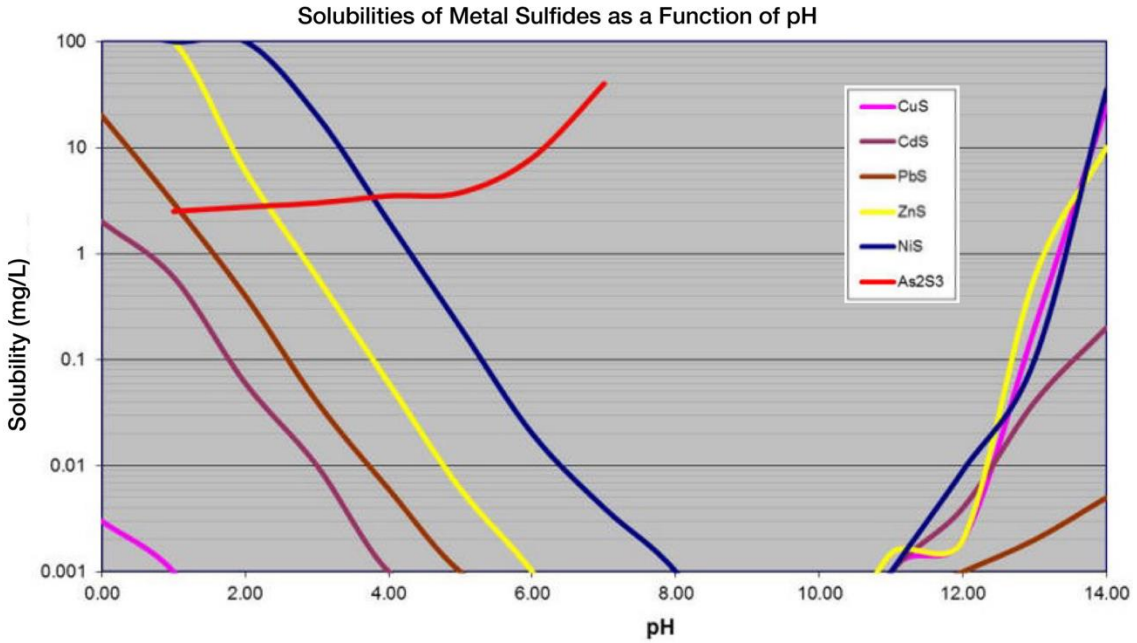
Battery Salts – Requires scale; impurities/reprocessing increase costs

pCAM/CAM – High-value, but challenging to control purity & morphology

Copper Removal Methods & Impacts

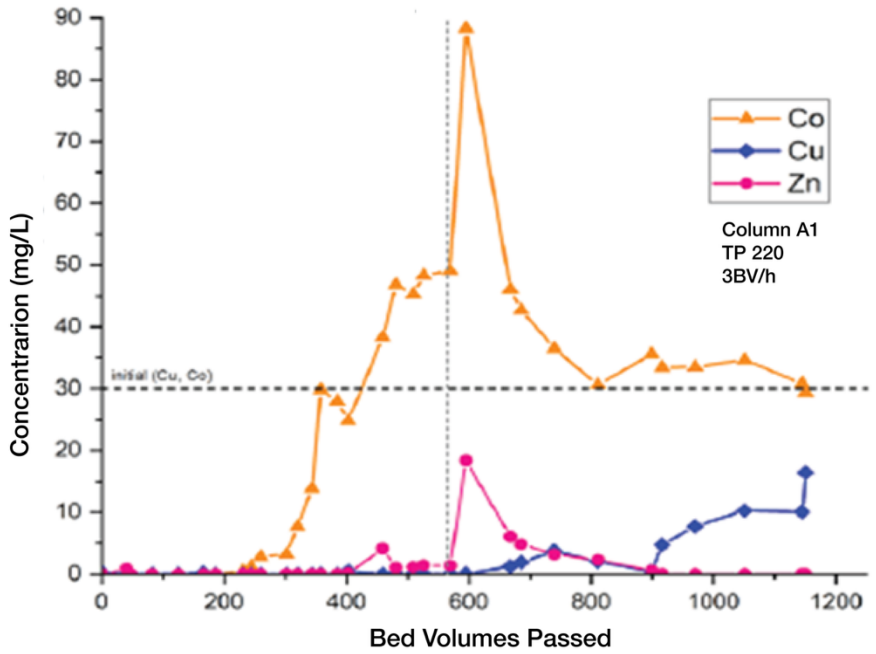
Selective Precipitation

- Sulfide/Caustic Precipitation
- Significant Yield Loss
- Low Value Products

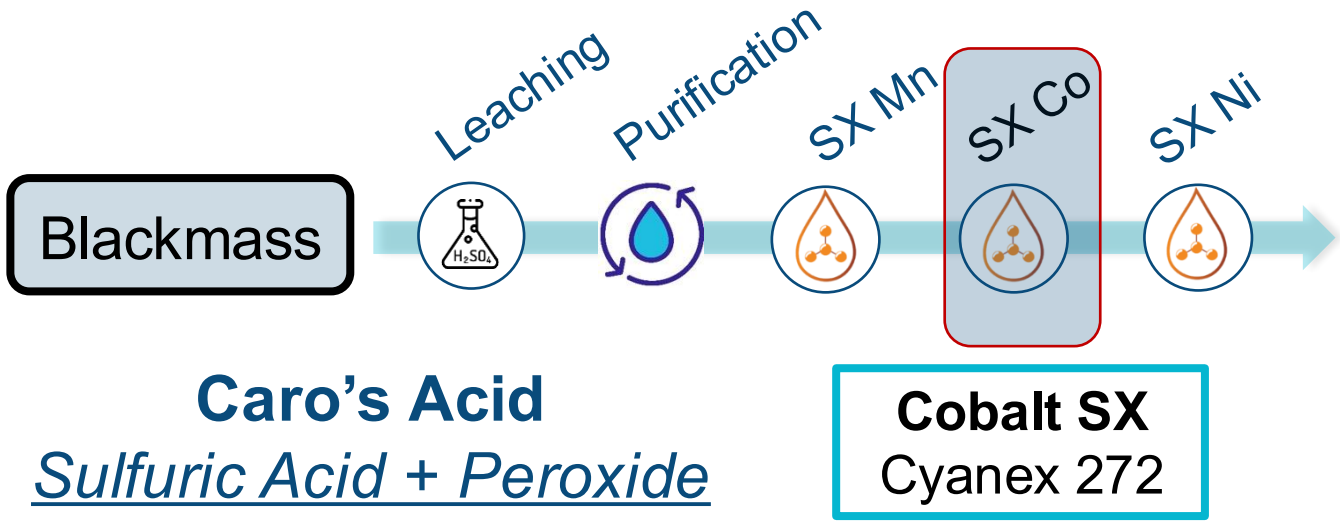


Ion-Exchange

- Complicated Operation
- Large Footprint & Chemical Use
- Co Yield Loss

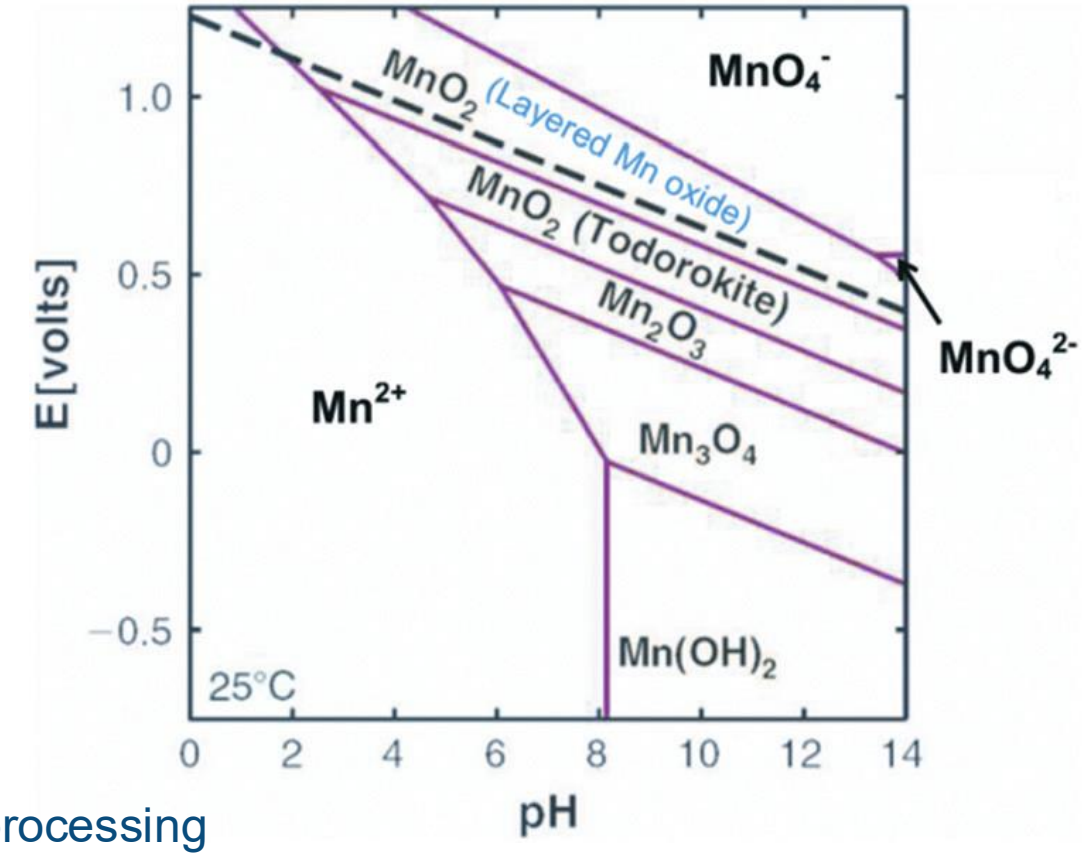


Manganese Removal Methods & Impacts



Caro's Acid
Sulfuric Acid + Peroxide

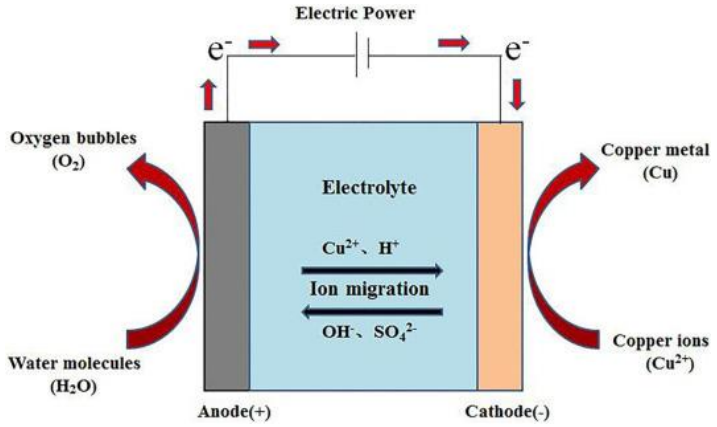
Cobalt SX
Cyanex 272



Challenges

- Needs to be alkaline
- Only treat trace [Mn] (< 100 ppm)
- Add acid and sulfates to product stream
- May Add Chemicals to Product Stream – Need Downstream processing

Is Electrochemistry an Option for Trace Metal Purification?

