Nickel supply: primary metallurgical processing capacity does not satisfy changing demand

2023 International Round Table on Materials Criticality

Jamie Faubert
Dr. Steven Young

February 16th, 2023

Nickel Overview | **Current and future applications**

Current Applications

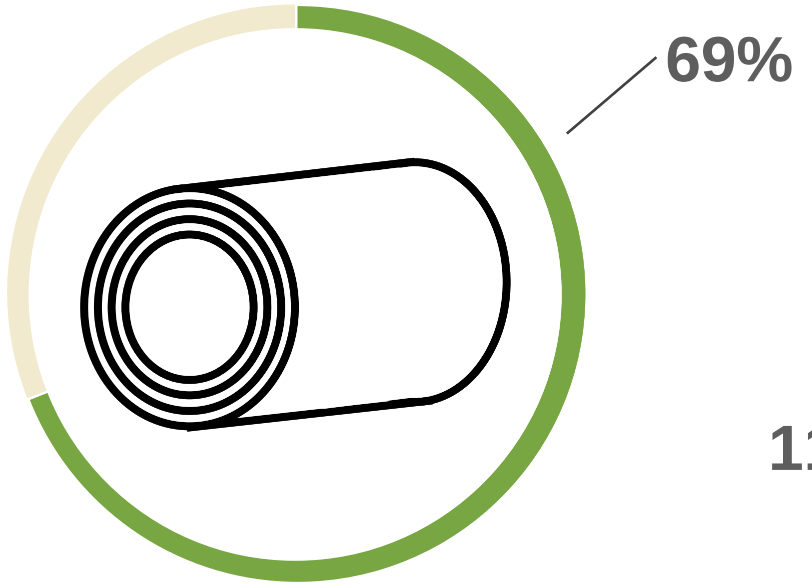
2020 Production: 2.51 million metric tonnes

2.3x →

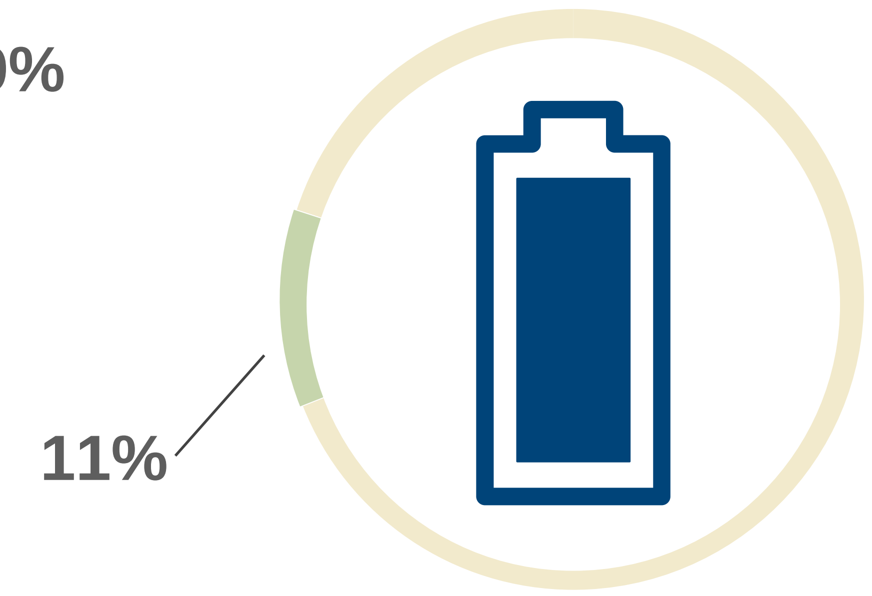
Future Applications

2040 Expected Demand: 6.0 million metric tonnes

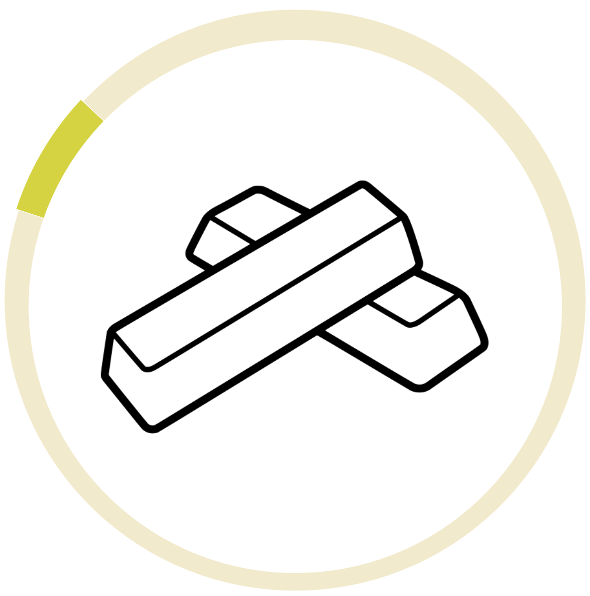
Current Applications



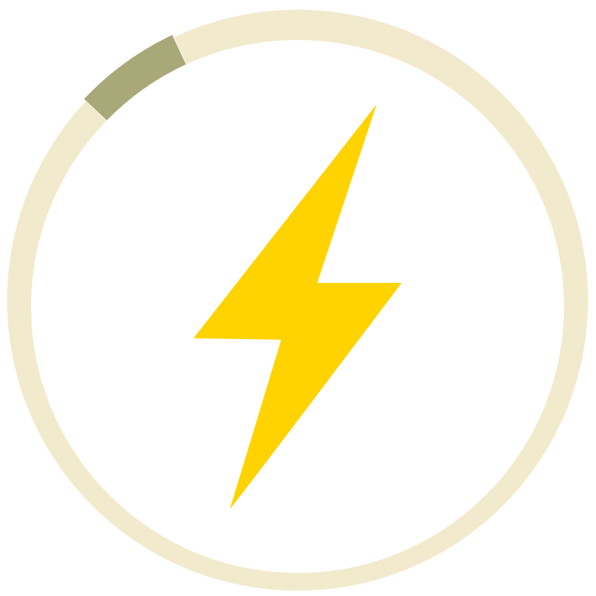
Stainless Steel
Nickel Quality: >90wt%, FeNi, NPI



Batteries
Nickel Quality: >22.3 wt% Ni ($NiSO_4$)

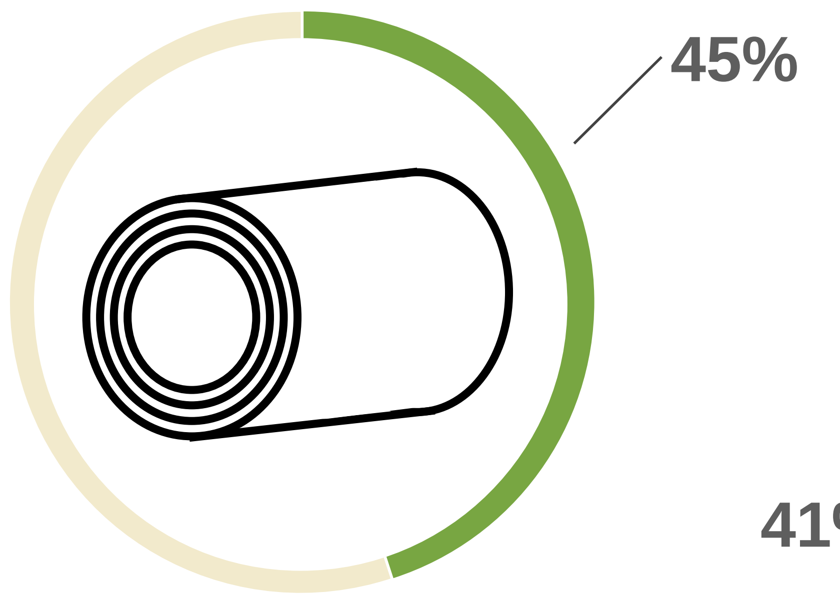


Non-Ferrous Alloys
Nickel Quality: Class 1

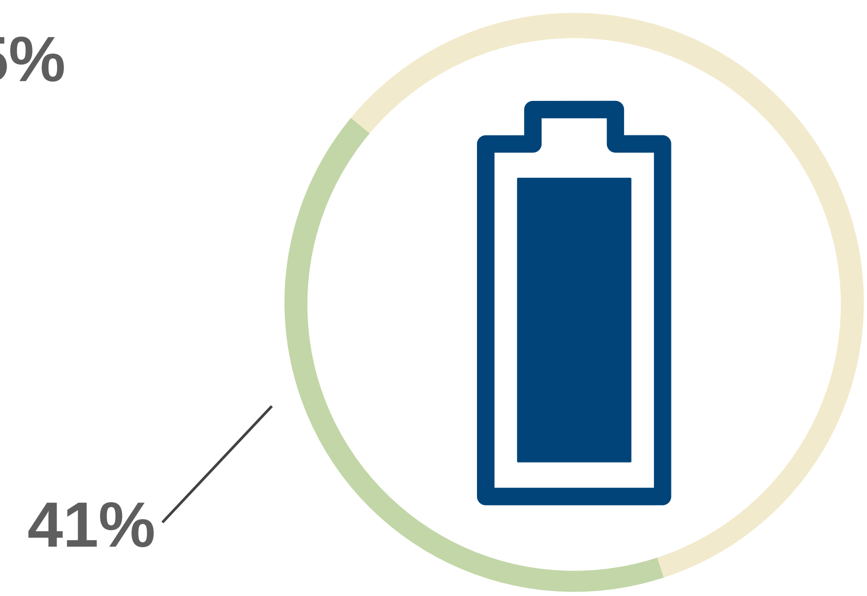


Plating
Nickel Quality: Class 1

Future Applications



Stainless Steel
Nickel Quality: >90wt%, FeNi, NPI



Batteries
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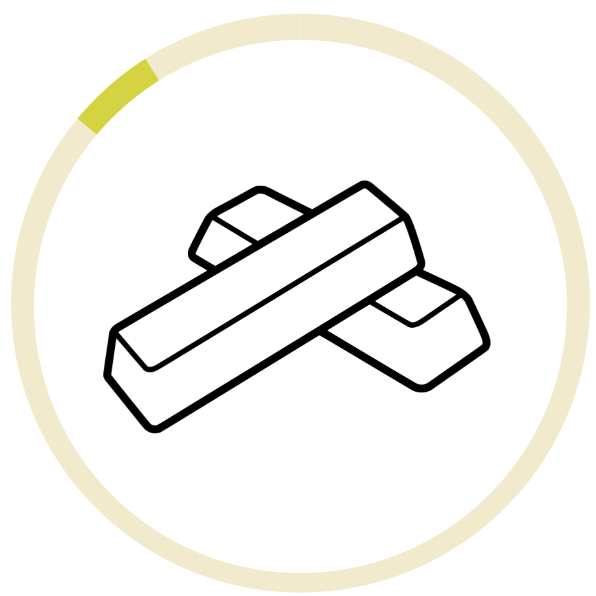
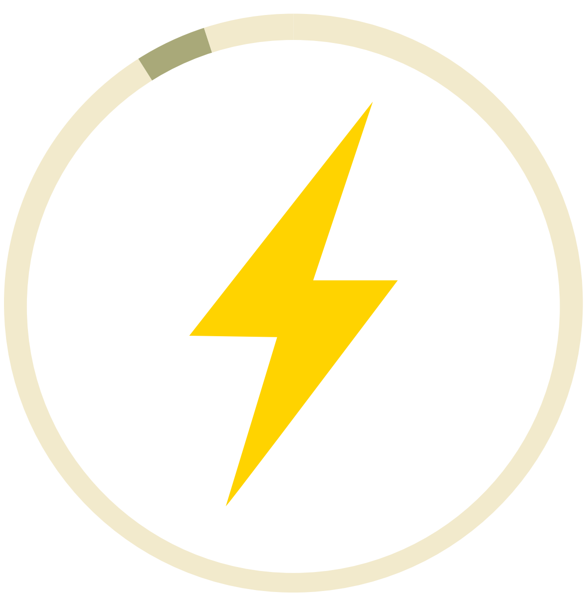


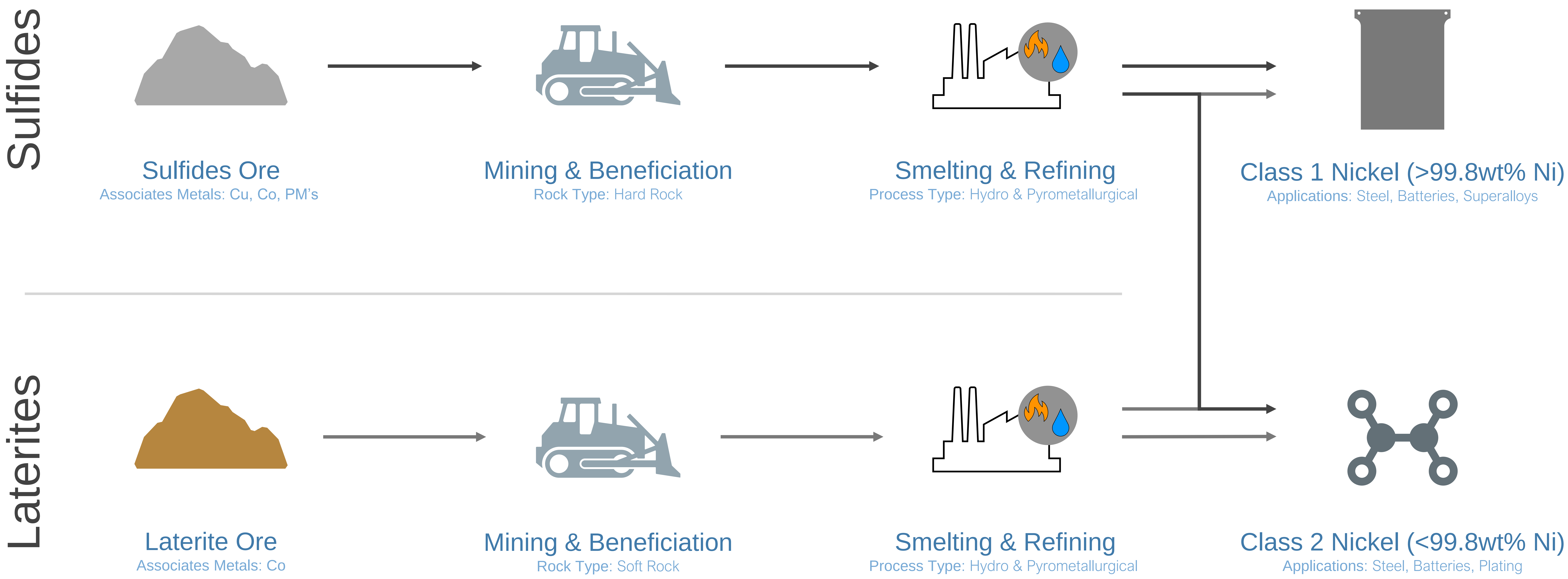
Non-Ferrous Alloys
Nickel Quality: Class 1