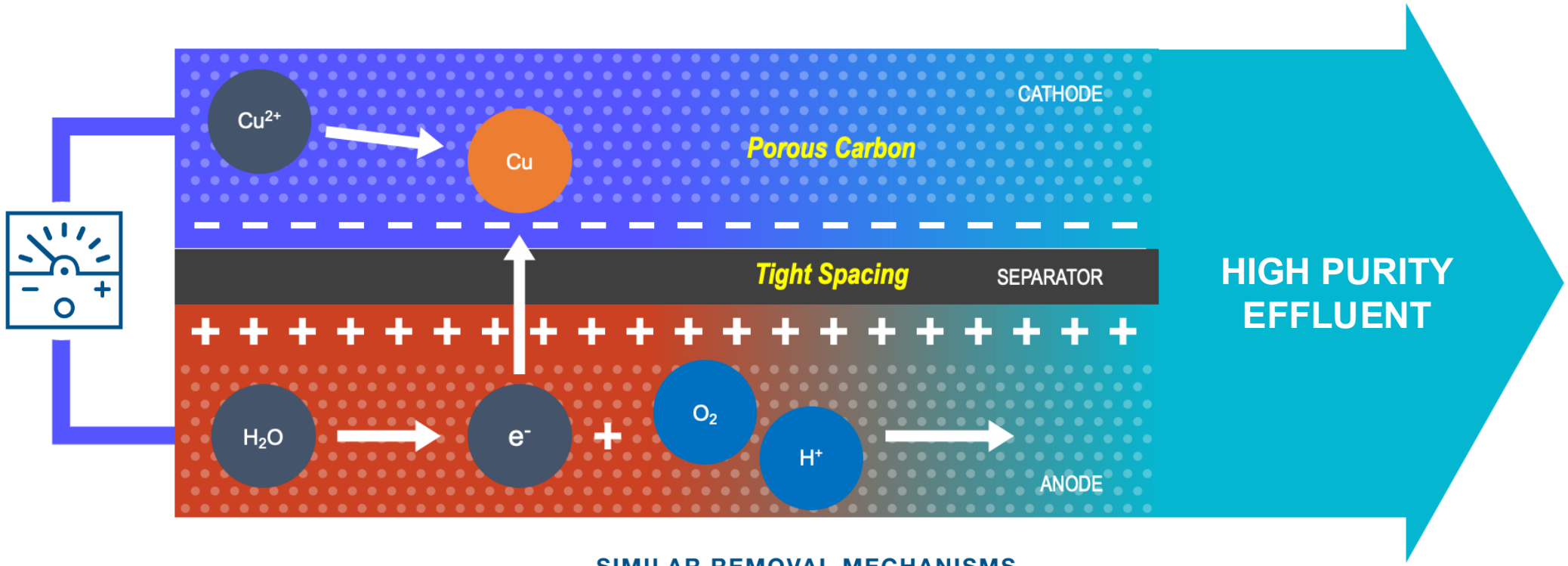




Parameters	Electrowinning
[M⁺] (ppm)	> 10,000
pH	0
Conductivity	Very High
Impurities	None

Parameters	Black Mass Leachate
[Cu/Mn] (ppm)	5 - 5000
pH	2 - 5
Conductivity	Med
Impurities	Metals, TSS, Organics

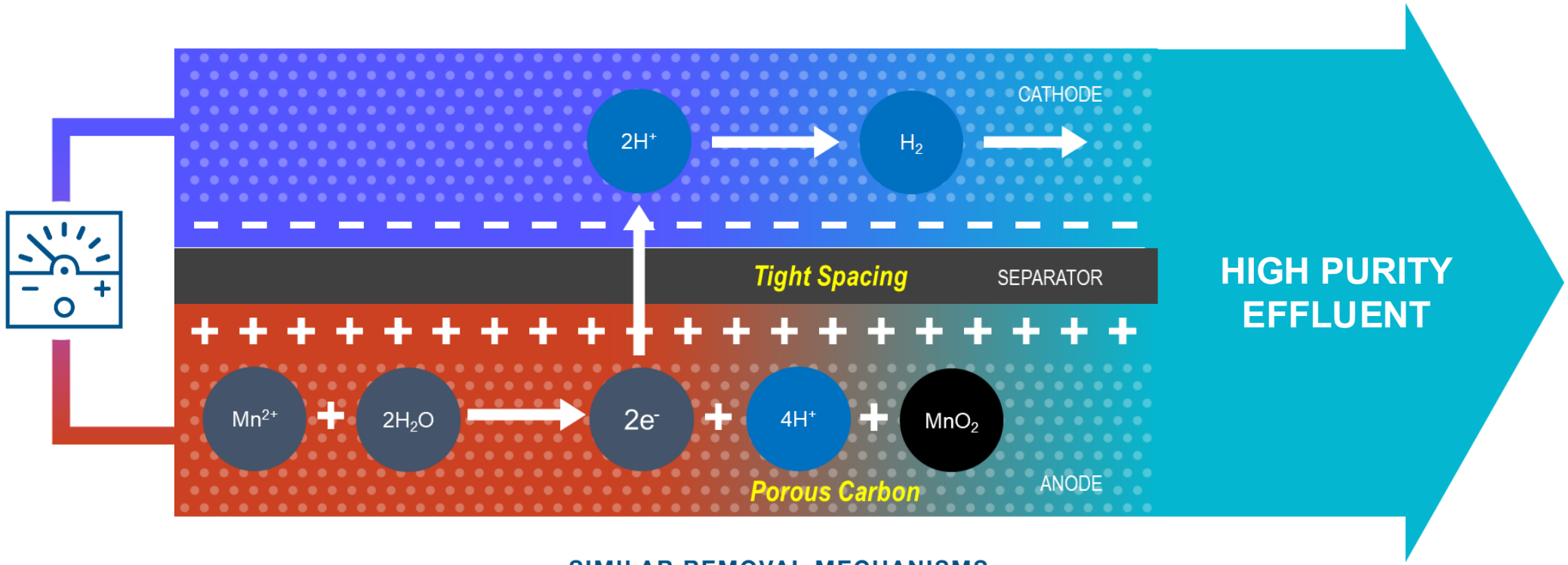
Reactor Design – The ElectraMet Approach



SIMILAR REMOVAL MECHANISMS

27	28	29	47	48
Co	Ni	Cu	Ag	Cd

Reactor Design – The ElectraMet Approach



SIMILAR REMOVAL MECHANISMS

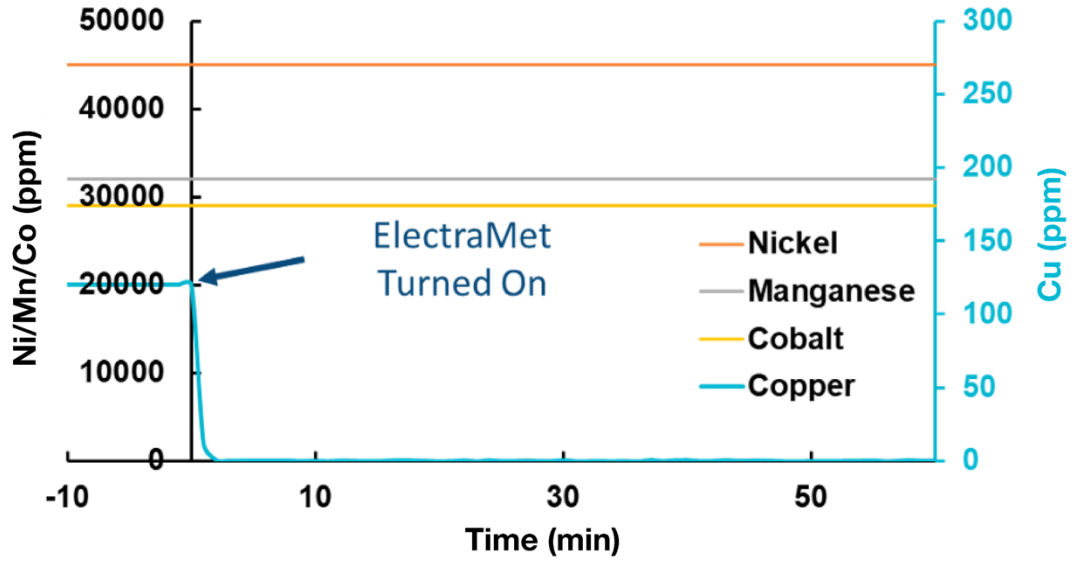
25	26	32	82
Mn	Fe	Ge	Pb

ElectraMet is Selective for Target Impurity w/ No Yield Loss



Trace Cu Impurity Removal

- Near 100% Cu selectivity to sub ppm levels
- Single pass operation for process relevance
- > 95% Current Efficiency



ElectraMet is Selective for Target Impurity w/ No Yield Loss



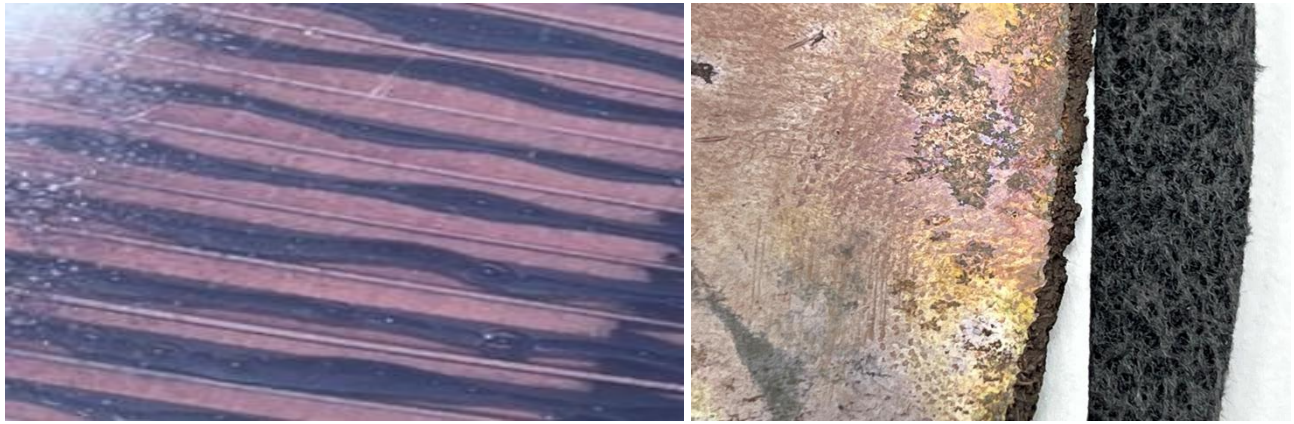
Trace Cu Impurity Removal

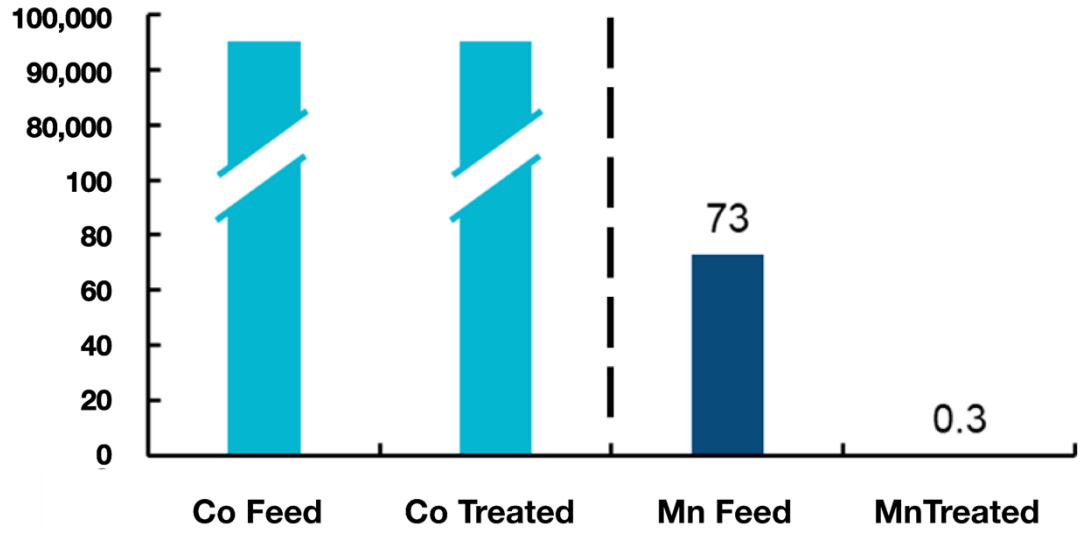
- Near 100% Cu selectivity to sub ppm levels
- Single pass operation for process relevance
- > 95% Current Efficiency



Trace Mn Impurity Removal

- 100% Mn selectivity vs Co to sub ppm levels
- Single pass operation for process relevance
- Recover Mn as MnO_2 powder





ElectraMet Advanced Automation & Process Control = ElectraLink

Integrated/Remote Monitoring

- Reduced labor requirements
- Simple controls
- Tie into existing BMS/DCS/SCADA systems

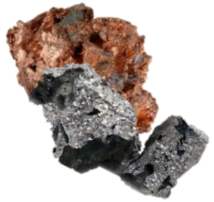
Actionable Intelligence

- Real-time display
- AI supported diagnostics & analytics
- Increased plant uptime

UNRIVALED PROCESS CONTROL



ElectraMet is Modular to Scale With Your Process



Pilot-Scale

- Single-pass and Batch-mode operations
- 3 gallons per minute, batch process



Commercial Scale

- 0.3 – 0.8 kWh/m^3
- Scalable to handle any volume

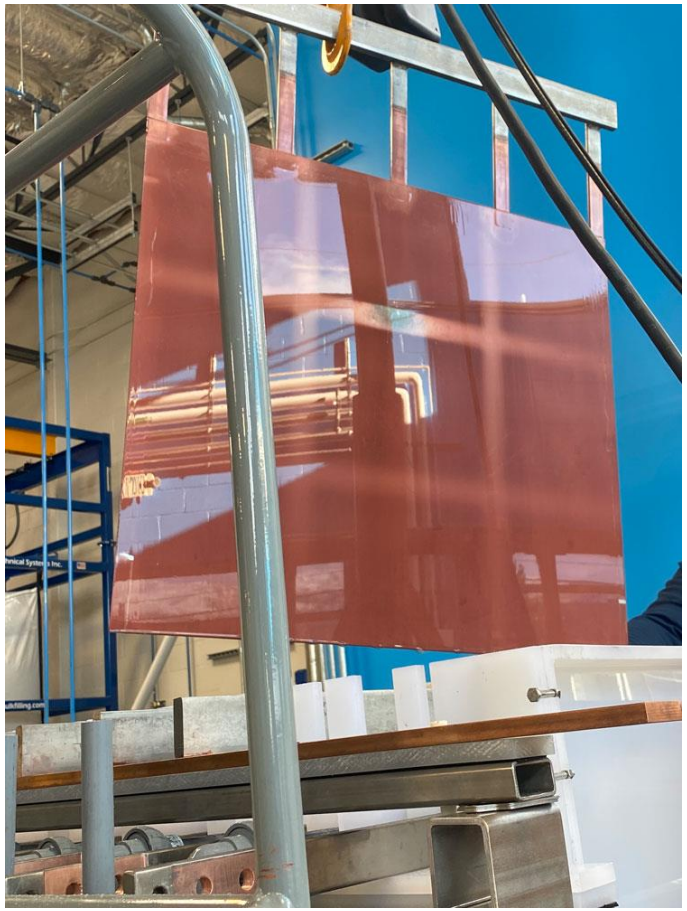


Modular Pilot Skids



4.5ft D x 17ft L x 7ft H

Electrochemical Product Differentiation – Aqua Metals







Electrochemical Differentiation - Aepnus

Sodium Sulfate Waste

Batteries



Nickel



Lithium



Industrial Facilities

- Lower OpEx
- No supply chain risk
- Valorizes waste product

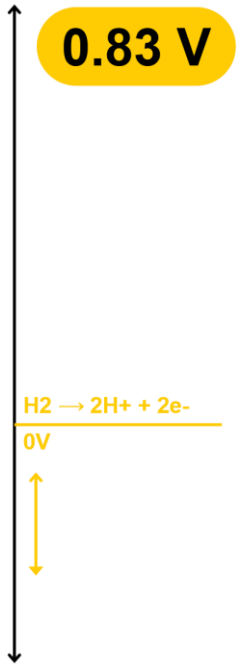


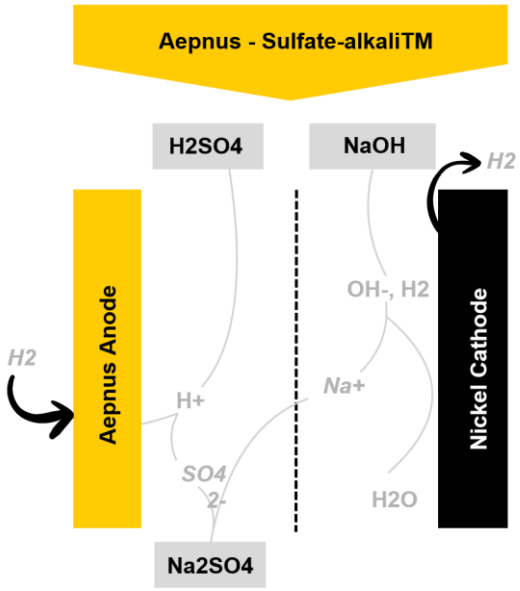
aepnus TECHNOLOGY

Caustic Soda

Sulfuric Acid*

Ammonium Sulfate*





Thank You | Q&A

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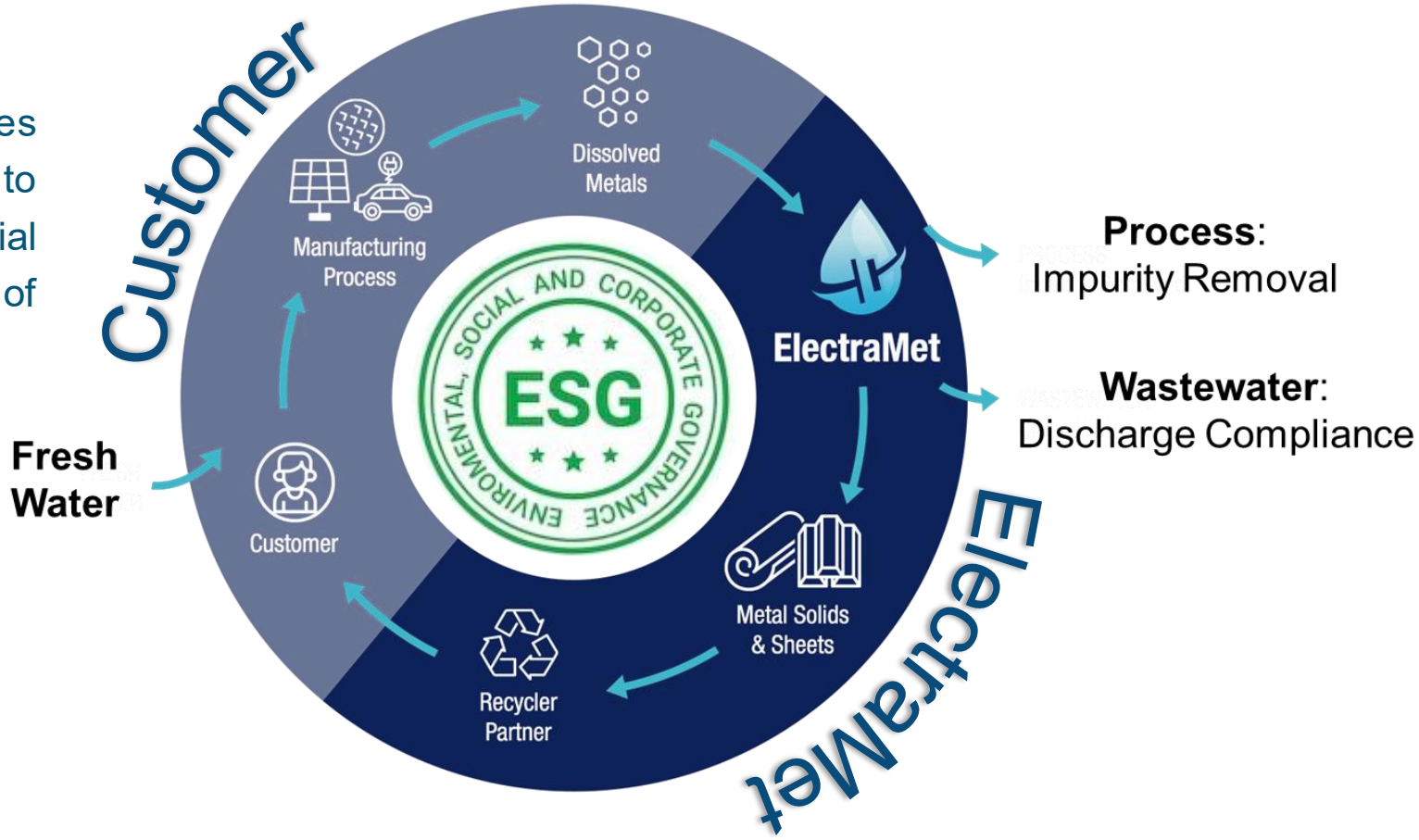
ElectraMet™

ElectraMet Enables a Circular Economy

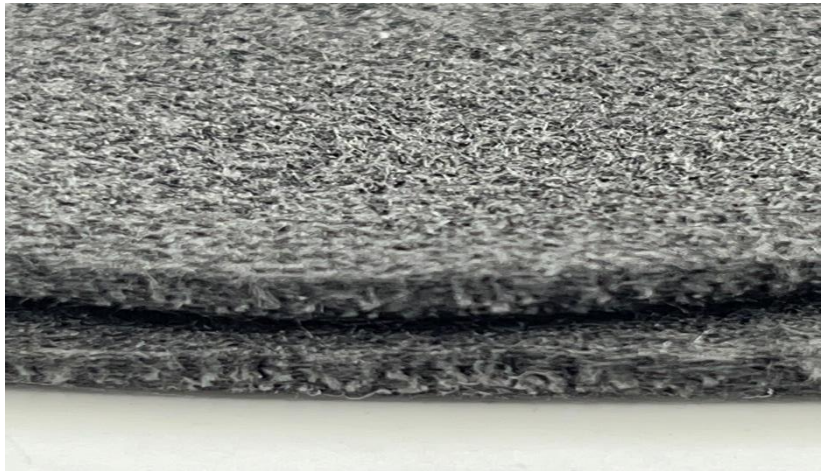
A Circular Economy

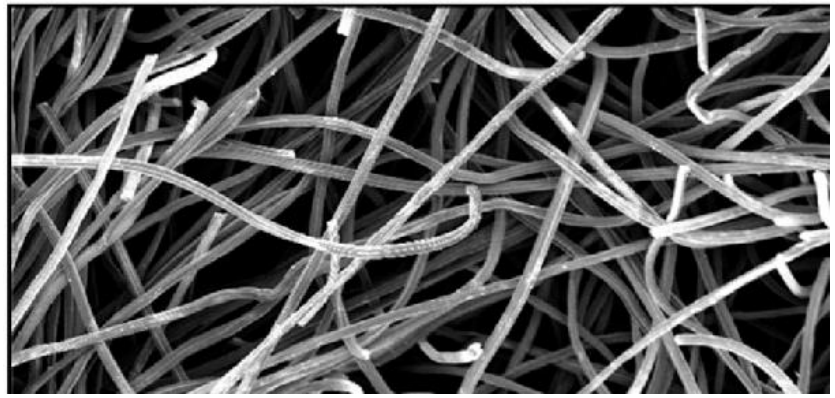
ElectraMet is a sustainable solution that uses electrochemistry (chemical and solvent free) to remove and recover dissolved metals from industrial streams. We enable circularity through re-entry of used metals back into the economy.