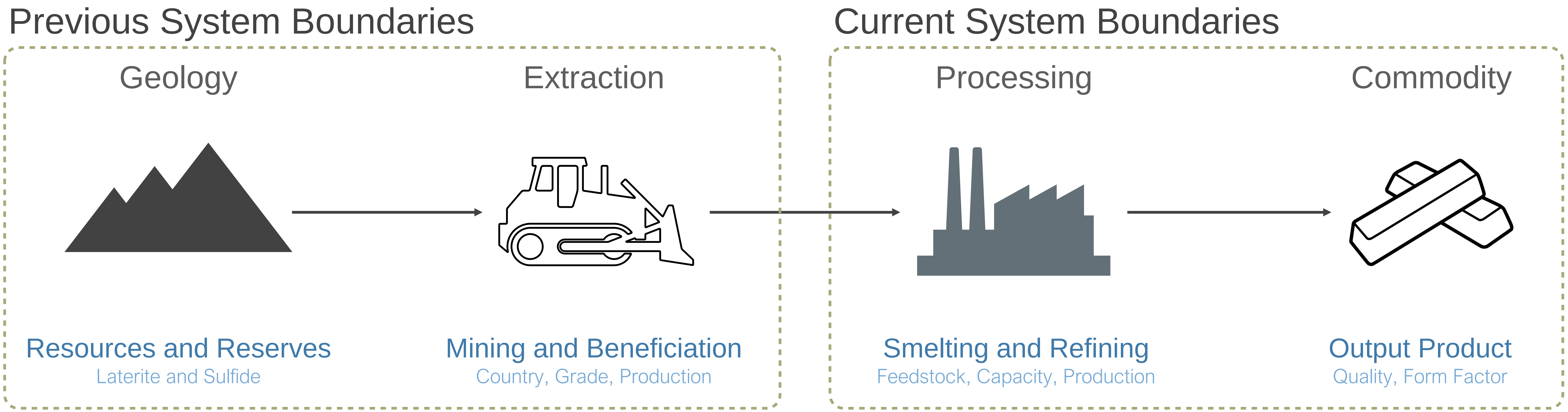
Plating
Nickel Quality: Class 1

Source: Wood Mackenzie, Nickel Institute

Nickel Overview | **Mineral supply chain**



Research Gap | Bottom-Up Facility-by-Facility



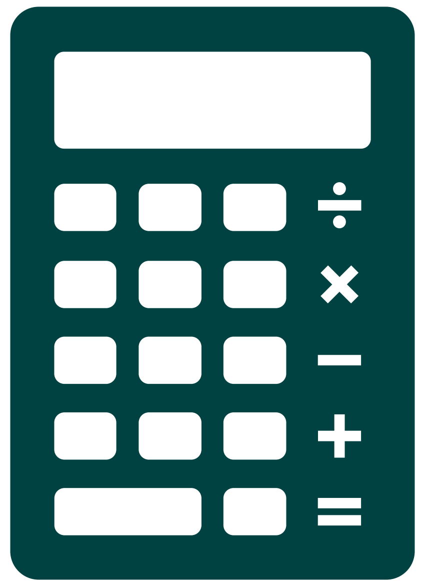
Reference: *Mudd (2009, 2011), Mudd & Jowitt (2014, 2022), Heijlen et al. (2021)*

Research Gap | Target groups in OEM organizations

Procurement

Sourcing
Available nickel suppliers

Engineering



Availability
Quality and capacity of materials

Environmental

Sustainability
Carbon footprint, ESG

Research Gap | **Research questions**

Ore & Product Bifurcation

Critical Mineral

Net Zero Goals

New Mines ✓
New Refineries?

GHG

Opaque Supply Chain
What are nickel supply chains?

Geopolitical Risk
Where are nickel facilities located?

Carbon Neutral Operations
Who has environmental commitments?

Limited Refining Capacity
How much capacity is available?

Methods and Data | **Data collected**

Reference Year

2021

Historical Data up to 2000

Facility Type

Non-NPI, Partial Inclusion of FeNi

Scope

Global Scope

Data Quality

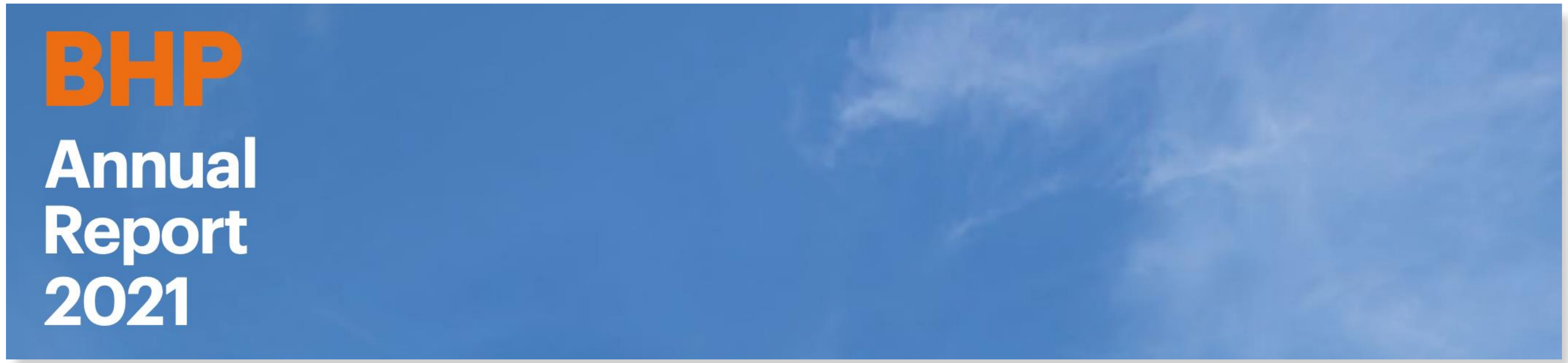
Secondary Sources

Data Points Collected

- Ownership
- Location
- Development History
- Facility Type
- Process Type
- Material Recovery
- Nickel Capacity
- Nickel Products
- Nickel Product Quality
- Nickel Product Application
- Nickel Recovery Rate
- Historical Nickel Production
- Cobalt Production
- Copper Production
- By-Products
- Feed Sources
- Feed Type
- Feed Quality
- Environmental Goals
- Environmental Impact
- Recycling Plans
- Expansion Plans

Methods and Data | **Data sources**

Corporate Annual, Financial, and Sustainability Reports



Industry Reports, News Articles

Academic Articles

Assessing the adequacy of the global land-based mine development pipeline in the light of future high-demand scenarios: The case of the battery-metals nickel (Ni) and cobalt (Co).

Wouter Heijlen [a,*], Guy Franceschi [b], Chris Duhayon [c], Kris Van Nijen [c]

[a] *Tercienco BV, Spijkstraat 185, B-9040, Ghent, Belgium*
[b] *GF Consult BV, Antwerpsesteenweg 644, B-9040, Ghent, Belgium*
[c] *Global Sea Mineral Resources NV, Slijkensesteenweg 2, B-8400, Ostend, Belgium*

Methods and Data | **Database**

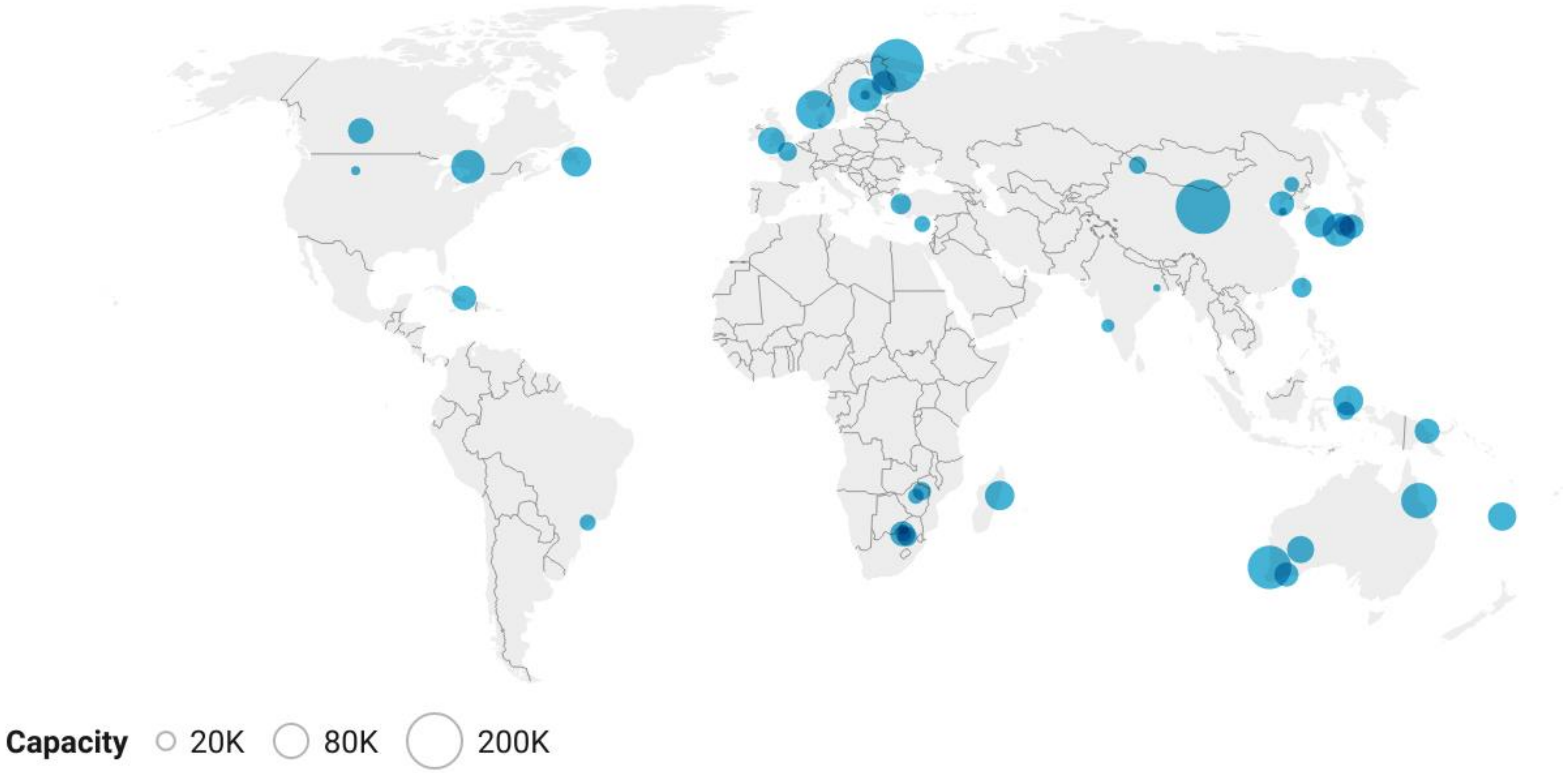
Operation	Primary Owner	Location				Ow
Name	Company	Latitude	Longitude	Region	Country	Ownership Type
Moa JV - Fort Saskatchewan	Sherritt	53.72	-113.19	North America	Canada	Private & State
Vale Copper Cliff Smelter (North Atlantic)	Vale	46.48	-81.06	North America	Canada	Private
Copper Cliff Nickel Refinery (North Atlantic Operations)	Vale	46.45	-81.08	North America	Canada	Private
Long Harbour	Vale	47.42	-53.81	North America	Canada	Private
Clydach Refinery	Vale	51.69	-3.89	Europe (w/out Russia)	United Kingdom	Private
PT Vale Indonesia	Vale	-2.57	121.38	Asia (w/ Russia)	Indonesia	Private
Matsusaka Refinery	Vale	34.60	136.55	Asia (w/ Russia)	Japan	Private
Taiwan Nickel Refining Corporation	Vale	22.66	120.28	Asia (w/ Russia)	Taiwan	Private
Vale Nickel (Dalian) Co. Ltd	Vale	39.09	121.84	Asia (w/ Russia)	China	Private
Korea Nickel Corporation	Vale	35.43	129.34	Asia (w/ Russia)	South Korea	Private
Onca Puma	Vale	-6.57	-51.09	South America	Brazil	Private
Goro	Prony Resources	-22.31	166.90	Oceania	New Caledonia	Private & State
Sudbury INO	Glencore	46.58	-80.81	North America	Canada	Private
Nikkelverk	Glencore	58.14	7.97	Europe (w/out Russia)	Norway	Private
Canadian Copper Refinery	Glencore	45.63	-73.50	North America	Canada	Private
Murrin Murrin	Glencore	-28.77	121.90	Oceania	Australia	Private
Koniambo	Glencore	-21.01	164.73	Oceania	New Caledonia	Private & State
SNNC CO. LTD	Societe Miniere du Sud Pacifique	34.92	127.77	Asia (w/ Russia)	South Korea	Private & State
Nickel West (Kwinana Nickel Refinery)	BHP	-32.25	115.77	Oceania	Australia	Private
Nickel West (Kalgoorlie Nickel Smelter)	BHP	-30.80	121.47	Oceania	Australia	Private
Cerro Matoso	South32	7.92	-75.55	South America	Colombia	Private
Ravensthorpe Nickel Operation	First Quantum	-33.65	120.40	Oceania	Australia	Private
Yabulu Nickel Refinery	Queensland Nickel Sales	-19.20	146.61	Oceania	Australia	Private
Falcondo	Americano Nickel	18.93	-70.36	South America	Dominican Republic	Private
Euronickel Industries	Euronickel Industries	41.44	21.94	Europe (w/out Russia)	North Macedonia	Private
Barro Alto	Anglo American	-15.06	-48.94	South America	Brazil	Private
Codemin	Anglo American	-14.16	-48.34	South America	Brazil	Private
Loma de Niquel	CVM	10.15	-67.12	South America	Venezuela	State
Rustenburg Base Metals Refinery	Anglo American	-25.69	27.33	Africa	South Africa	Private

Ownership and Development | Operation Overview | Nickel | Cobalt | Other Product | Source | Environmental Data | Investment | Nickel Products | Nickel Product Composition | Mines_Mine | Mines_Producers_Deposit