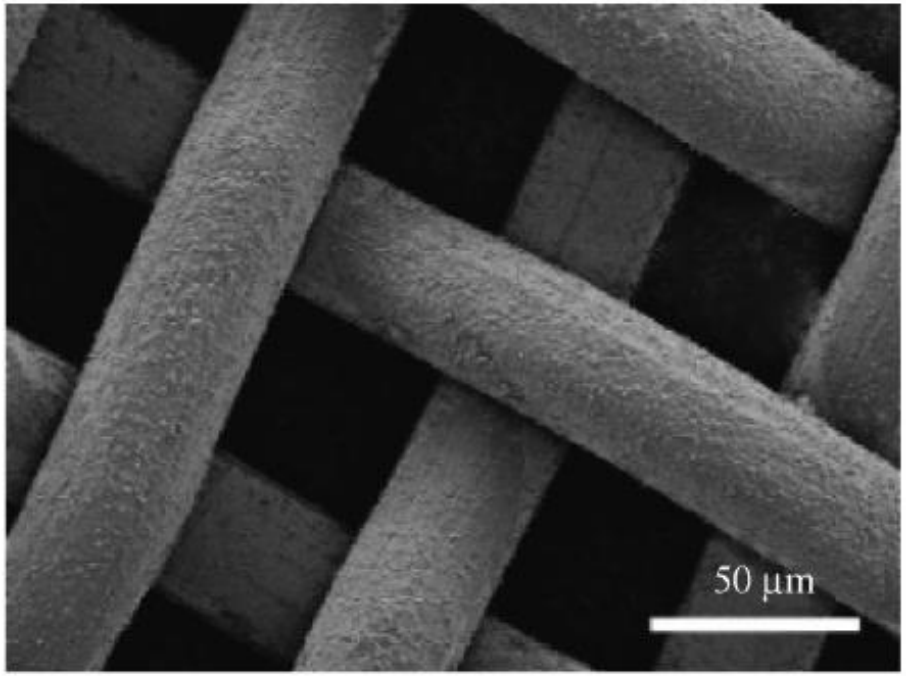
A New Reactor Design – The ElectraMet Approach





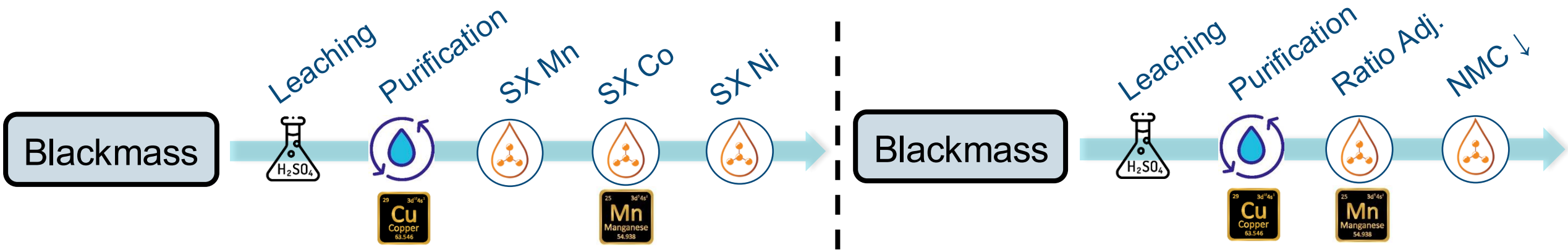
Gap between carbon pieces ~δ

Low concentration removal possible

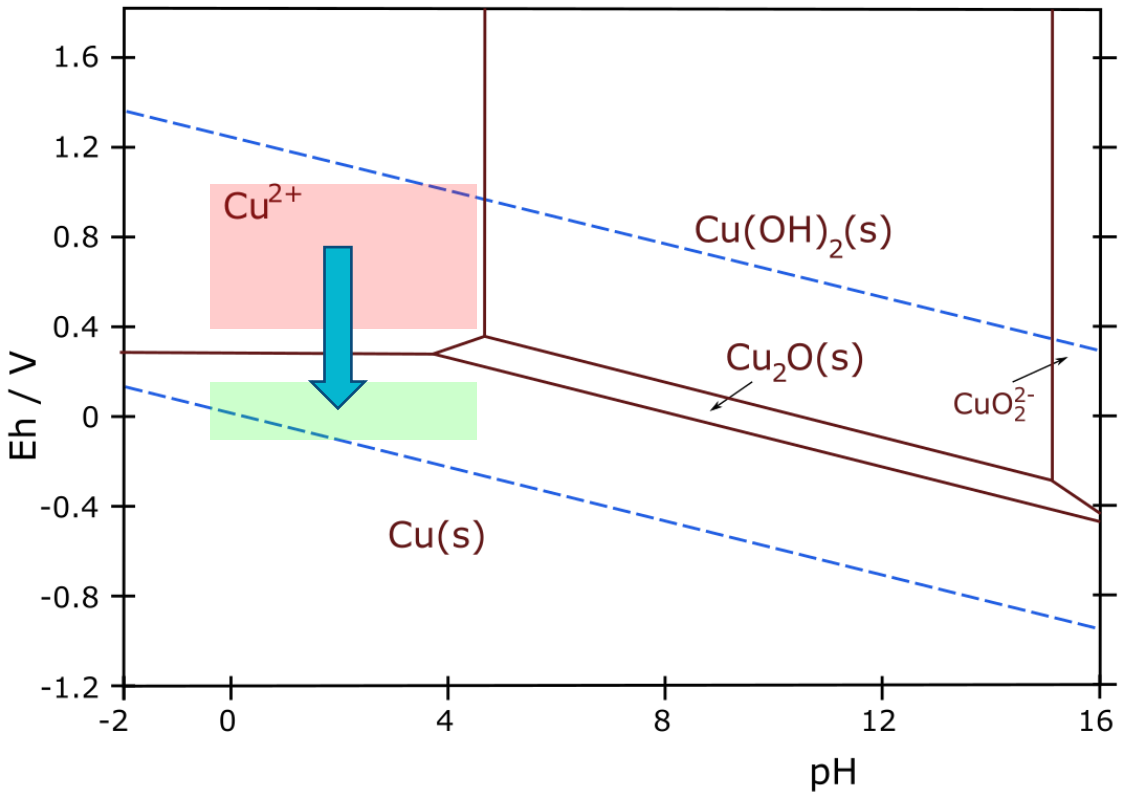


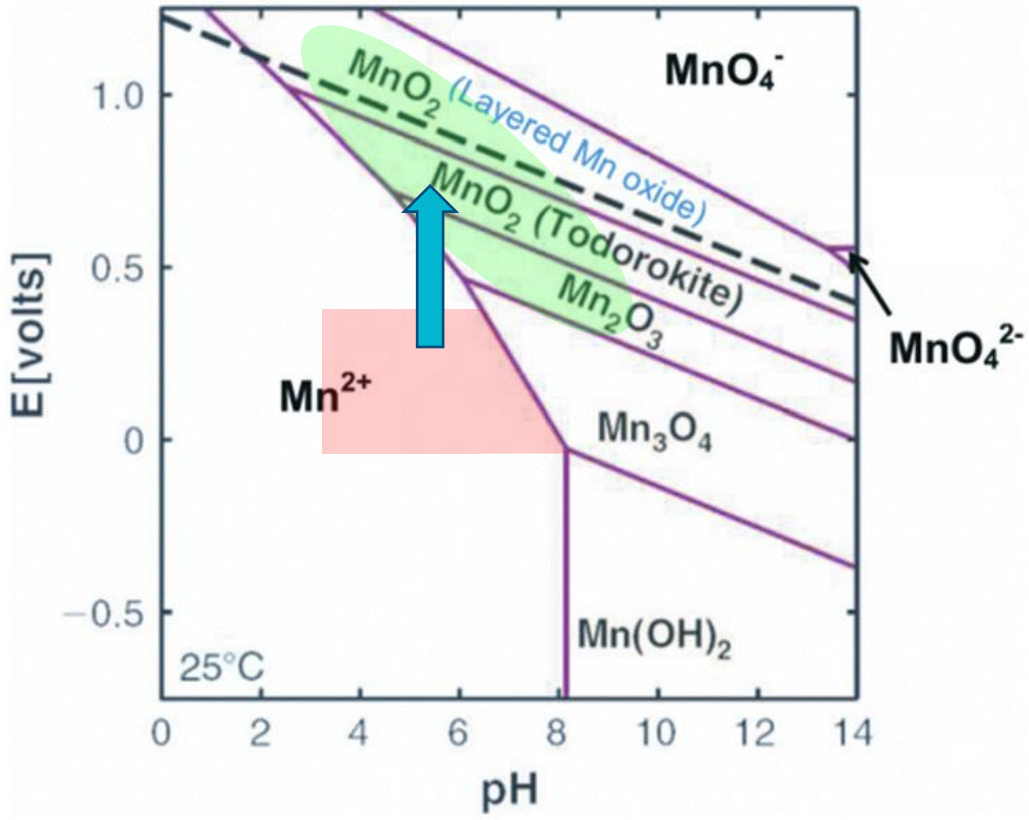
Methods to Remove Trace Metal Impurities

Metal Impurity	Removal Methods	Benefits	Challenges
Copper	Chemical Precipitation *Sulfide* *Caustic* IX	/ achieve low ppb/ppb levels simple process achieve low ppm levels	/ small particulates, toxic gas, consumables, not selective, yield loss, consumables large footprint, yield loss, consumables
Manganese	Carro's Acid	achieve low ppm levels	difficult process controls, consumables
Cadmium	Chemical Precipitation IX	achieve low ppm levels achieve low ppm levels	not selective, yield loss, consumables low selectivity, yield loss, consumables



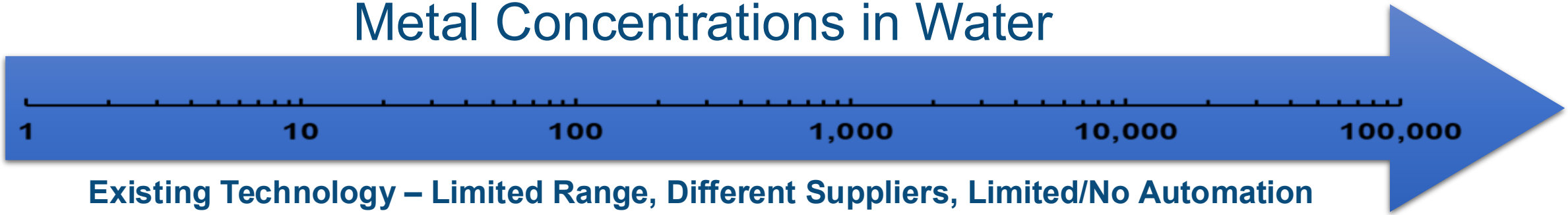
Operating Principles – Pourbaix Diagrams





Finding the Right Tool for the Job

Metal Concentrations in Water



Existing Technology – Limited Range, Different Suppliers, Limited/No Automation

Ion-Exchange

Chemicals

SX

Electrowinning

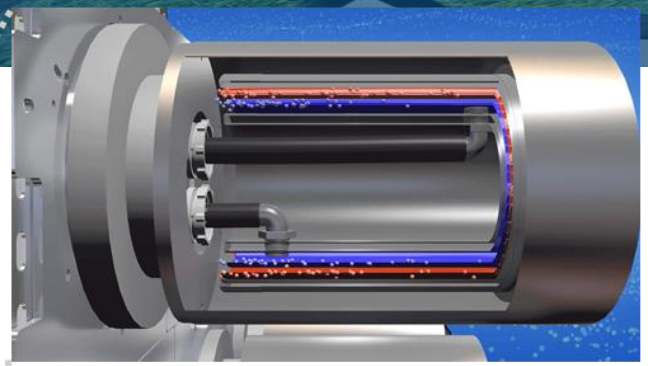
ElectraMet Product Lines

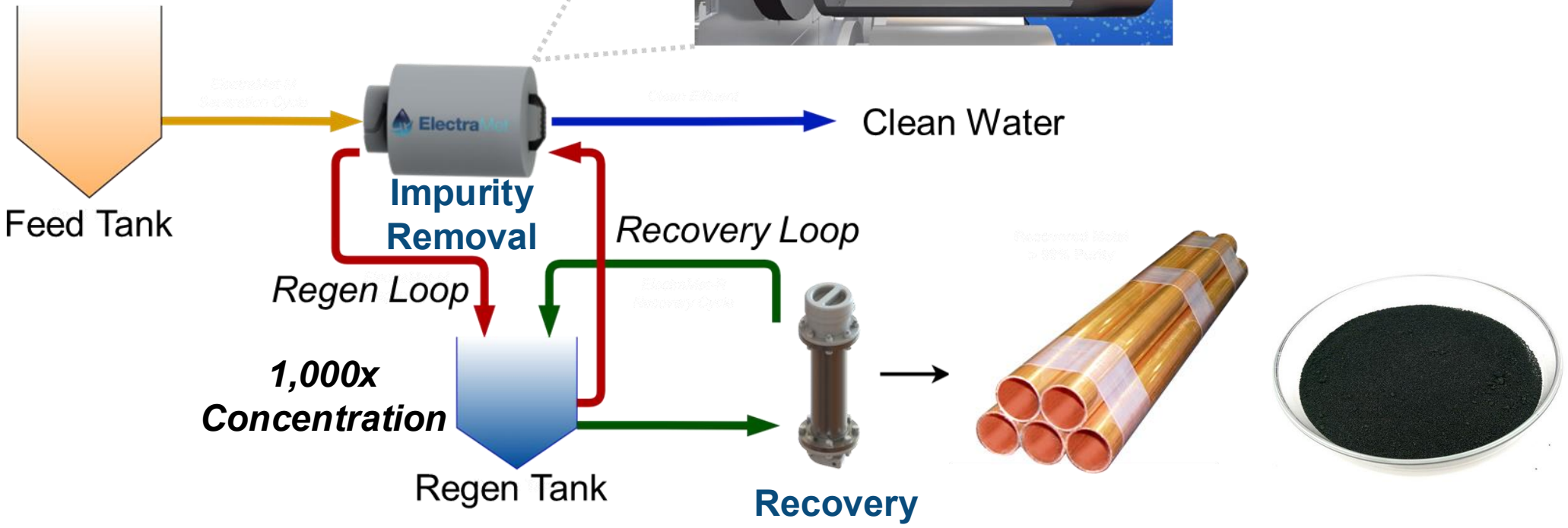
Coarse Removal Cartridge

Bulk Recovery Cartridge

*Bars are estimated ideal concentration ranges to yield best economics

ElectraMet Delivers a Sustainable Solution





ElectraMet Advanced Automation & Process Control = ElectraLink

Integrated/Remote Monitoring

- Reduced labor requirements
- Simple controls
- Tie into existing BMS/DCS/SCADA systems

Actionable Intelligence

- Real-time display
- AI supported diagnostics & analytics
- Increased plant uptime

Trace Cu Removal System Parameters





ElectraMet Advanced Automation & Process Control = ElectraLink

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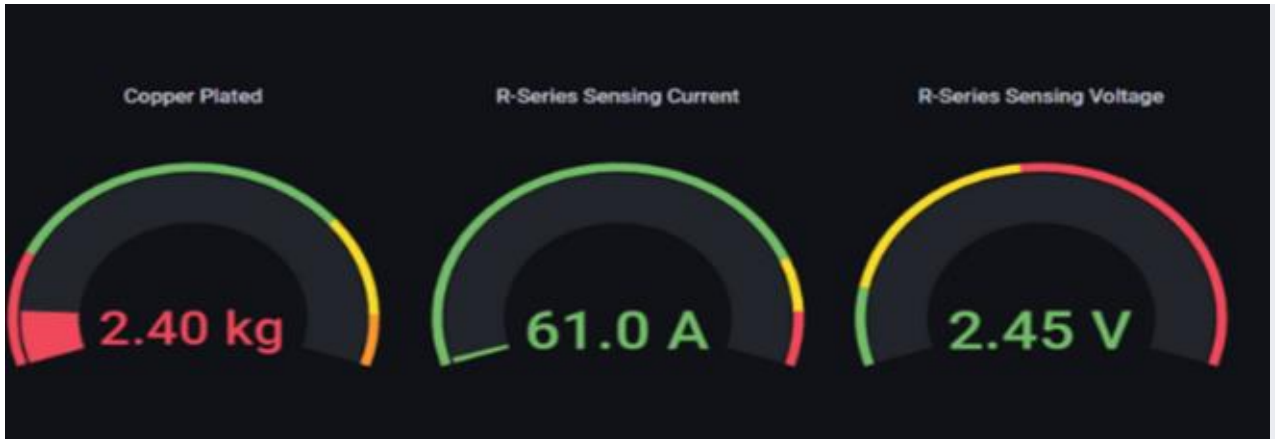
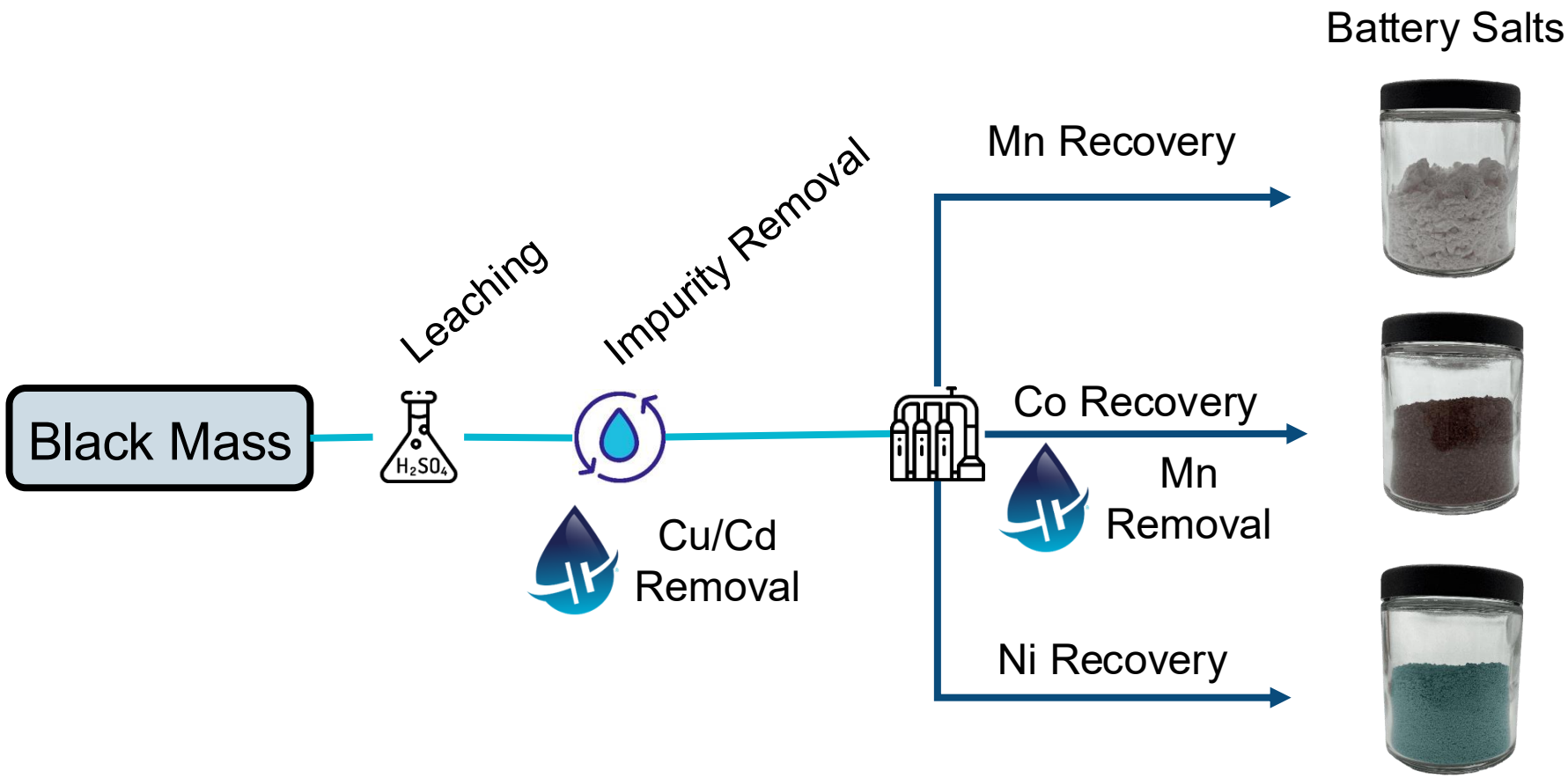
Bulk Cu Recovery System Parameters