Results and Analysis | **Data overview**

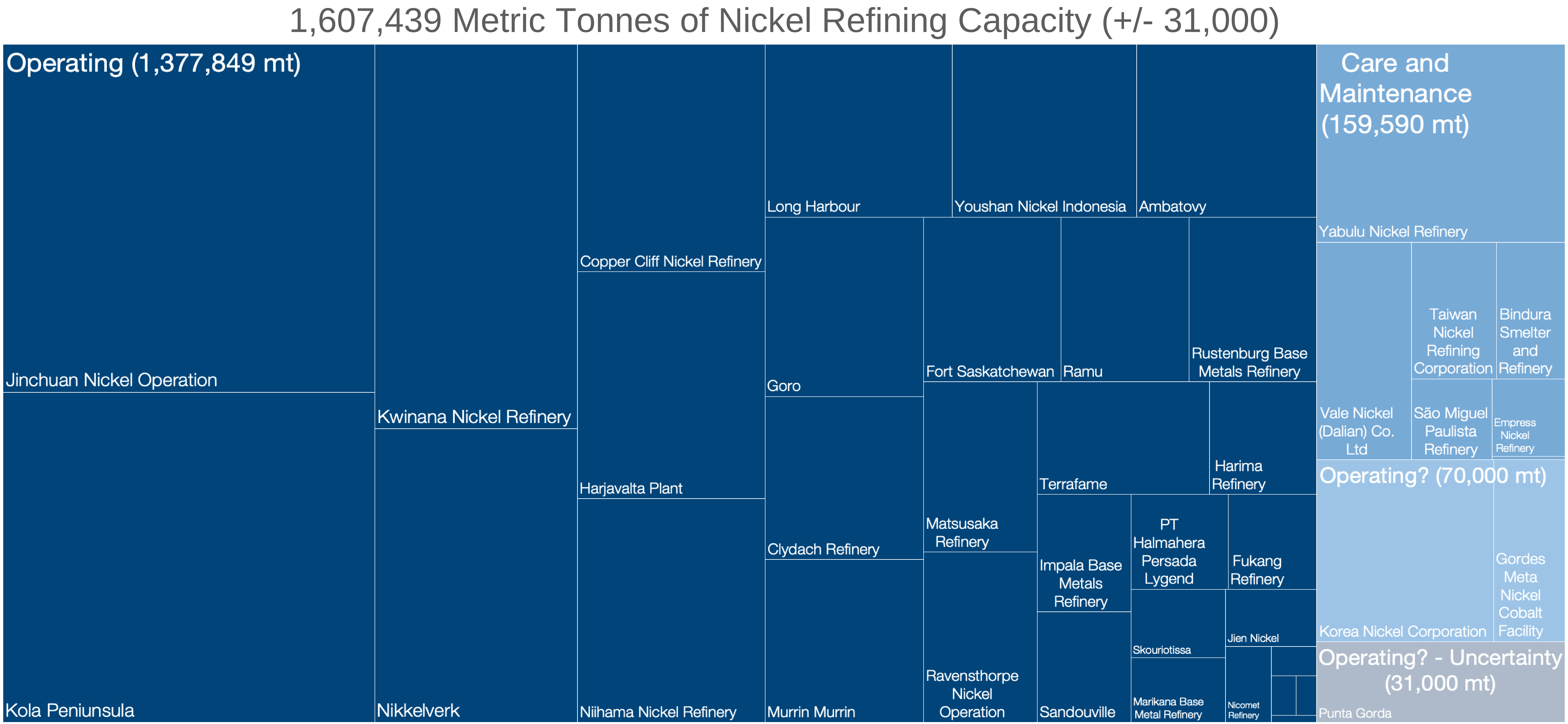
Data Points Collected	Companies Analyzed	Facilities Analyzed	Nickel Products Analyzed
+5k	31	42	122

Results and Analysis | **Geographic capacity of refined product**



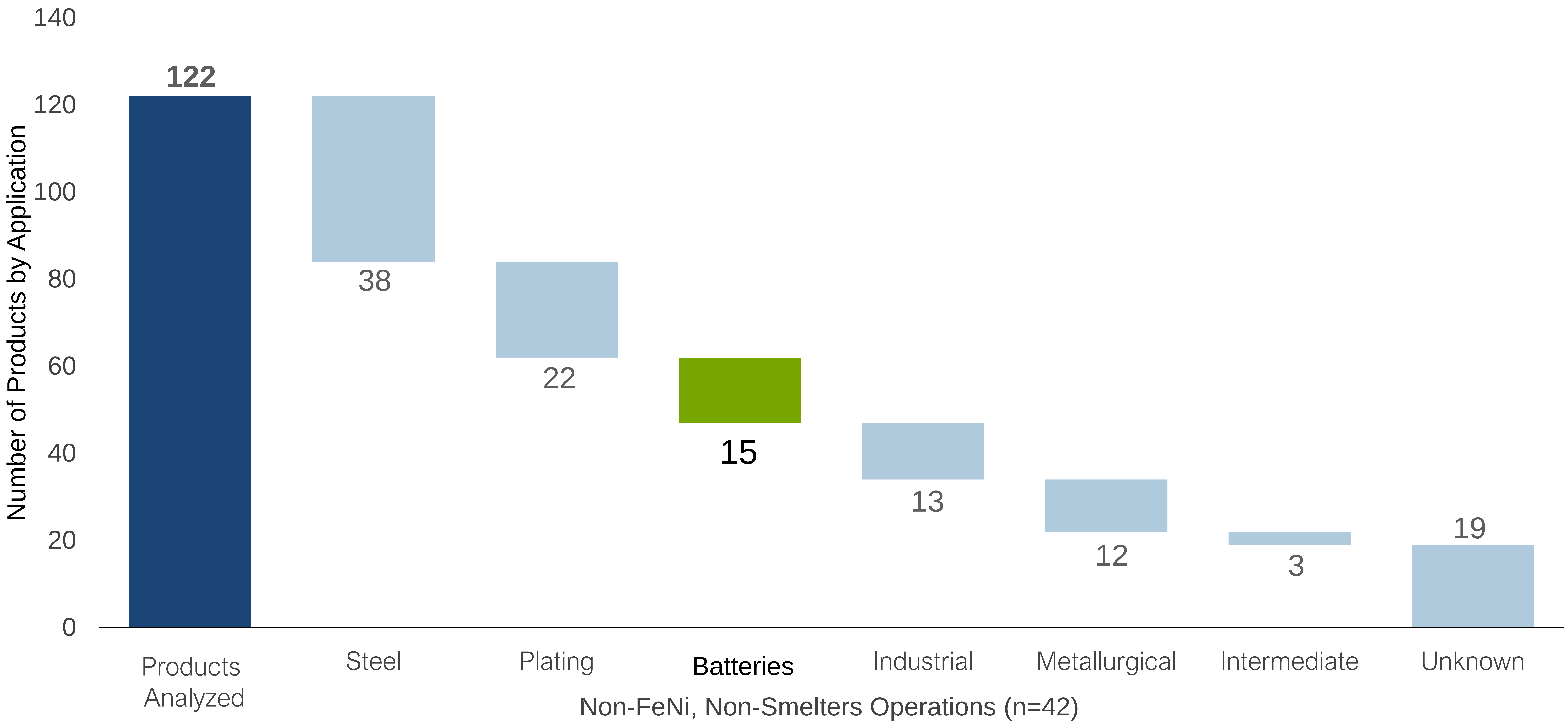
Non-FeNi, Non-Smelters Operations (n=42)

Results and Analysis | **CY21 operation capacity breakdown**

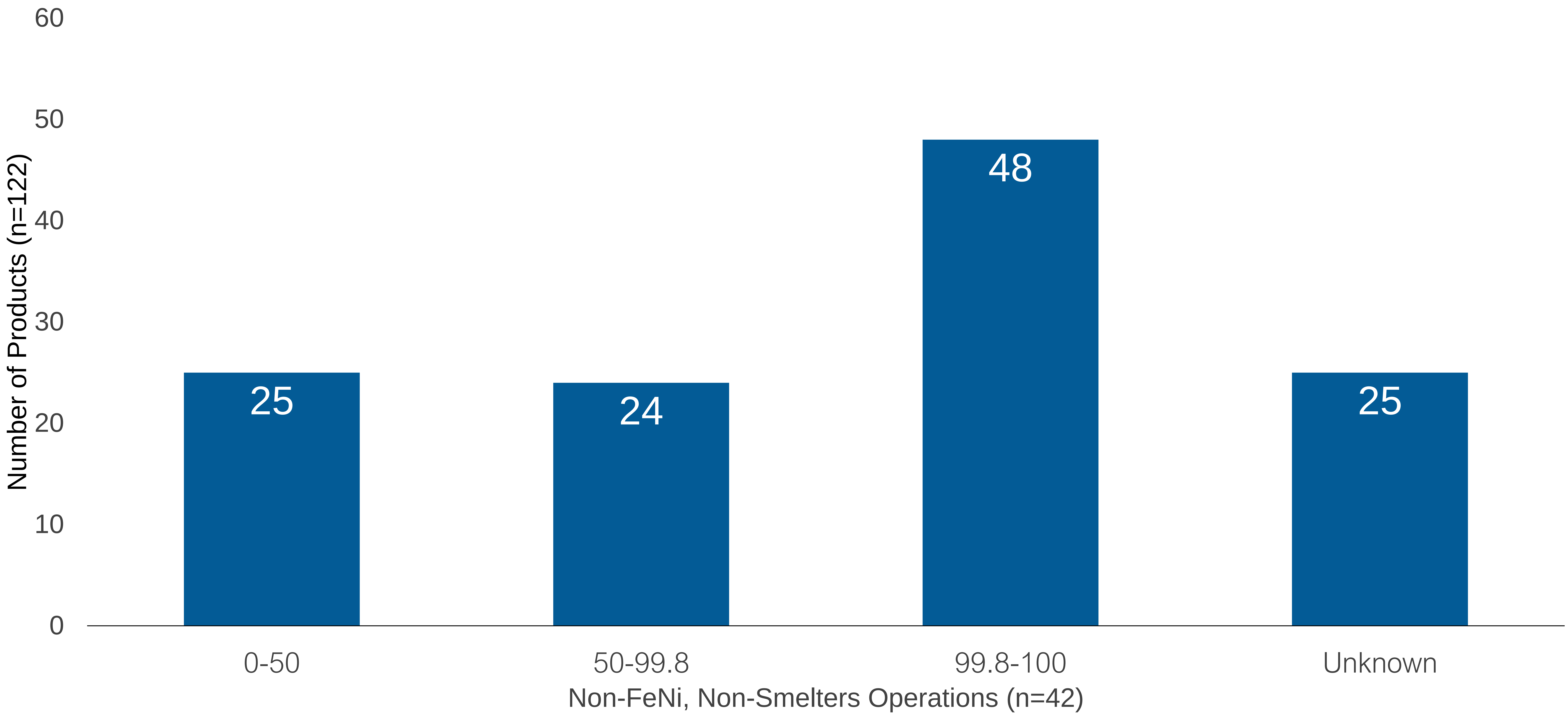


Non-FeNi, Non-Smelters Operations (n=42)

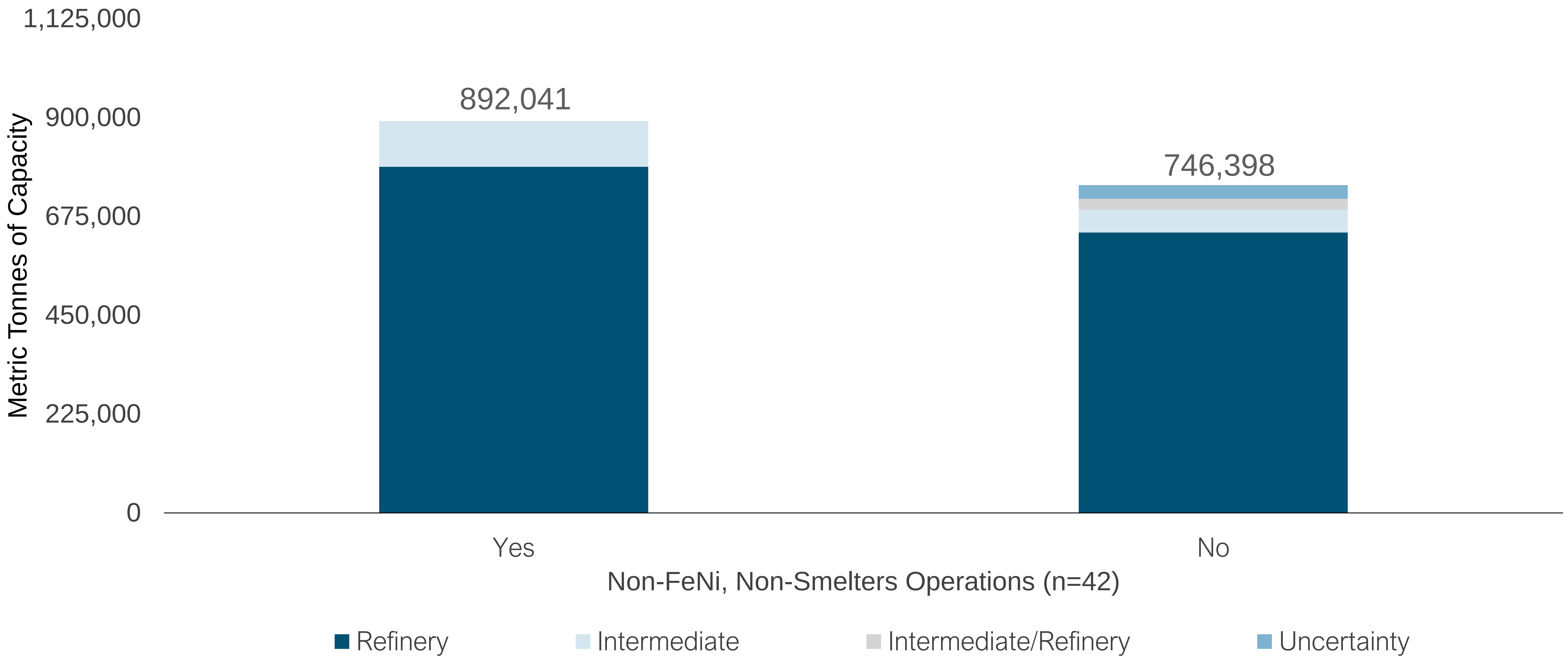
Results and Analysis | Product application breakdown