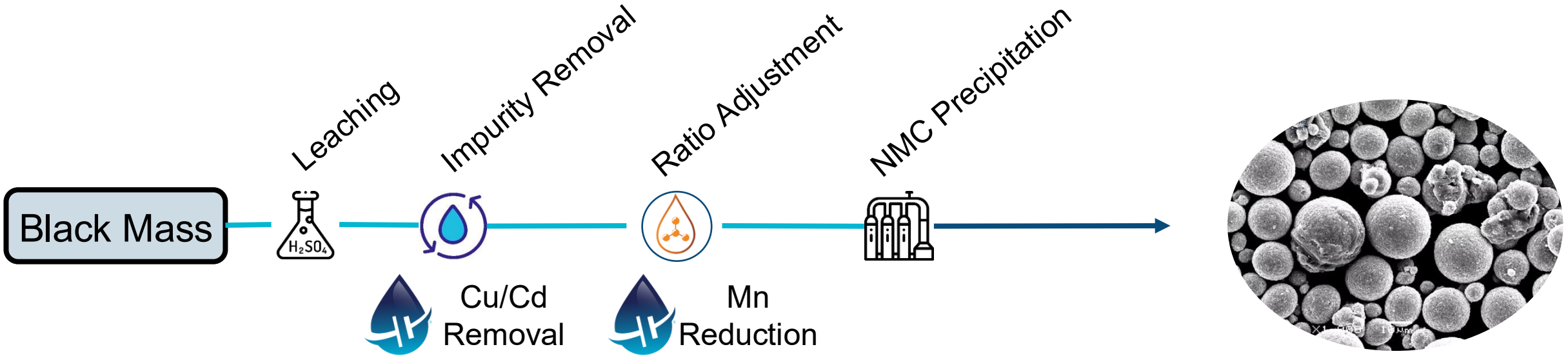




General Hydrometallurgical Process Options



General Hydrometallurgical Process Options



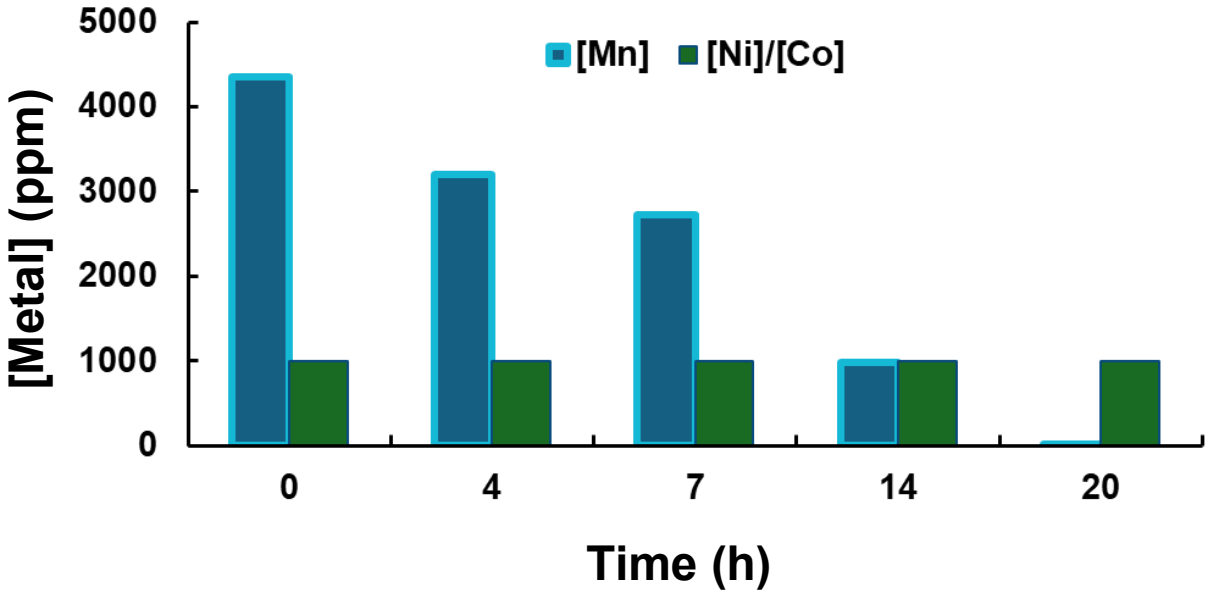
pCAM Material

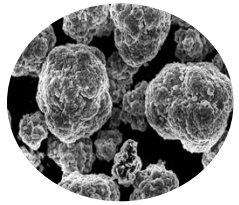
ElectraMet is Selective for Target Impurity w/ No Yield Loss



Ni/Co Yield Recovery – Mn SX

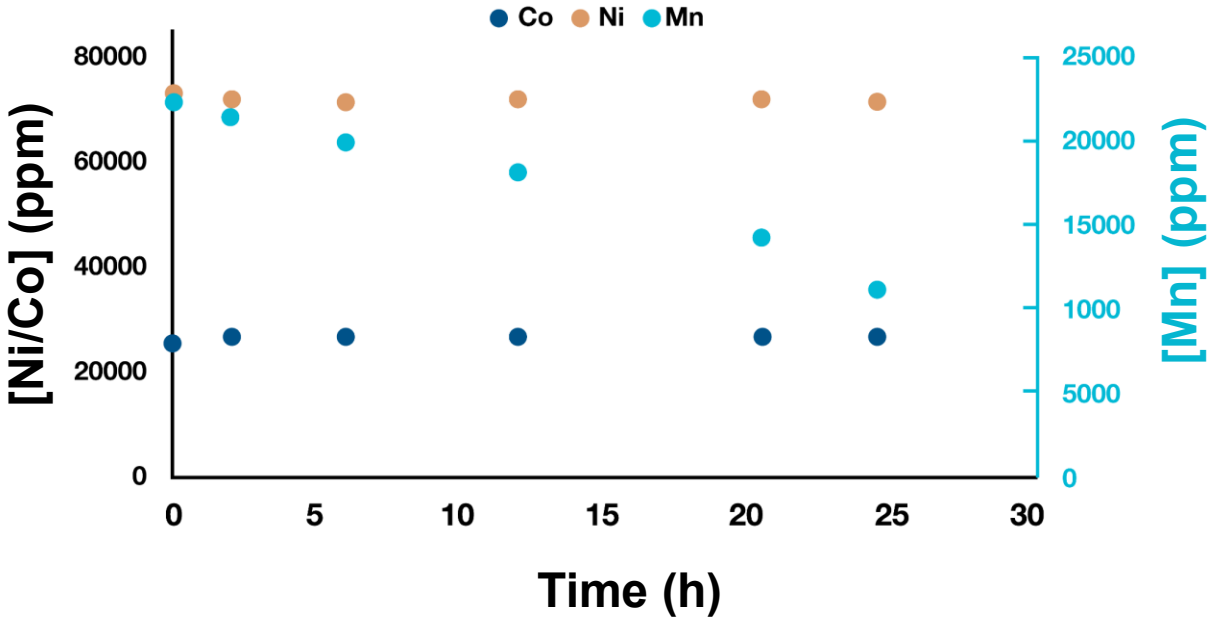
- 100% Mn selectivity to < 1 ppm
- Increase Ni/Co yields



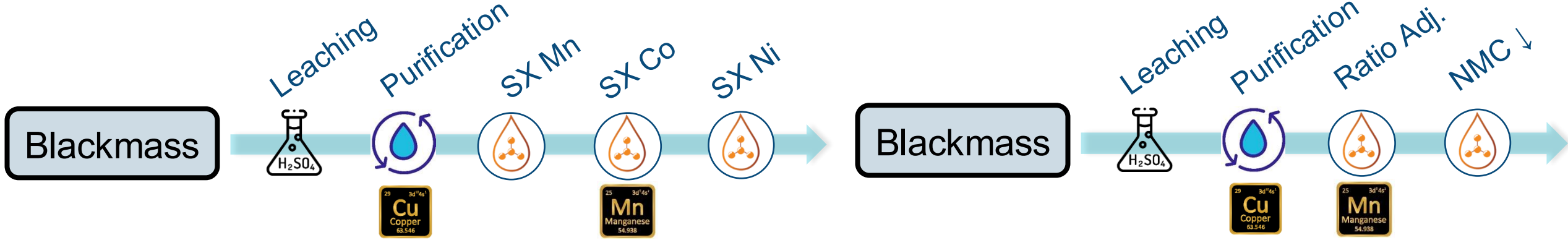


NMC Ratio Adjustment

- 100% Mn selective & easy to tune
- Easily upgrade/tune NMC chemistry



ElectraMet Achieves Purity Targets Economically



	Process Water	Bulk Removal	Polishing	Water for re-use & recovered materials
STEP 1	10,000 ppm (Cu)	100-10 ppm (Cu)	0.5 ppm (Cu)	Cu Copper Sheets
STEP 2	5,000 ppm (Mn)	60-15 ppm (Mn)	0.41 ppm (Mn)	Mn Manganese Salts
STEP 3	5,000 ppm (Ni) 15,000 ppm (Co)	20-15 ppm (Ni) 20-10 ppm (Co)	0.44 ppm (Ni) 0.43 ppm (Co)	Co Cobalt, Ni Nickel — Cobalt & Nickel Salts

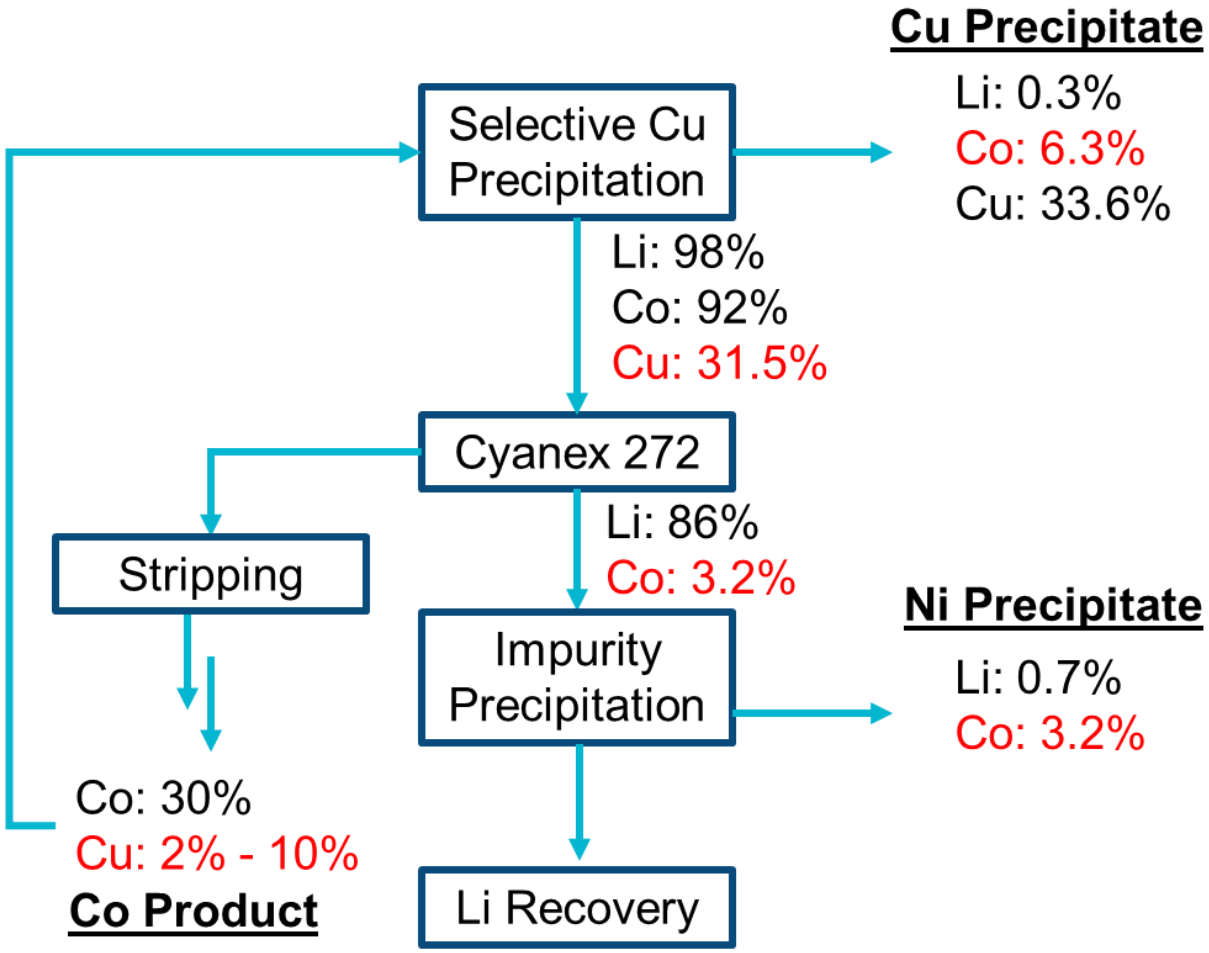
Pilot Results for Trace Cu Removal – Chemicals/IX

Test(s)	mg/L Concentrations		
	Cu	Al	Fe
Initial Sample	532	2350	1810
1	2	0.4	0.2
2	17	37	3
3	11	897	414
4	332	922	14
5	155	611	41
6	67	769	462
7	24	132	0.4
8	56	339	9
9	8	18	1

Challenges

- **Selective Precipitation & IX Failing to Achieve Purity Targets of < 1ppm Cu**
- Hydrometallurgical Pilot Plant
- Mixed Supply Black Mass
- Higher pH/Chemical Doses Showed Yield Loss of Co/Ni
  - UP TO 15%!!!

Example Yield Loss – Precipitation and SX



Challenges

- Cu precipitation = 6% Co loss
- Cyanex 272 grabs “Everything”
  - Will yield Cu/Mn Impurities in Final Product
- Chemicals & SX Impart a Burdensome Operation w/ “Retreats” Needed

A New Tool is Needed!