Results and Analysis | Product application breakdown



Results and Analysis | **Carbon neutral goal**



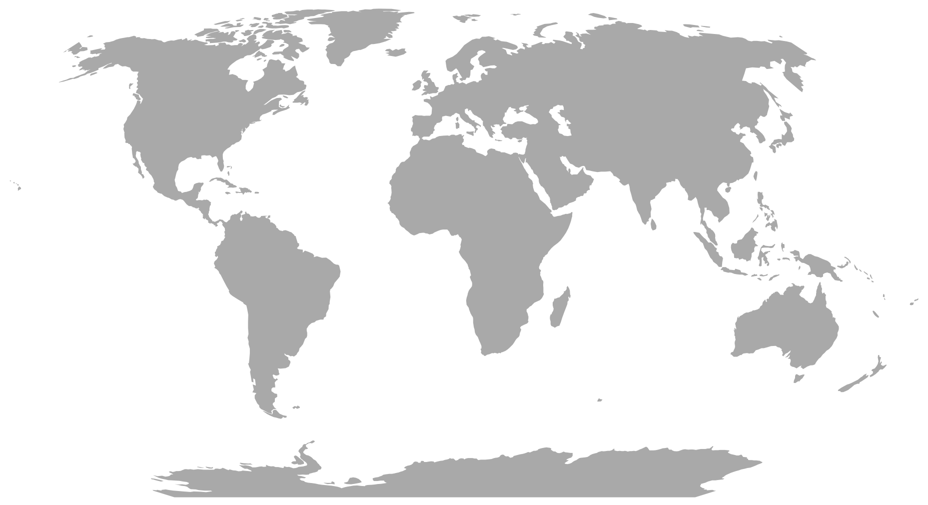
Discussion | Capacity bottleneck

Limited Excess Capacity

New Battery Capacity Required

Insignificant excess capacity currently available

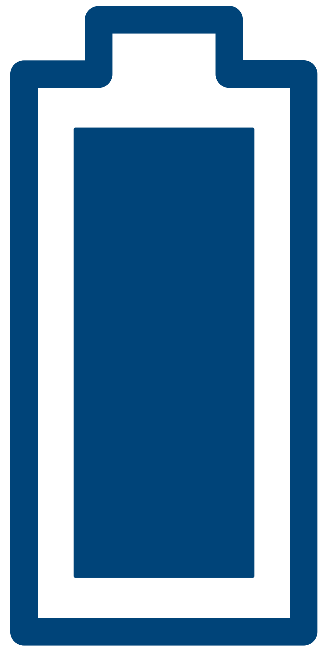
Geographic Distribution



Capacity Concentrated

Production chiefly in Asia and Oceania

Product Capacity



Products Intended for Steel

Limited number of products intended for batteries

UNIVERSITY OF WATERLOO

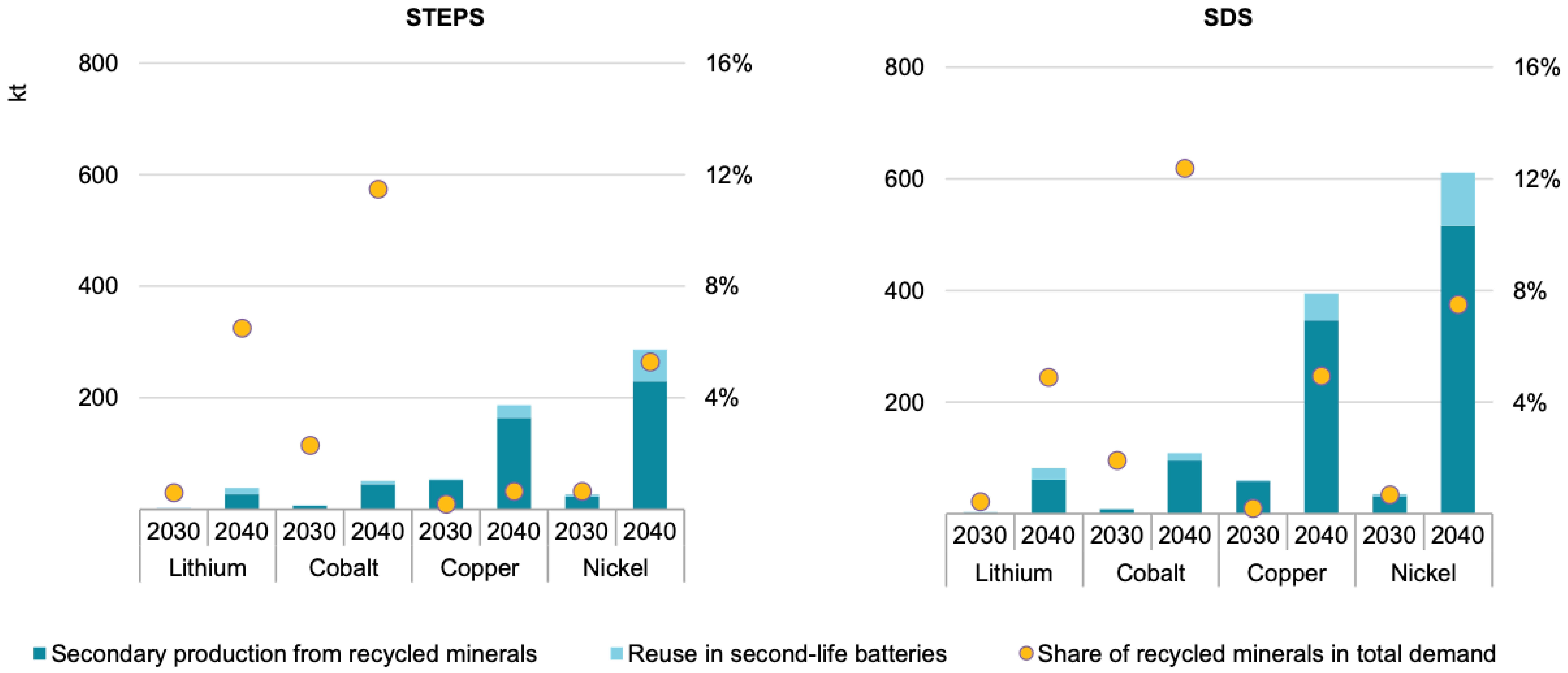
Jamie Faubert: jfaubert@uwaterloo.ca

Dr. Steven B. Young: sb.young@uwaterloo.ca

Research Gap | Recycling

Battery recycling: By 2040 recycling and reuse of EV and storage batteries could reduce the primary supply requirement for minerals by up to 12%

Contribution of recycling and reuse of batteries to reducing primary supply requirement for selected minerals by scenario