Peng et al., *Journal of Power Sources* **2020**

Purity Has Significant Economic Impacts

- Economics Highly Dependent on [Ni/Co]
- Cd Can Impart Major Cost Impacts

AVG BLACK MASS COMPOSITION *(highly variable)*	
RECOVERABLES	**%**
Ni	30%
Co	5%
Mn	5%
Li	5%
Cu	7%
Al	3%
Fe	3%
Graphite + Others	39%

	VALUE CAPTURE *($/kg)*				
Product	**Black Mass**	**Metal Salts** *(battery grade)*	**Metal Salts** *(battery grade)*	**CAM**	**CAM Scrap**
Black Mass		48%	34%	5%	14%
Metal Salts *(tech)*	210%		72%	11%	30%
Metal Salts *(battery grade)*	290%	138%		15%	42%
CAM	1982%	944%	683%		284%
CAM Scrap	698%	332%	241%	35%	

	VALUE CAPTURE *(Normalized Yield)*				
Product	**Black Mass**	**Metal Salts** *(battery grade)*	**Metal Salts** *(battery grade)*	**CAM**	**CAM Scrap**
Black Mass		52%	37%	10%	29%
Metal Salts *(tech)*	194%		72%	20%	56%
Metal Salts *(battery grade)*	268%	138%		27%	77%
CAM	985%	509%	683%		284%
CAM Scrap	347%	179%	130%	35%	

Electrification Requires a Large Infrastructure



Generation and grid infrastructure

kt	2020	2025	2030
Cu	40	170	536

+



Grid storage

kt	2020	2025	2030
Cu	24	86	180
Ni	20	71	150
Co	7	26	55

+



Charging infrastructure

kt	2020	2025	2030
Cu	23	115	392

+



Non-ICE vehicles

kt	2020	2025	2030
Cu	304	1068	2972
Ni	66	299	985
Co	17	80	259

=

Total

kt	2020	2025	2030
Cu	391	1439	4080
Ni	86	370	1135
Co	24	106	314

Vehicle sales

M	2020	2025	2030
Total	91	103	107
EV	2.1	10.1	31.7
%EV	2%	10%	30%

Source: CRU "Mobility and Energy Futures – Perspectives towards 2035", prepared for Glencore by CRU Consulting – "Green" Scenario. See slide 26 for more detail on modelling framework. (1) The Electric Vehicles Initiative is a multi-government policy forum comprising Canada, China, Finland, France, Germany, India, Japan, Korea, Mexico, Netherlands, Norway, Portugal, South Africa, Sweden, UK and USA. http://www.cleanenergyministerial.org/News/new-cem-campaign-aims-for-goal-of-30-new-electric-vehicle-sales-by-2030-85068.

ElectraMet Offerings



α

ALPHA



φ

PHI



δ

DELTA



γ

GAMMA



ω

OMEGA



ι

IOTA

Customer Need	Discharge Compliance	Process Purification	Incumbent Optimization	Oxidant Abatement	Bulk Recovery	Onsite Evaluation
Treatment	Any Range	Any Range	100-3000 ppm	Any Range	>3000 ppm	Any Range

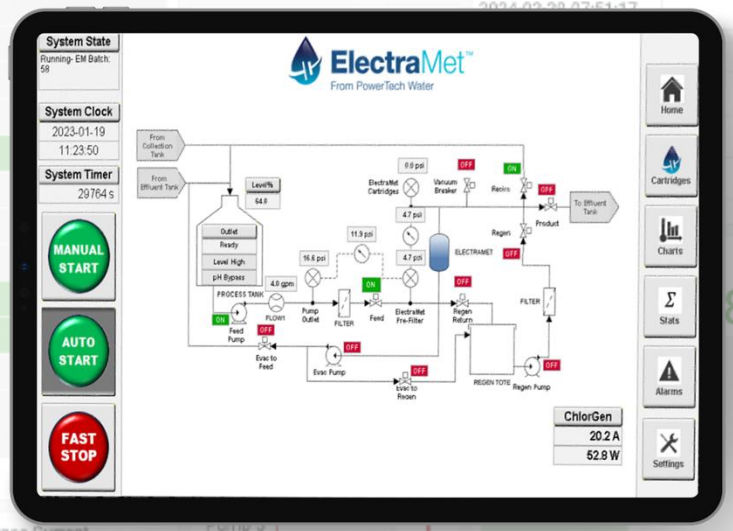
ElectraMet Includes Advanced Automation

Remote Operation

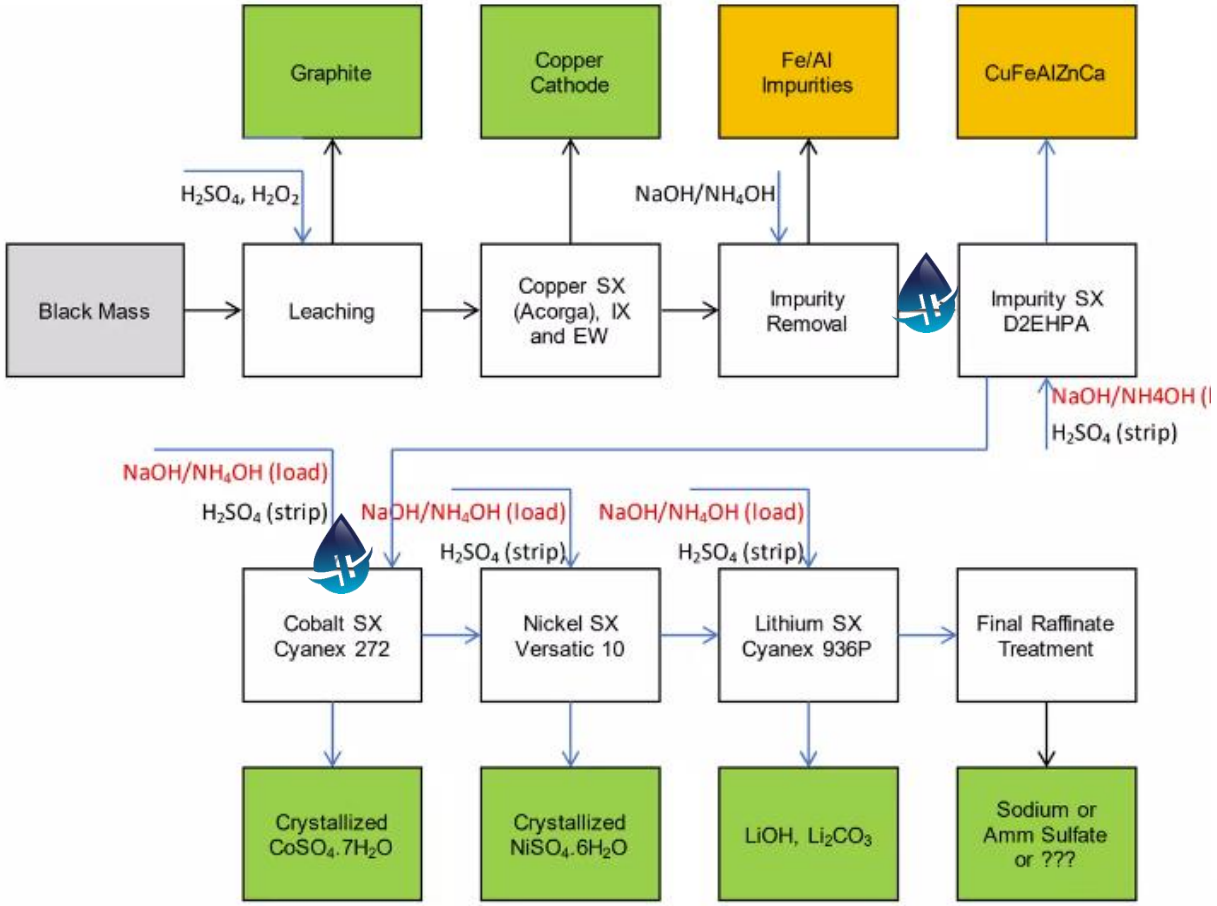
- Reduced labor requirements
- Simple controls
- Tie into existing SCADA systems

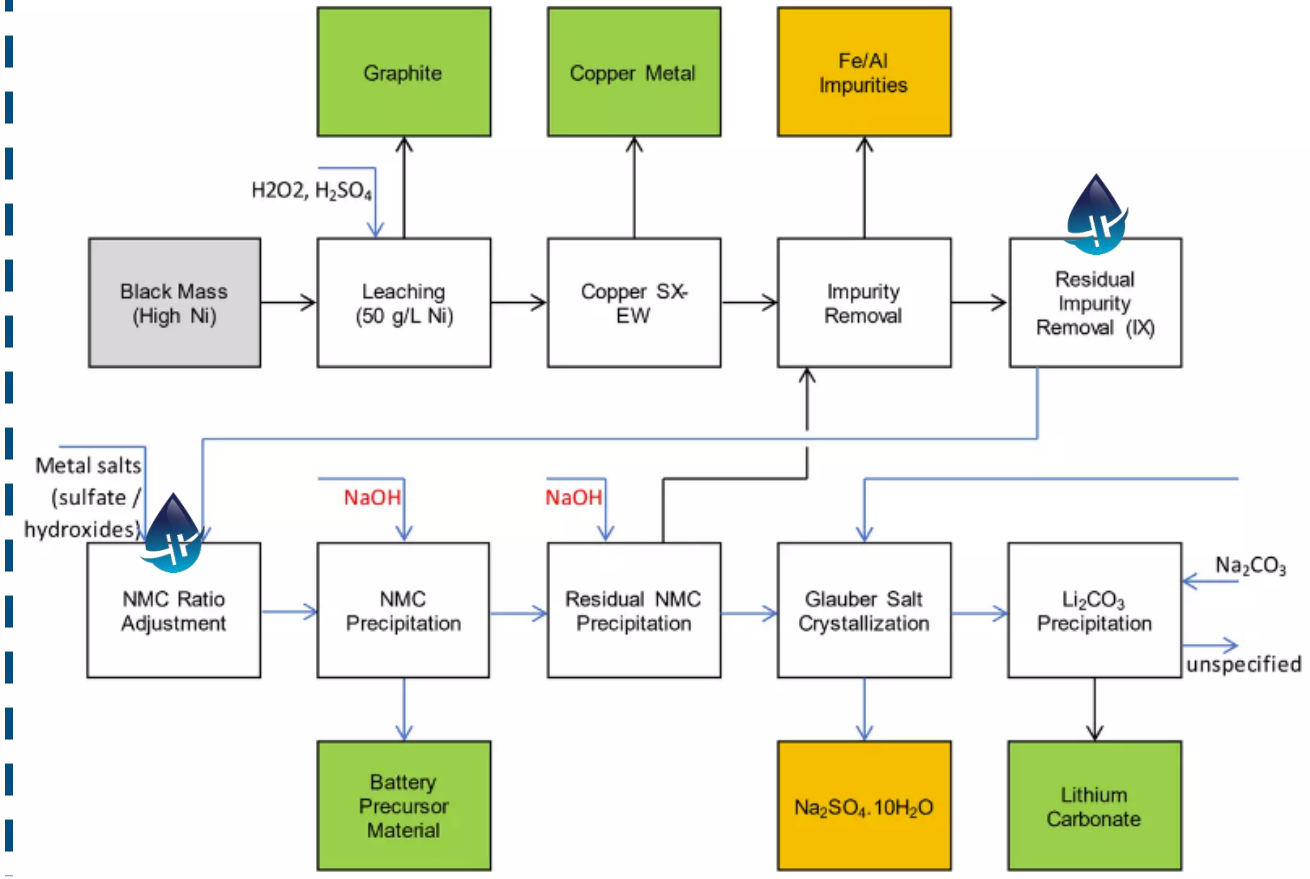
Actionable Intelligence

- Real-time display
- AI supported diagnostics & analytics
- Increased plant uptime