Methods and Data | **Limitations**

Reporting

Inconsistent Accounting

Tolling, Operations Included

System Boundaries

Unique Flowsheets

HPAL, Refining

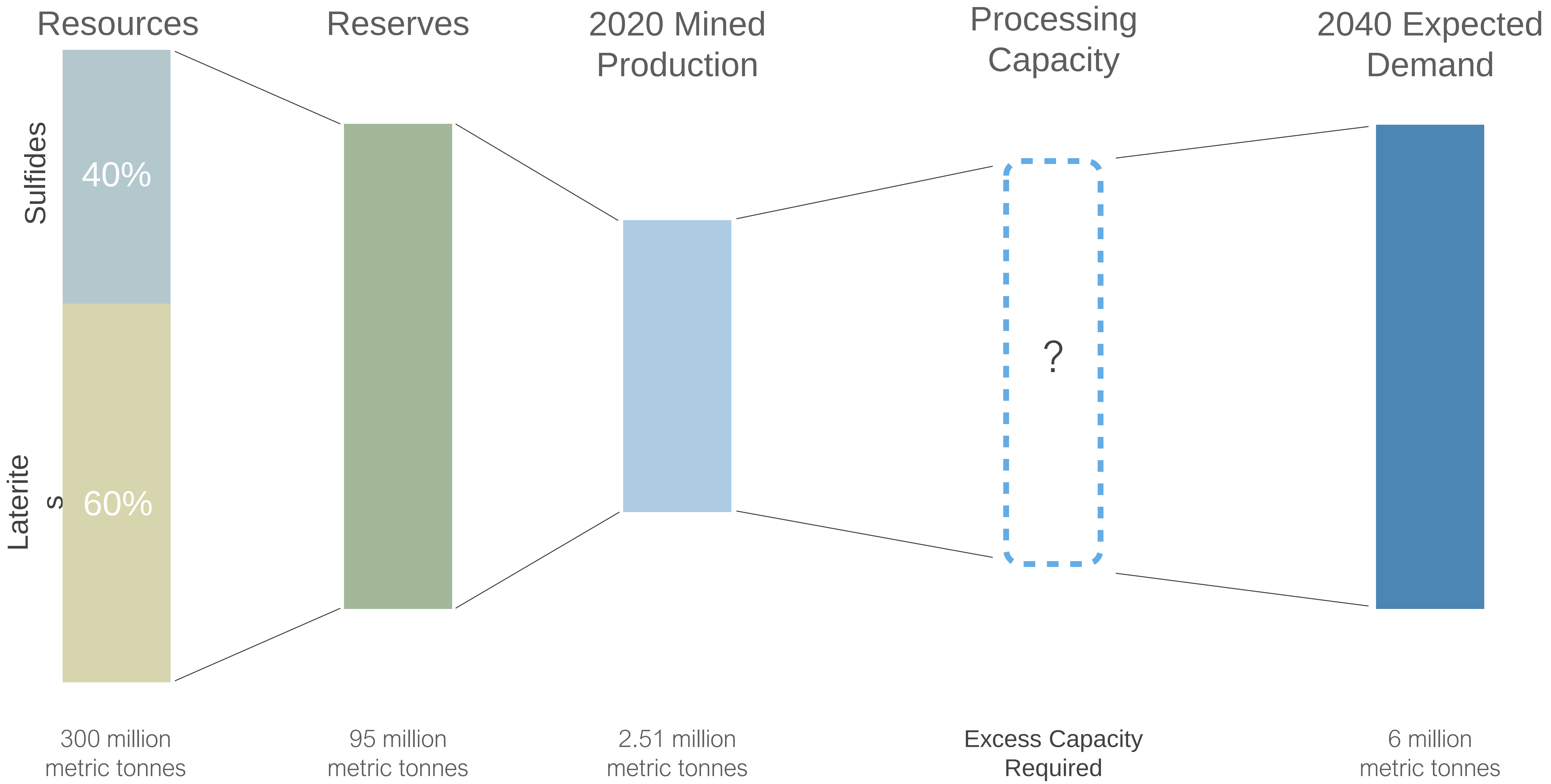
By-Product

Copper and PM Refineries

Crude Nickel Sulfate Production

*PM: Precious Metals

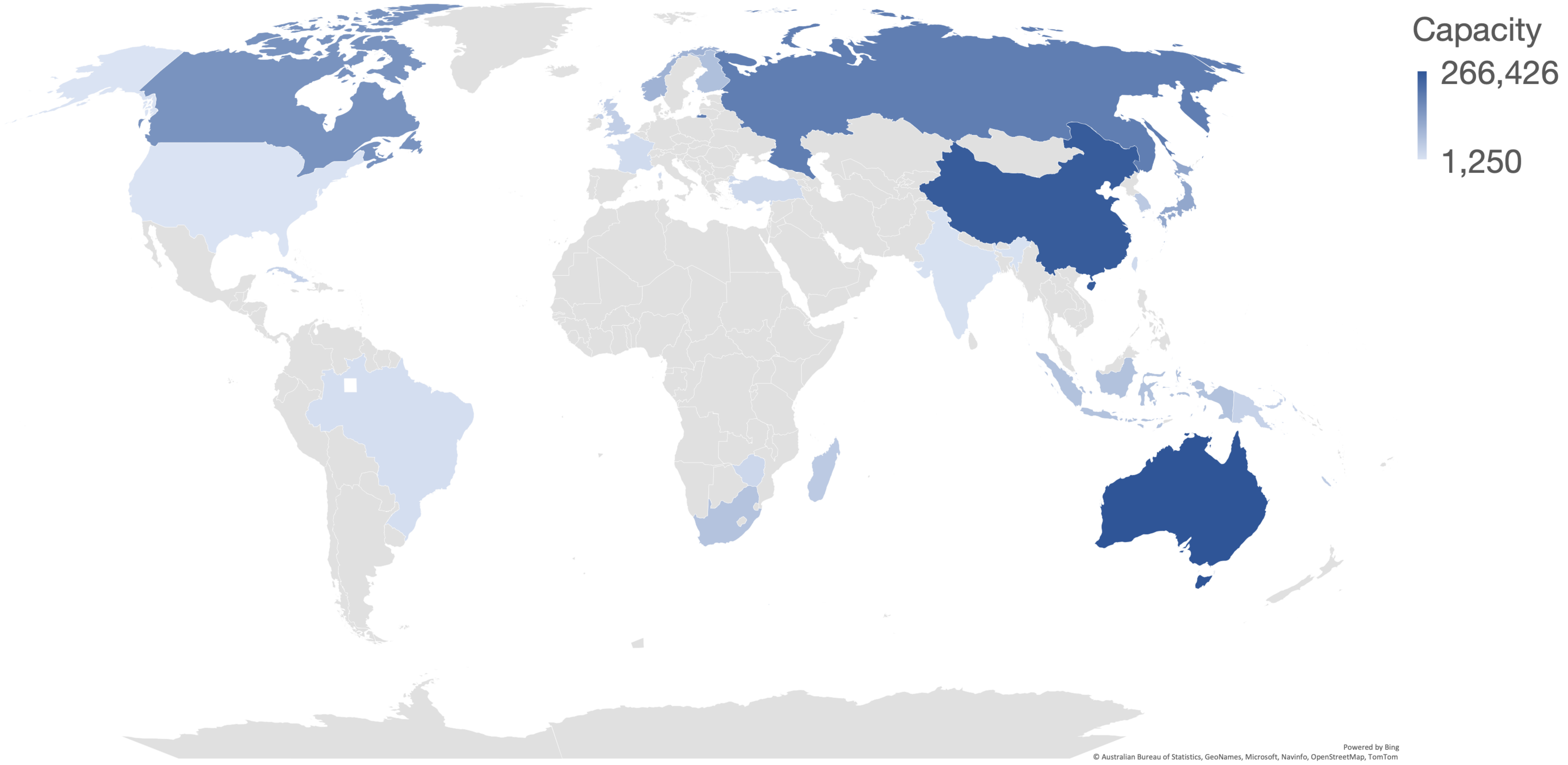
Research Gap | **Processing capacity**



Source: USGS

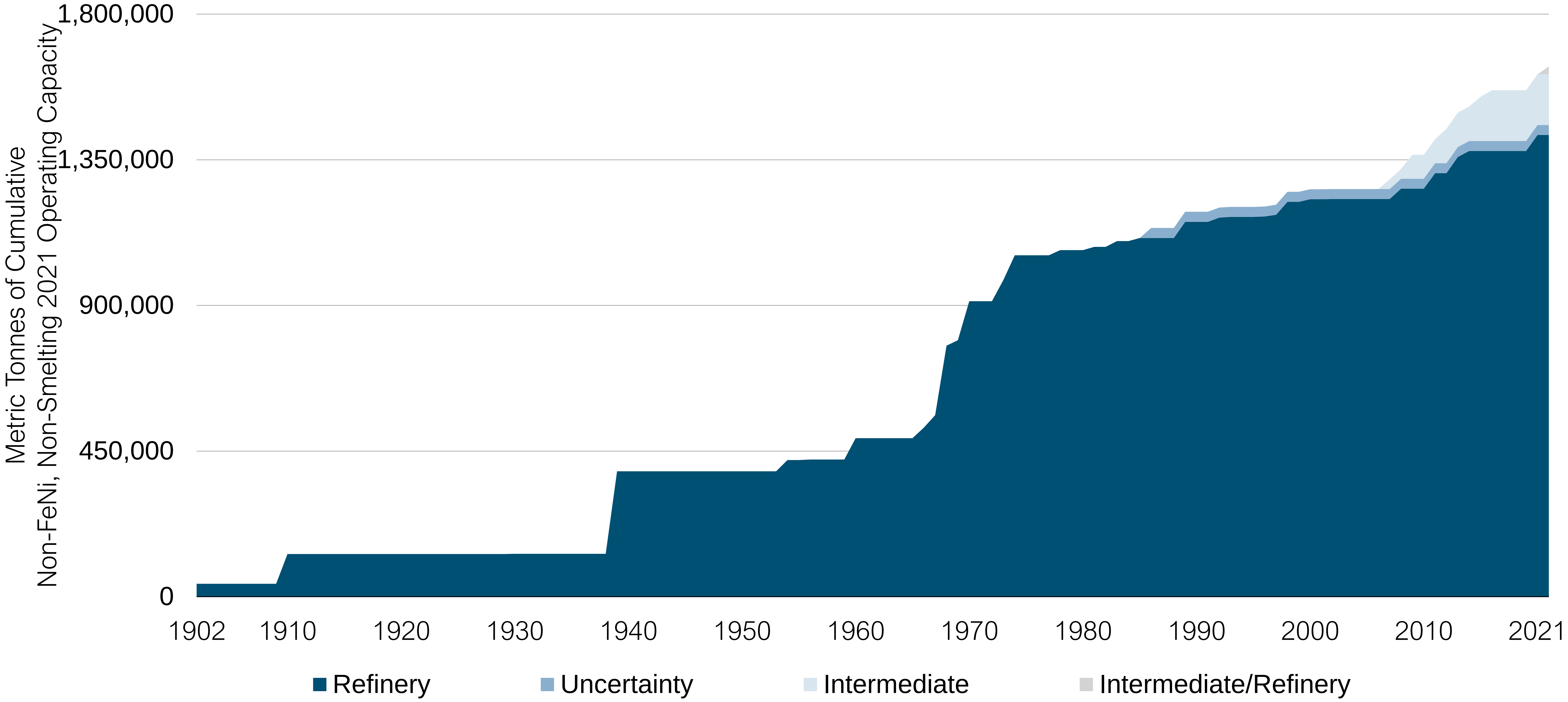
*Not to scale

Results and Analysis | **Geographic capacity breakdown**



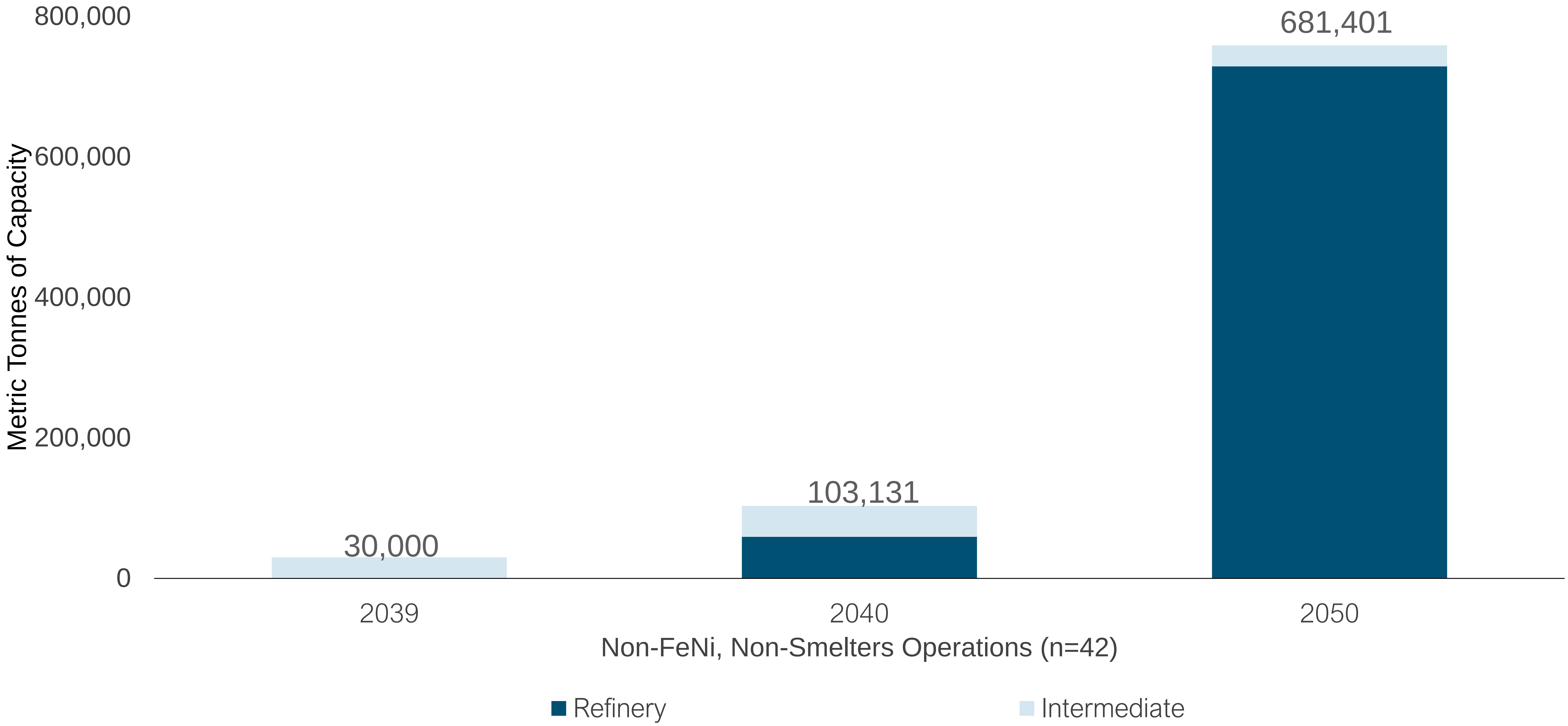
Non-FeNi, Non-Smelters Operations (n=42)

Results and Analysis | Timeline to capacity

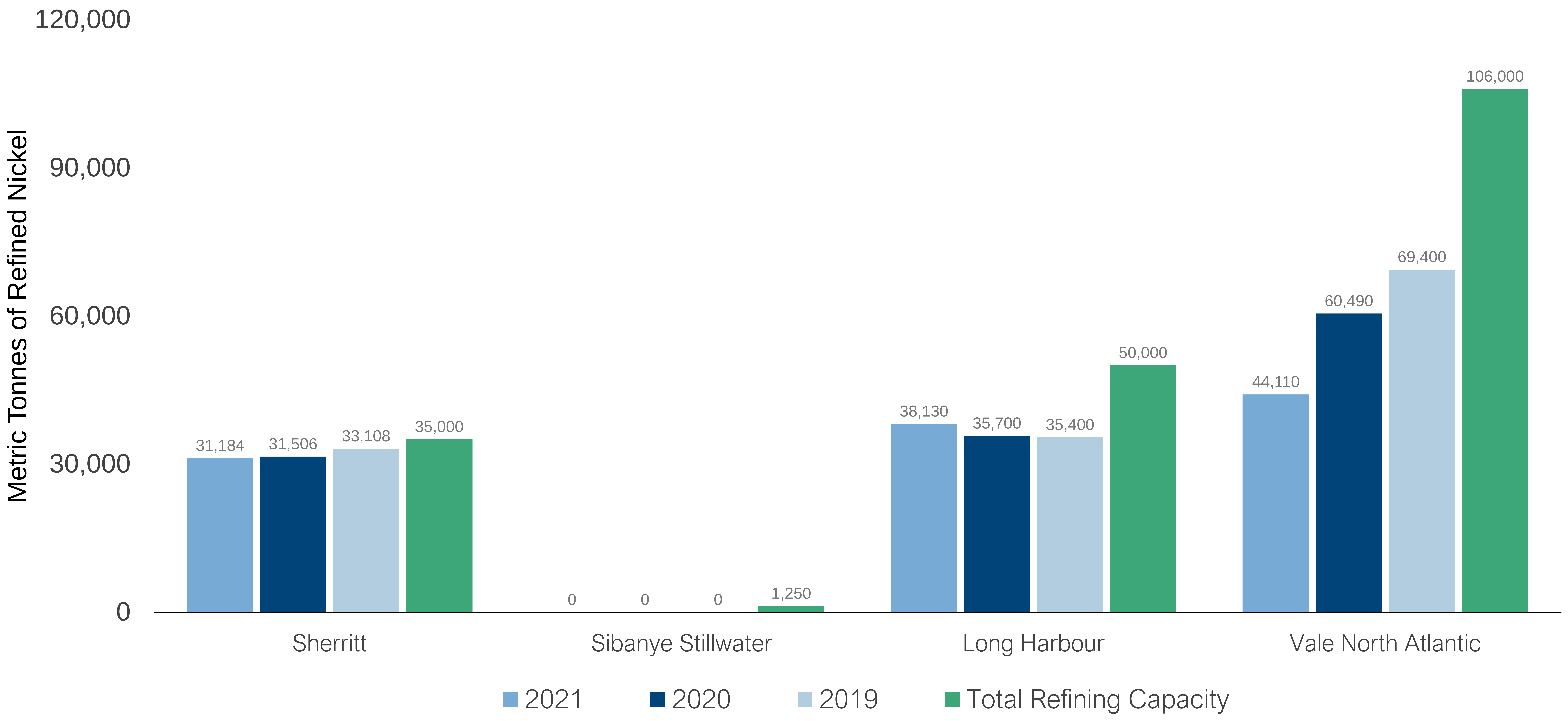


*Assumes total current operating capacity installed at year of construction

Results and Analysis | **Carbon neutral goal — year**

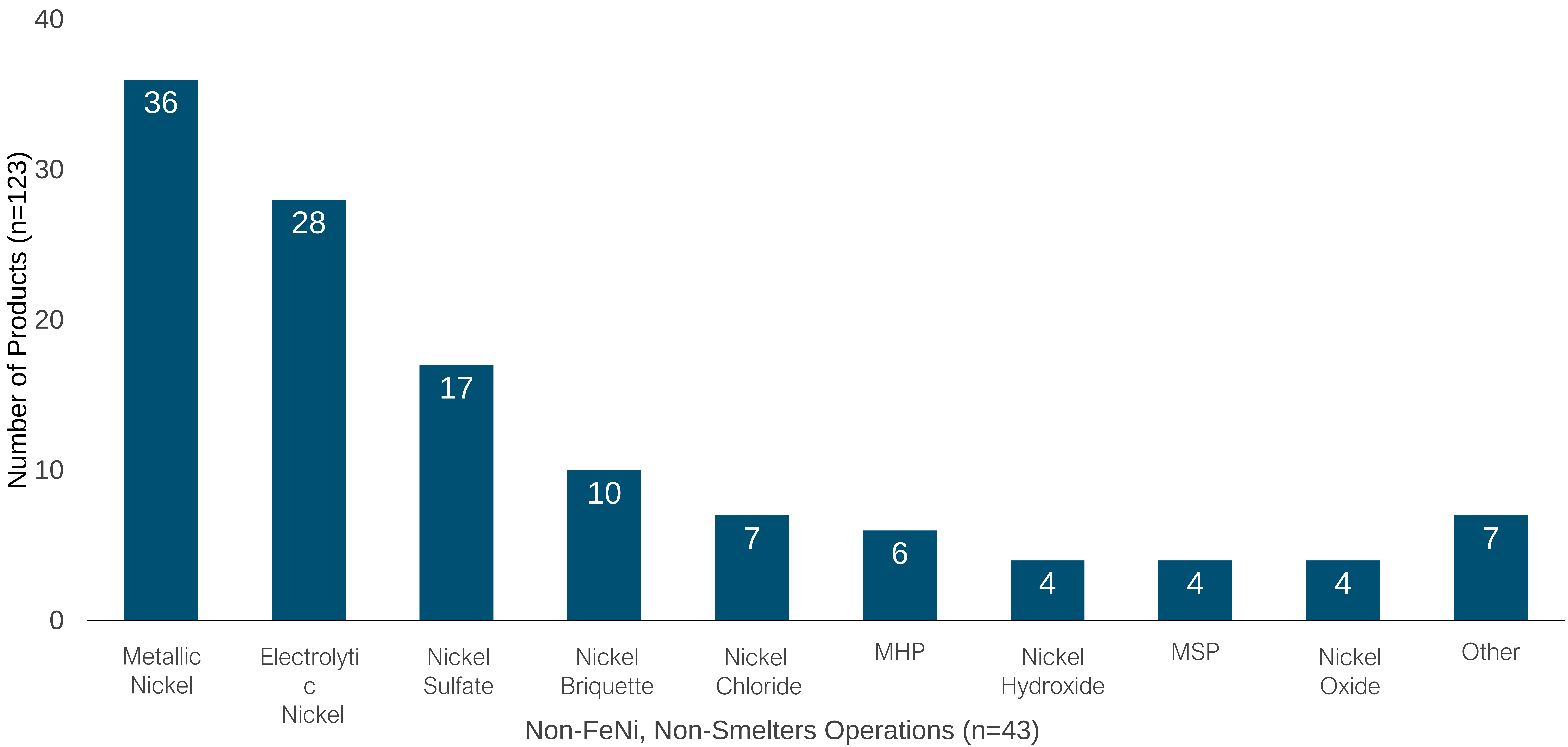


Discussion | North American excess refining



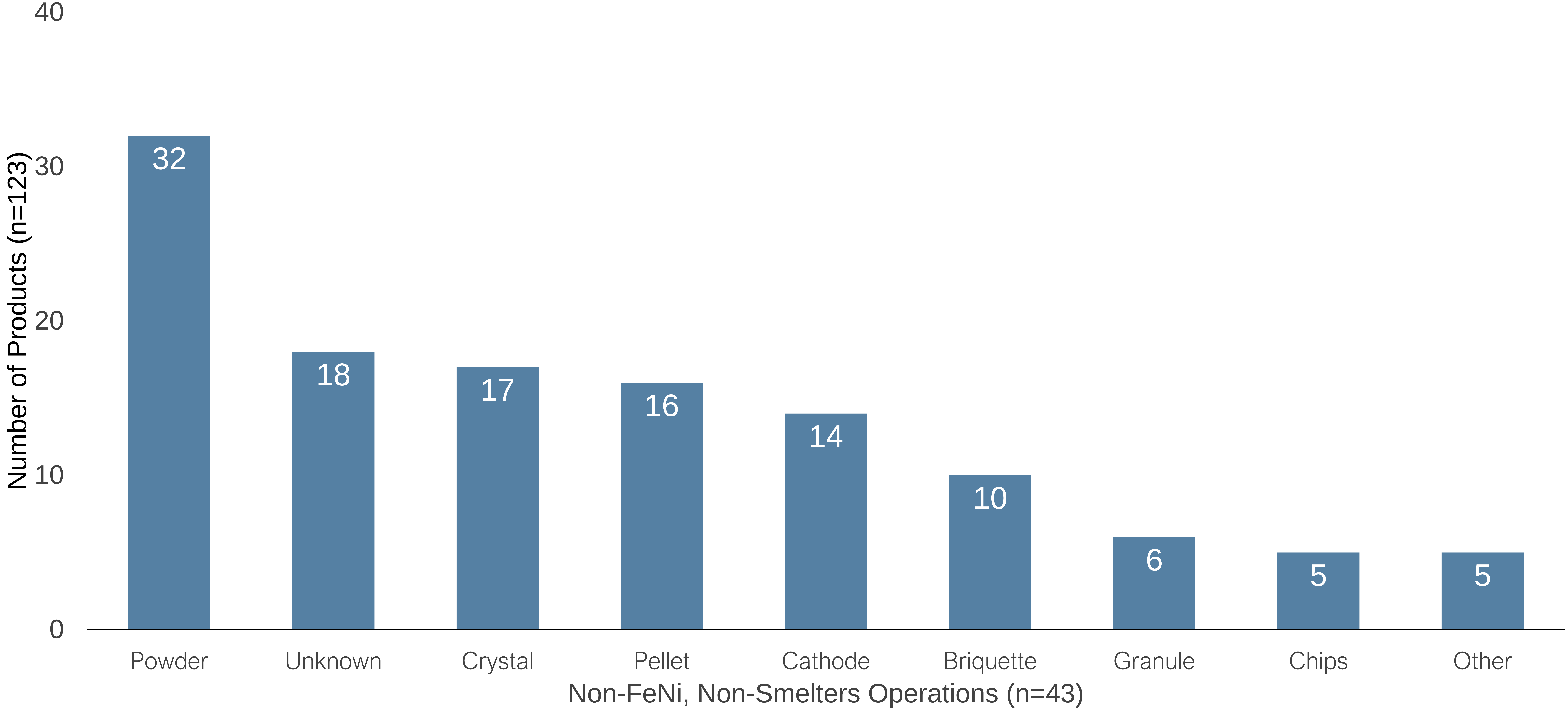
*North Atlantic Include Sudbury and Clydach Refineries and Sudbury, Thompson, and External Sources

Results and Analysis | Product chemistry



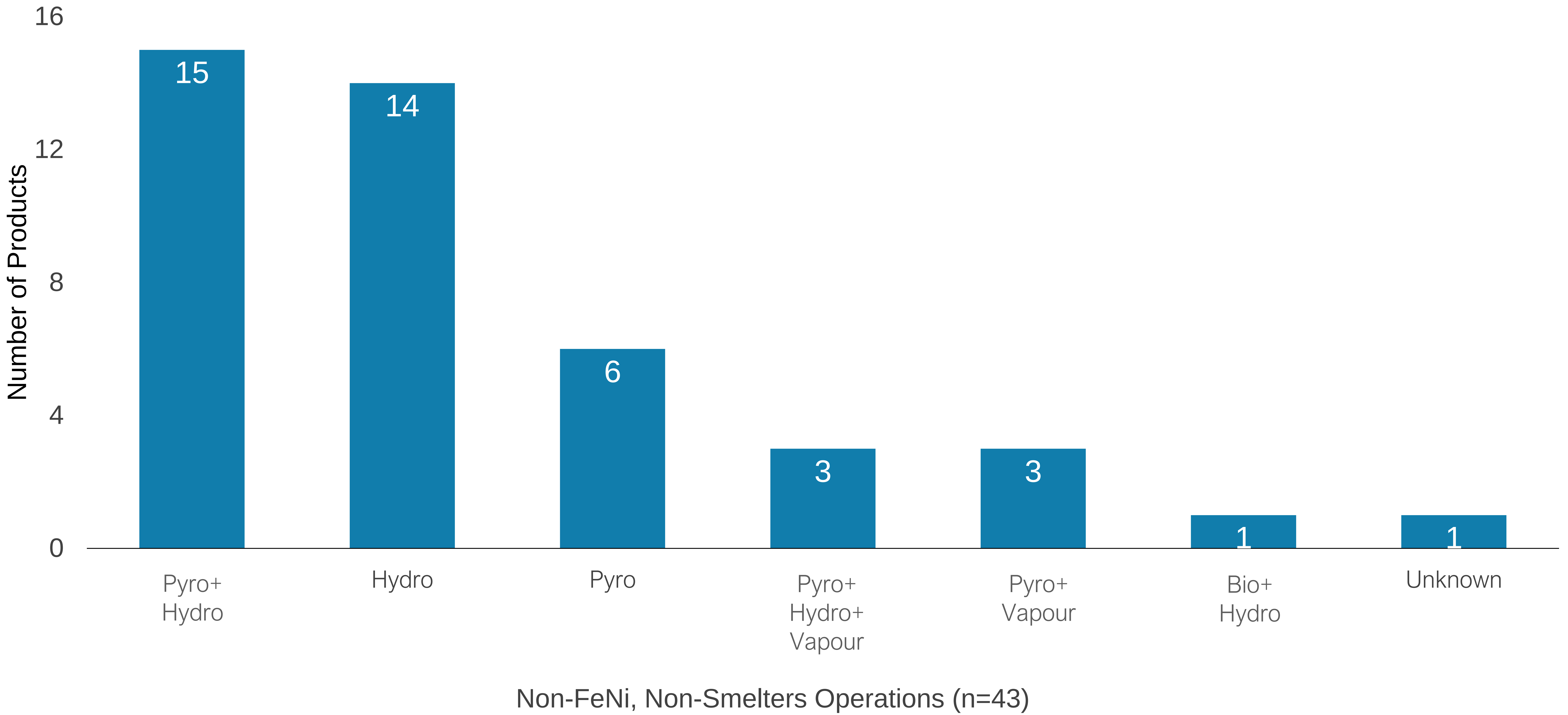
*Other: $C_2H_4NiO_8$ (3x), NMC (1x), NiS (1x), $NiCO_3$ (1x), Nickel Reclaim (1x)

Results and Analysis | **Product form factor**



*Other: Compacts (2x), Blocks (2x), Solution (1x), Cake (1x)

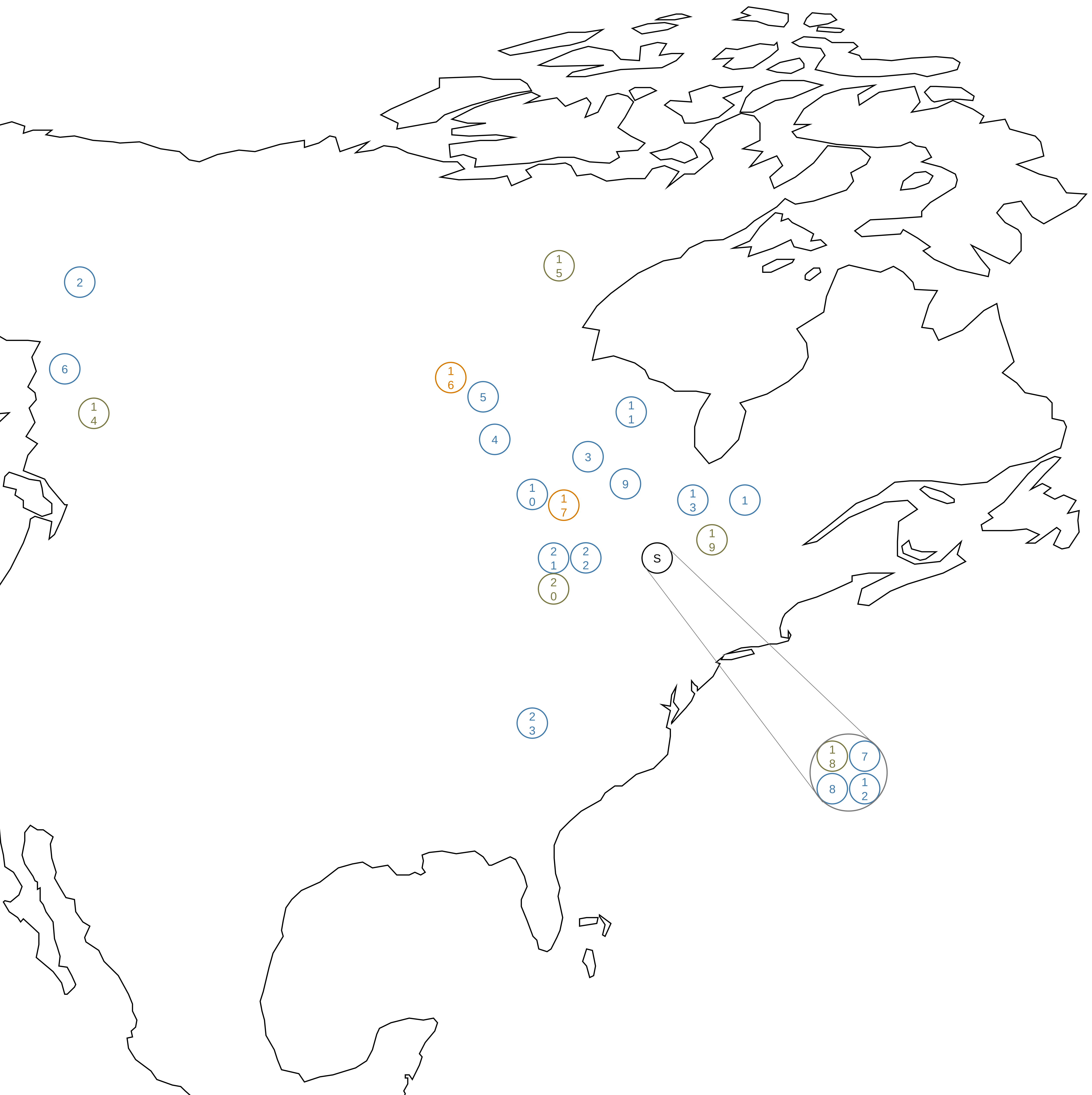
Results and Analysis | **Processing route**



*Unknown likely Hydro

Discussion | Active North American nickel facilities

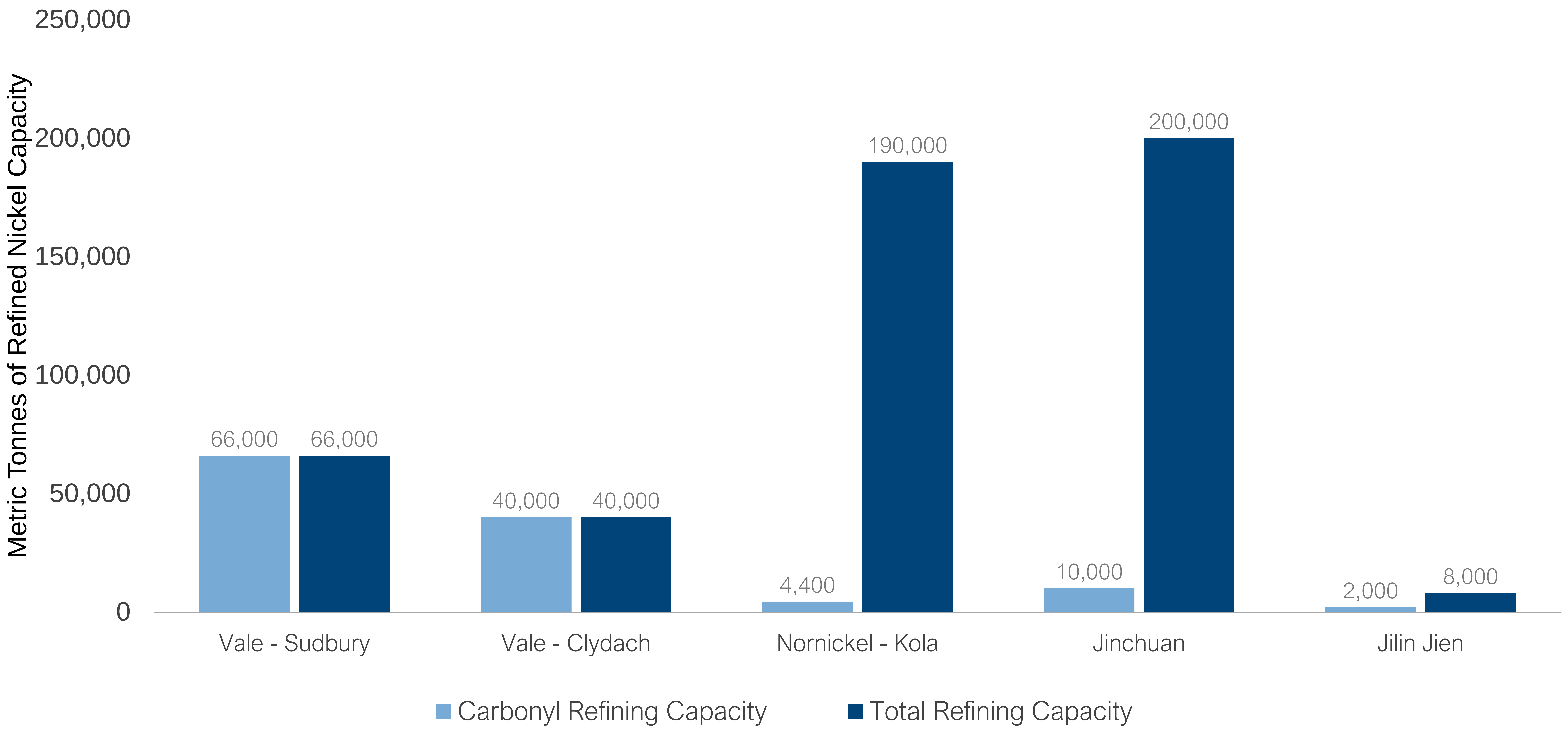
Discussion | North American nickel projects



	Property	Commodities	Facilities	Output	Carbon Goal	Sequestration
1	Dumont	Ni, Co, Fe, PM	Mine	Concentrate	Yes	Yes
2	Nickel Shaw	Ni, Cu, Co, PM	Mine	Concentrate	Yes	Yes
3	Thierry	Ni, Cu, PM	Mine	Concentrate	No	No
4	Minago	Ni, Cu, Co, PM, Other	Mine	Concentrate	Yes	No
5	Lynn Lake	Ni, Cu, Co, Pb, PM	Mine	Concentrate	No	No
6	Turnagain	Ni, Co, Cu, PM	Mine	Concentrate	Yes	Yes
7	River Valley	Ni, Cu, Co, PM	Mine	Concentrate	No	No
8	Shakespeare	Ni, Cu, Co, PM	Mine	Concentrate	Yes	No
9	Junior Lake	Ni, Cu, Co, PM, Other	Mine	Concentrate	No	No
10	Makwa Mayville	Ni, Cu, Co, PM	Mine	Concentrate	No	No
11	Eagle's Nest	Ni, Cu, PM	Mine	Concentrate	Yes	Yes
12	Victoria	Ni, Cu, Co, PM	Mine	Conncentrate	Yes	No
13	Crawford	Ni, Fe, Co, PM	Mine	Concentrate	Yes	Yes
14	Decar	Ni, Fe, Cr	Mine + Processing	Nickel Sulfate?	Unclear	No
15	Ferguson Lake	Ni, Cu, Co, PM, Other	Mine + Processing	Refined product	No	No
16	Hidden Bay	U, Co, Ni	Mine	Unknown	No	No
17	Kenbridge	Ni, Cu, Co, PM	Mine	Unknown	No	No
18	Onaping Depth	Ni, Cu, Co, PM	Mine	Existing Process	Yes	No
19	Battery Material Park	Co, Cu, Ni, Li, C	Processing	Nickel Sulfate	Yes	No
20	Tamarack	Ni, Cu, Co, PM	Mine + Processing?	Concentrate, Refined?	Yes	Yes
21	Mesaba	Ni, Cu, Co, PM	Mine	Concentrate	Yes	No
22	NorthMet	Cu, Ni, Co, PM	Mine	Concentrate	No	No
23	Missouri Cobalt	Co, Ni, Cu	Tailings Reprocessing	Concentrate	No	No

*PM: Precious Metals

Discussion | Carbonyl nickel refining



Natural and synthetic graphite | Trade-offs between carbon footprint and supply risk of different sourcing options

IRTC 2023 – Lille

Aina Mas Fons
Anish Koyamparambath
Philippe Loubet
Guido Sonnemann

Index

- Context
- Objectives
- Methodology
  - GeoPolRisk
  - LCA
- Supply chain
  - Natural graphite
  - Synthetic graphite
- Results and trade-offs
- Conclusions

The big picture

Raw and processed materials → **Battery components** → **Batteries** → **E-mobility**

Graphite | Anode | LIBs | Europe's future is electric

Up to **20% wt.** of the battery cell

The big picture

Raw and processed materials → **Battery components** → **Batteries** → **E-mobility**

Natural graphite (NG)

Synthetic graphite (SG)

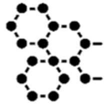
Anode

LIBs

Europe’s future is electric

Objectives

Natural graphite (NG)



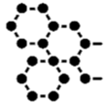
Synthetic graphite (SG)

- Assess the **trade-off** between carbon footprint versus supply risk of both graphite groups
- Identify the foreseeable **hotspots** and **bottlenecks** of the different sourcing options

Supply risk evaluation ⇄ **Environmental** evaluation

Objectives

Natural graphite (NG)



Synthetic graphite (SG)

- Assess the **trade-off** between carbon footprint versus supply risk of both graphite groups
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GeoPolRisk ⇄ **Life cycle assessment (LCA)**

Methodology | GeoPolRisk method

GeoPolRisk

Supply risk of importing one resource to one economic unit for one year.