ElectraMet Delivers a Sustainable Solution





ElectraMet is Easily Adaptable to Troublesome Impurities

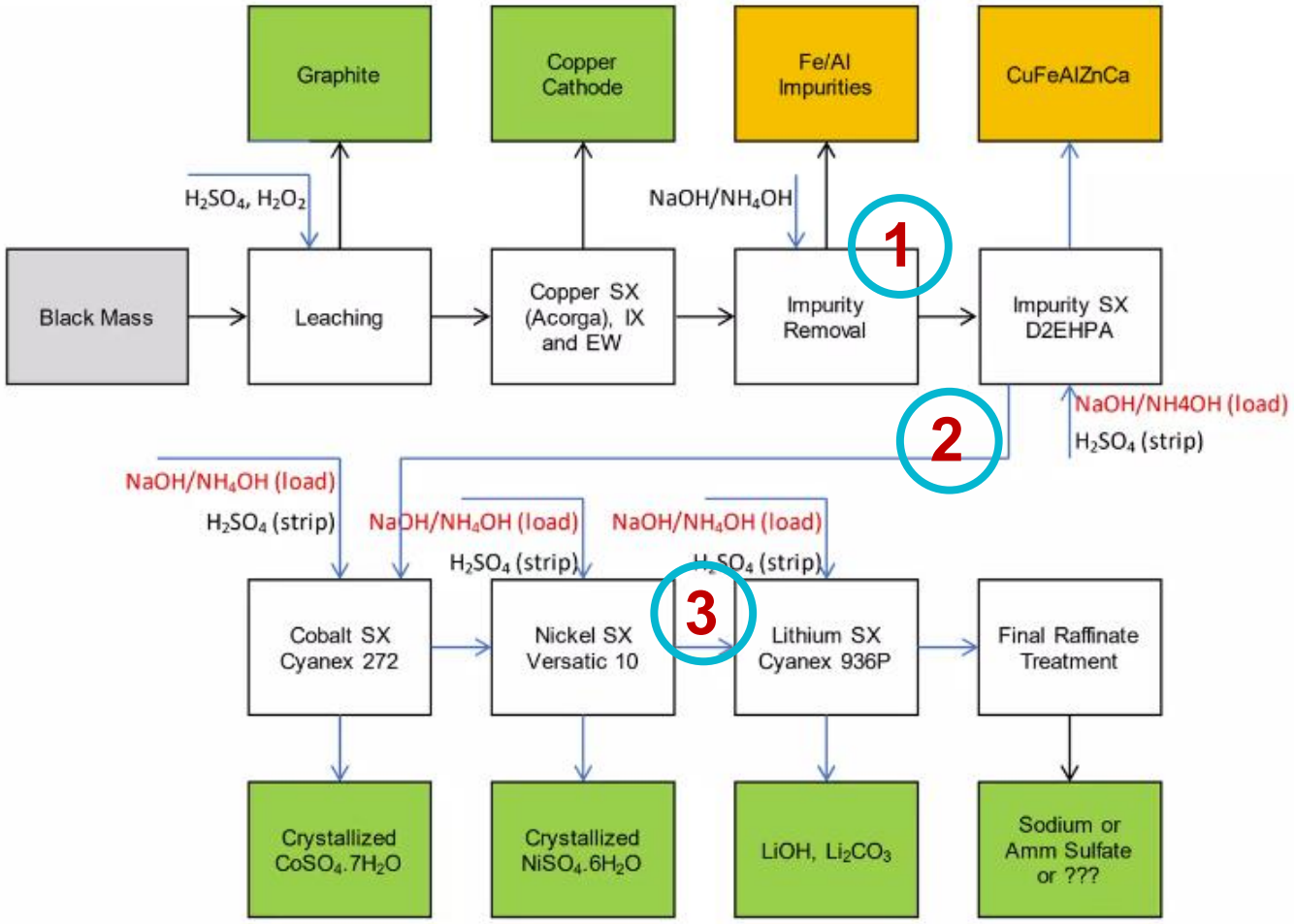


Trace Cd Impurity Removal

- Easily Adaptable to target Cd
- High Treatment Rates Achievable in Small footprint

Sample	[Cu] (ppm)	[Cd] (ppm)
Feed	0.24	4.08
Voltage 1	0.09	3.48
Voltage 2	0.07	0.08

Flow Sheet Example – Solvent Extraction Basis



MANGANESE RECOVERY STREAM

Metal Concentrations (g/L)						
Cu^{2+}	Mn^{2+}	Co^{2+}	Ni^{2+}	Na^{2+}	Li^{2+}	pH
10ppm	5	5	15	24	3	4-6

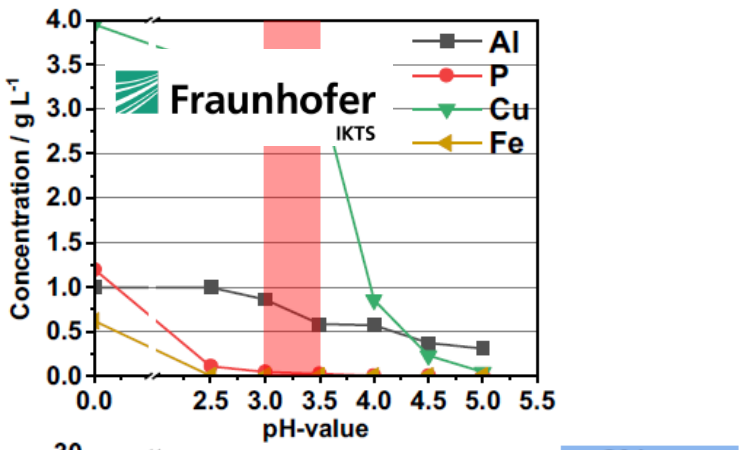
COBALT RECOVERY STREAM

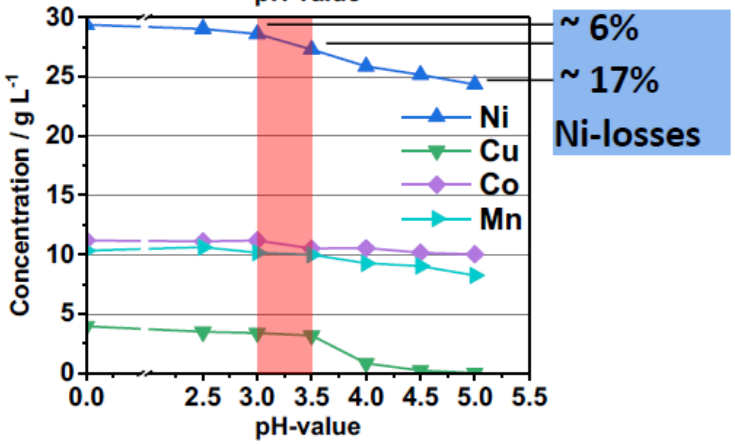
Metal Concentrations (g/L)						
Cu^{2+}	Mn^{2+}	Co^{2+}	Ni^{2+}	Na^{2+}	Li^{2+}	pH
3ppm	15ppm	4.5	13	26	3	2-4

Copper Removal Methods & Impacts

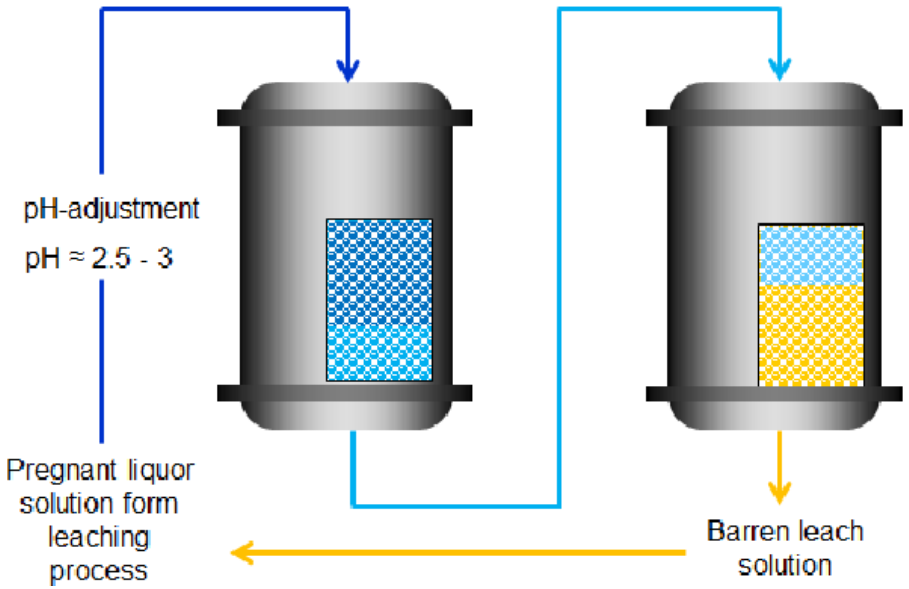


Selective precipitation

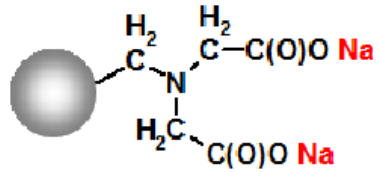




~ 6%
~ 17%
Ni-losses



Copper selective resin
LEWATIT® MonoPlus TP 207



57mg Cu/g resin
1.3 kg/ft³

Process Challenges

- Pre-load w/ Co
- High acid consumption for regen
- Large footprint
- Co yield loss (1% - 2%)

Resin Capacity Loss

- Every Regen
- Exposure to oxidizers
- Interfering metals

ELECTRAMET SOLUTION: EVIDENCE-BASED PROGRESSION

1

Feasibility Testing



2

Onsite Pilot For Validation



3

Commercial Implementation



CONFIDENTIAL ElectraMet © 2023

Cathode Materials Require Strict Specifications



Automotive News

Focusing on battery purity can accelerate EV revolution

If we're going to enable further rapid growth of the EV market, we're going to need to take battery manufacturing to the next level.

February 07, 2022 12:00 AM

TARGRAY

"…Cathode materials require extremely high purity levels and must be almost entire free of unwanted metal impurities…" ***Targray***

Why Is an Adaptive Process Needed?

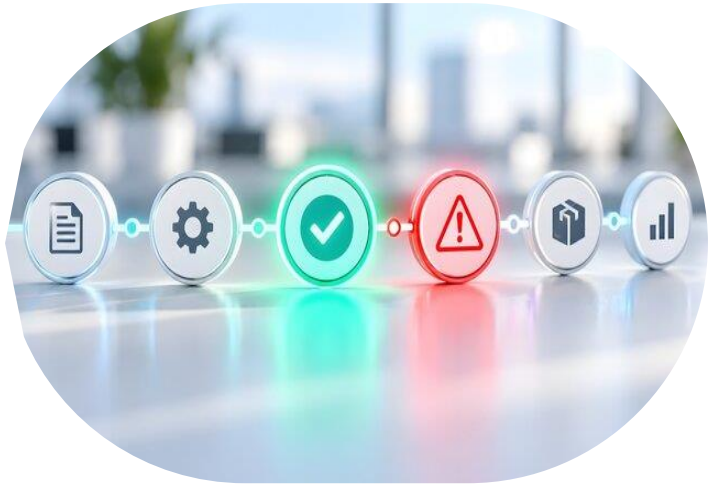
Volatile Prices



Impurities increase risk of fire

Over 200 fires blamed on Li-ion batteries in 2022

Surprise Contaminants



Impurities Decrease Value

Rogue chemistry (Cd) & impurities can disrupt standard refining processes

Glauber's Salt



Bipolar Cell to Produce Chemicals

Large volume of waste salts