- Data available for 32 resources including fossil fuels, metals and non metals.
- Political instability indicator data for over 200 countries, regions and economic blocks (Including former countries, regions) since 2000 (Including EU).

$$GPRS = HHI_A * \sum_i \left(\frac{g_i * f_{Aic}}{p_{Ac} + F_{Ac}}\right)_{RR}$$

Production concentration of a resource A
- Changes with year of assessment

Weighted average of imports to economic unit (c)
- Weighted using the political instability indicator (g_i)
- Values vary with the economic unit and year of assessment

Gemechu, Eskinder, Guido Sonnemann, and Steven Young. 2015. "Geopolitical-Related Supply Risk Assessment as a Complement to Environmental Impact Assessment: The Case of Electric Vehicles." *The International Journal of Life Cycle Assessment*, June. https://doi.org/10.1007/s11367-015-0917-4.

Santillán-Saldivar, Jair, Eskinder Gemechu, Stéphanie Muller, Jacques Villeneuve, Steven B. Young, and Guido Sonnemann. 2022. "An Improved Resource Midpoint Characterization Method for Supply Risk of Resources: Integrated Assessment of Li-Ion Batteries." The International Journal of Life Cycle Assessment, no. 0123456789. https://doi.org/10.1007/s11367-022-02027-y.

Methodology | GeoPolRisk method

GeoPolRisk

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EU perspective

$$GPRS = HHI_A * \sum_i \left(\frac{g_i * f_{Aic}}{p_{Ac} + F_{Ac}} \right)_{RR}$$

Production concentration of a resource A
- Changes with year of assessment

Weighted average of imports to economic unit (c)
- Weighted using the political instability indicator (g_i)
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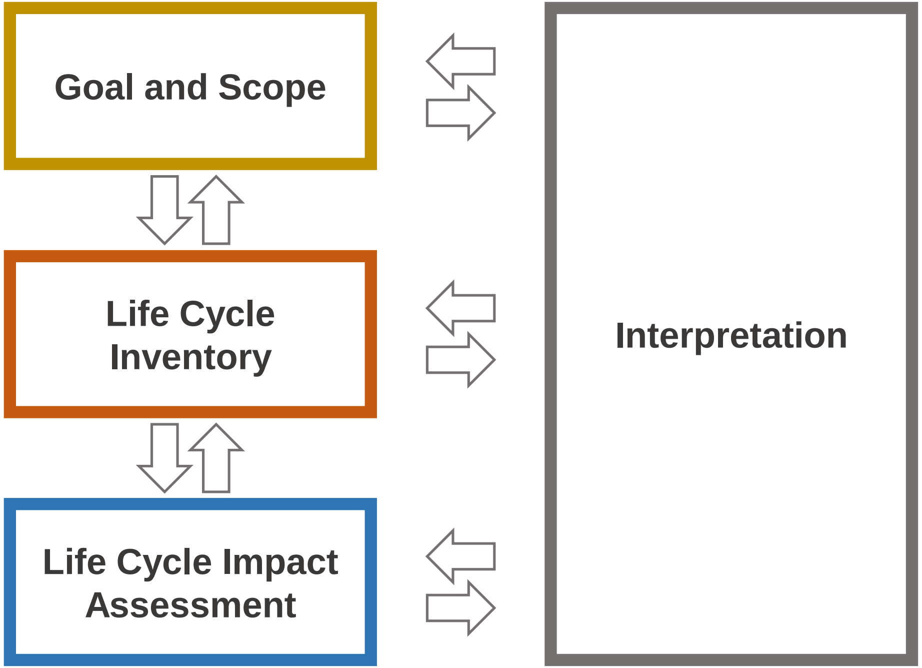
Koyamparambath, Anish, Jair Santillán-Saldivar, Benjamin McLellan, and Guido Sonnemann. 2022. “Supply Risk Evolution of Raw Materials for Batteries and Fossil Fuels for Selected OECD Countries (2000–2018).” Resources Policy 75 (November). https://doi.org/10.1016/j.resourpol.2021.102465.

Methodology | LCA

Standardized (ISO 14044) environmental impact assessment method

4 phases



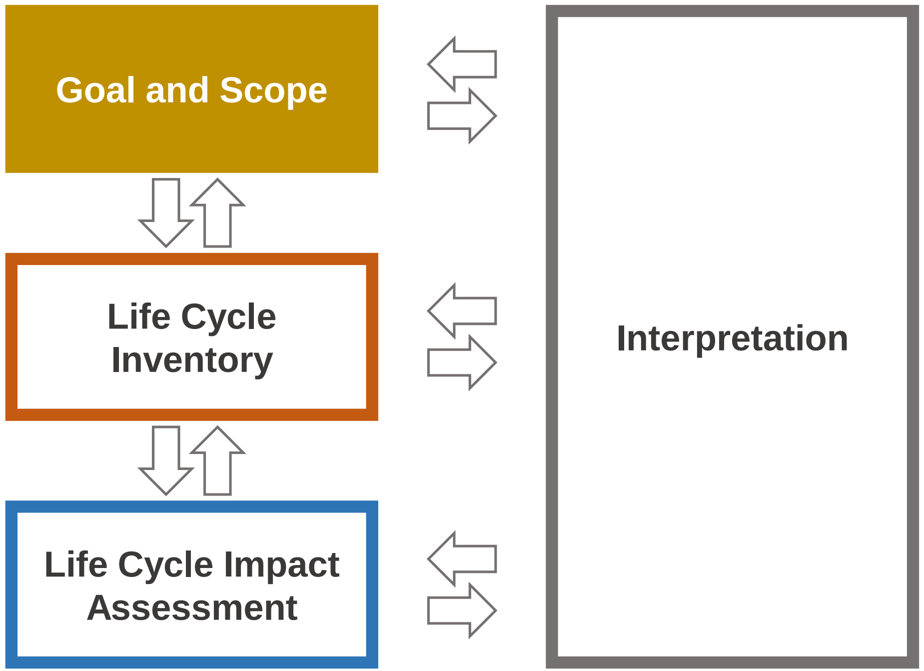
International Organisation for Standardization. 2006. “ISO 14044 - Environmental Management Life Cycle Assessment - Requirements and Guidelines.” Geneva.

Methodology | LCA

Production of battery-grade graphite:

- Natural graphite route
- Synthetic graphite route

Functional unit | Production of **1kg** of battery-grade graphite

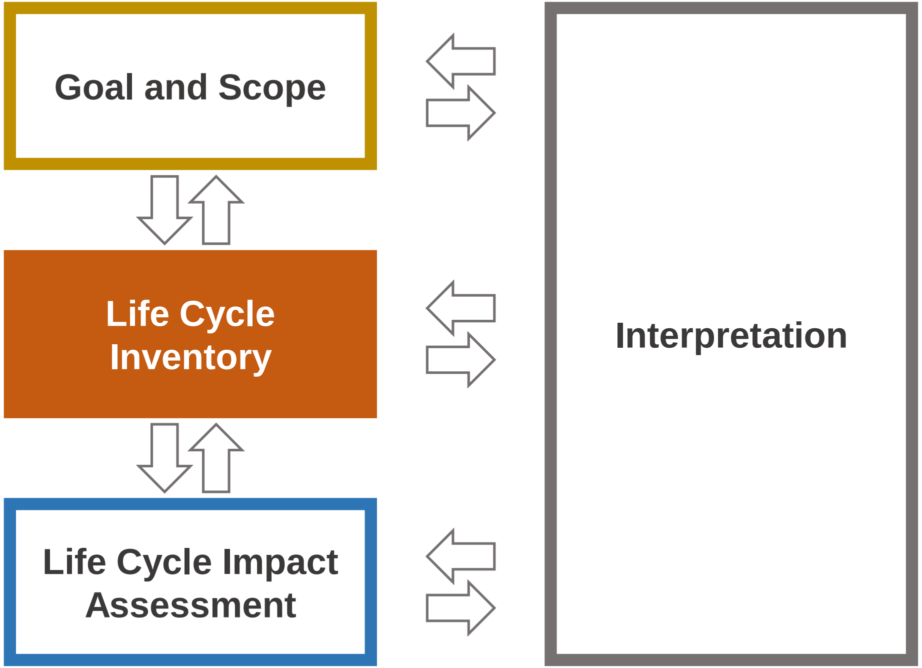


Methodology | LCA

Foreground data |

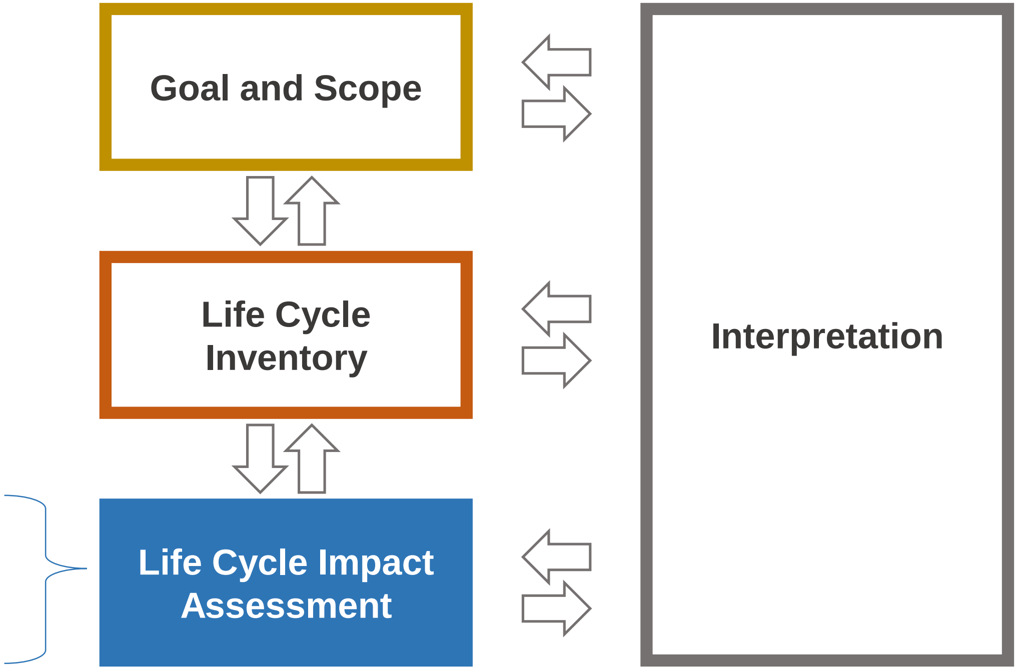
- Engels, Cerdas et. al. (2022)
- Surovtseva et. al. (2022)
- Dai et. al. (2019)

Background data | Ecoinvent 3.8



Methodology | LCA

Global warming (kg CO_2 eq.)
ReCiPe 2016 Midpoint (H)

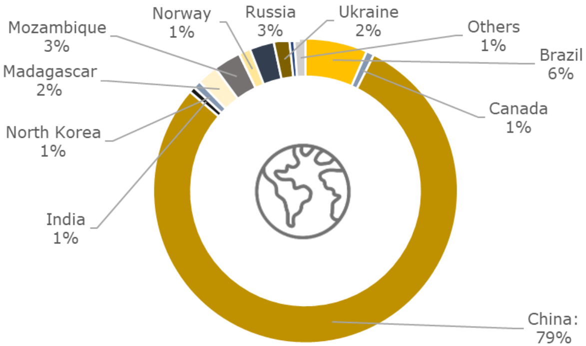


Supply chain | Battery-grade natural graphite

Natural graphite

Extraction and processing

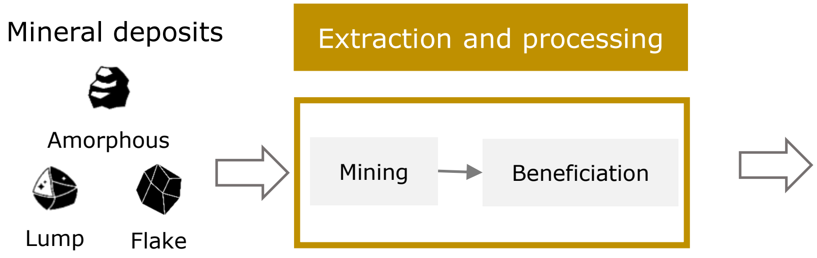
Mining → Beneficiation



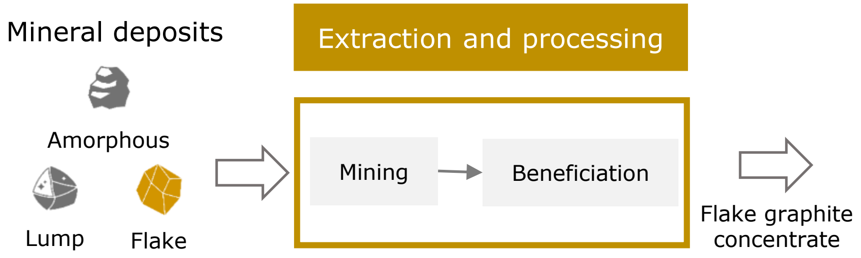
Natural graphite | Global production (2020)

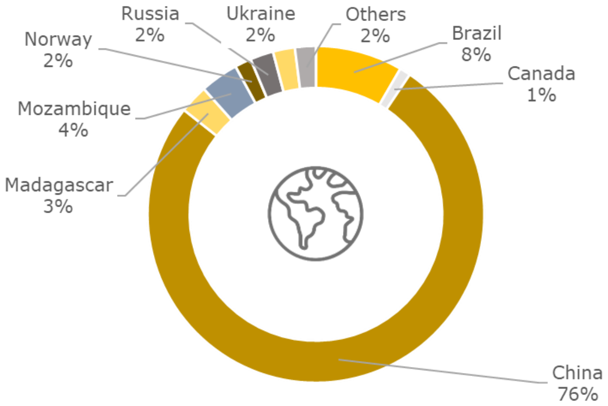
USGS. (2020). Mineral Commodity: natural graphite

Supply chain | Battery-grade natural graphite



Supply chain | Battery-grade natural graphite





Flake graphite | Global production (2020)

USGS. (2020). Mineral Commodity: natural graphite

Supply chain | Battery-grade natural graphite

Mineral deposits

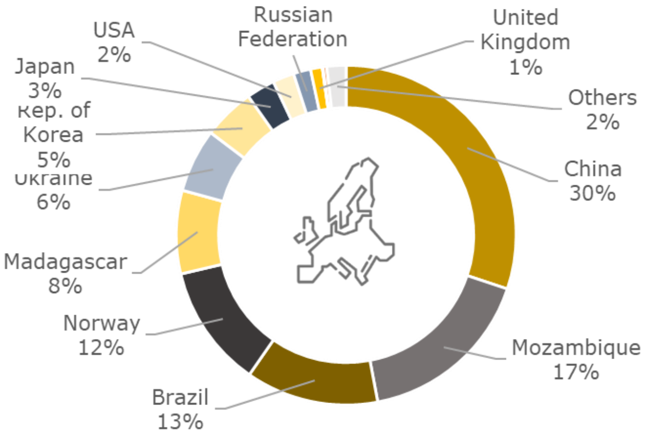
Amorphous

Lump   Flake

Extraction and processing

Mining → Beneficiation

Flake graphite concentrate

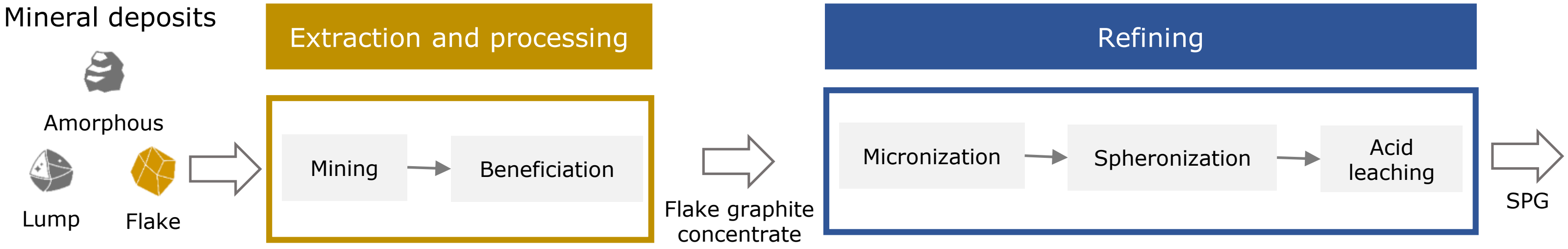


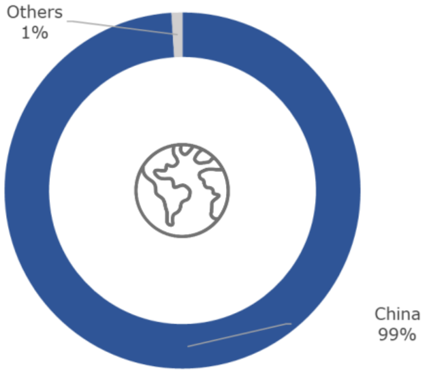
European imports for natural graphite in flakes or powder (2020)

UN Comtrade Database. (2020). 250410 | Graphite; natural in powder or in flakes. https://comtrade.un.org/data

Supply chain | Battery-grade natural graphite

SPG | Spherical purified graphite

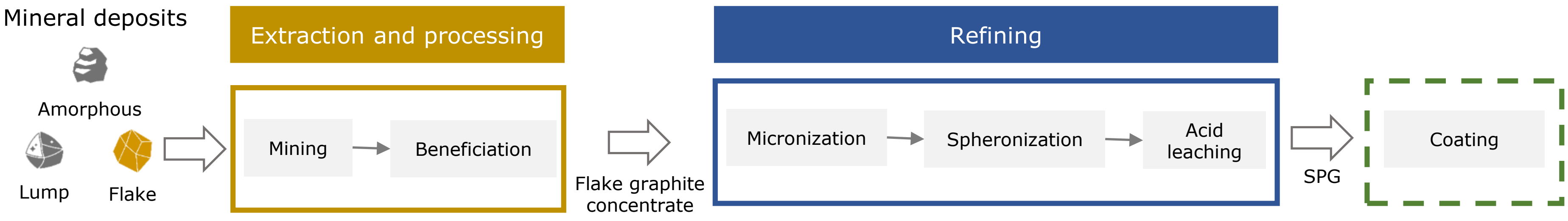




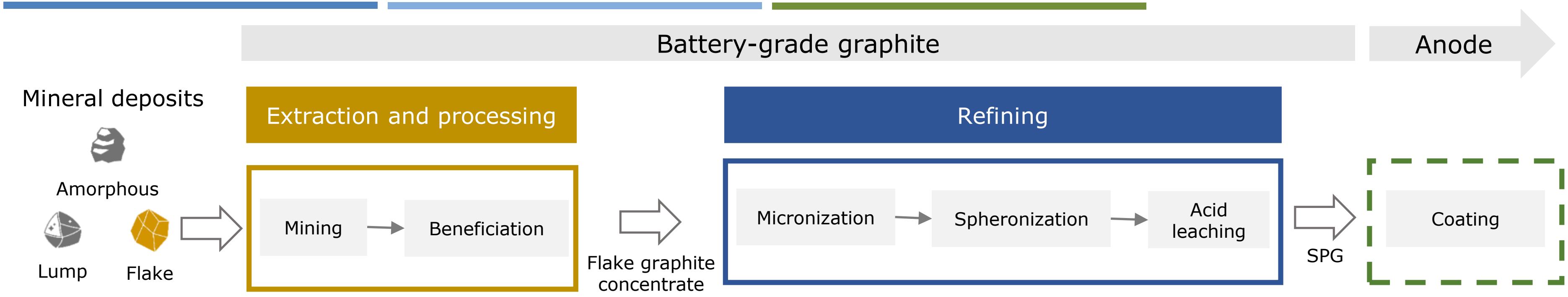
SPG | Global production (2020)

Mitchell, C., & Deady, E. (2021). Graphite resources, and their potential to support battery supply chains, in Africa.

Supply chain | Battery-grade natural graphite



Supply chain | Battery-grade natural graphite



Supply chain | Battery-grade synthetic graphite

Oil

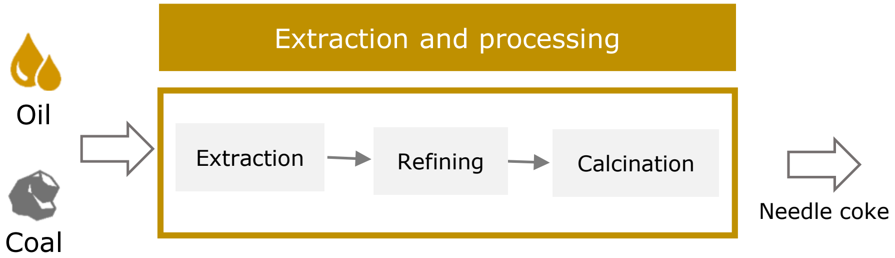
Coal

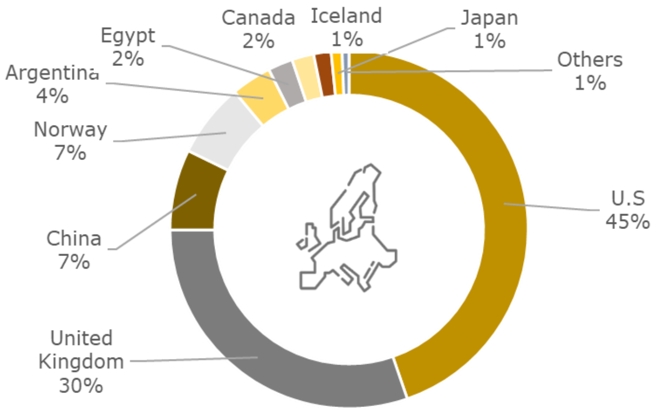
Supply chain | Battery-grade synthetic graphite

Oil

Coal

Supply chain | Battery-grade synthetic graphite

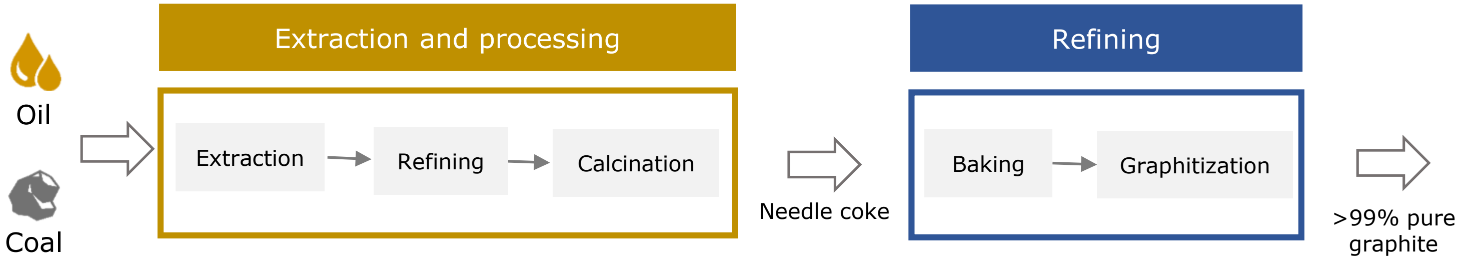


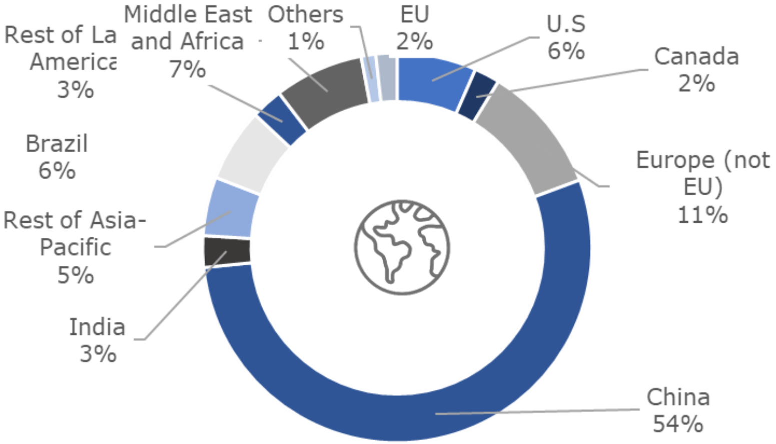


European imports for calcinated petroleum coke (2020)

UN Comtrade Database. (2020). 271312 | Petroleum coke; calcinated, obtained from bituminous minerals https://comtrade.un.org/data

Supply chain | Battery-grade synthetic graphite

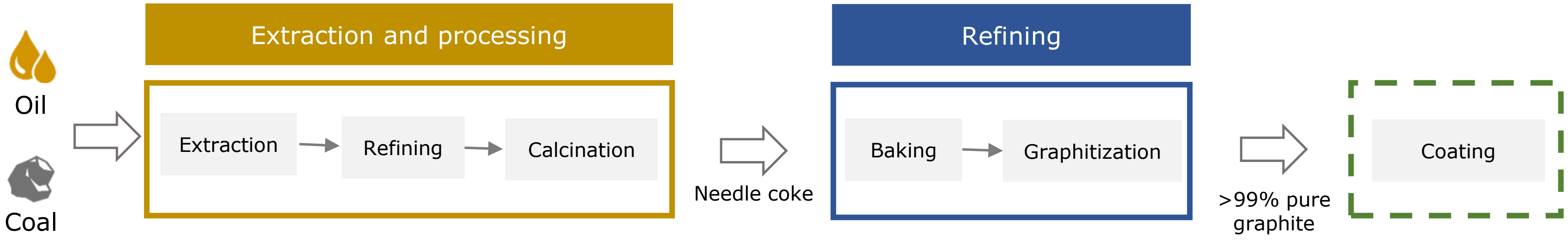




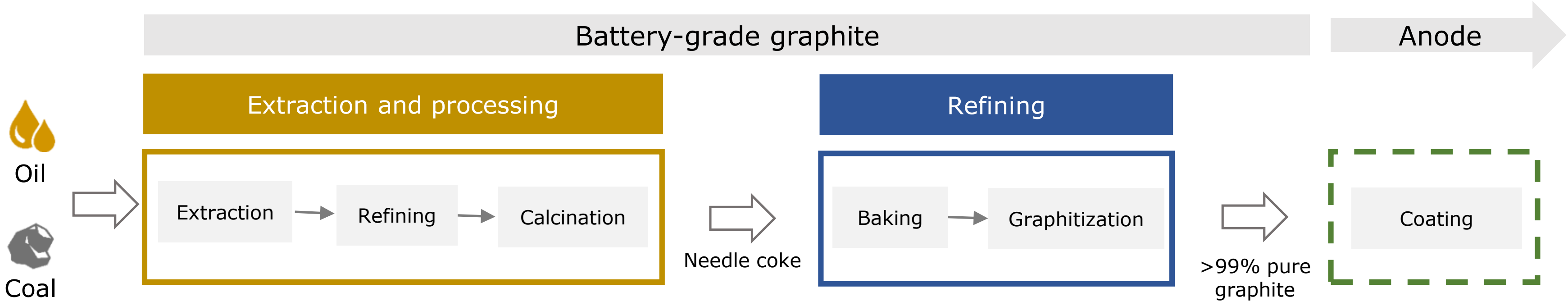
Battery-grade synthetic graphite | Global production (2020)

Verified market research report.

Supply chain | Battery-grade synthetic graphite

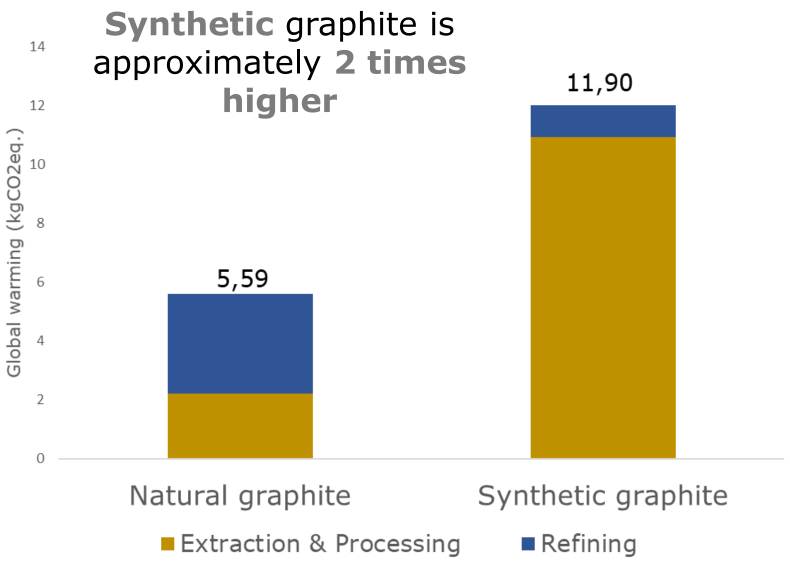


Supply chain | Battery-grade synthetic graphite

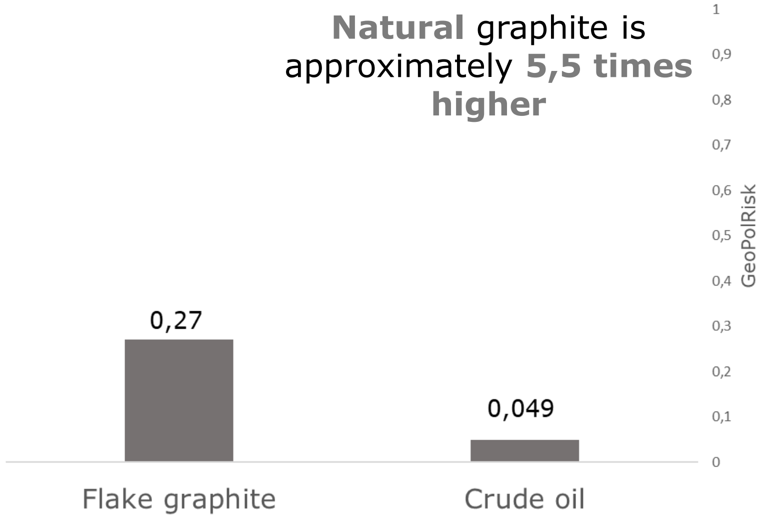


Trade-offs

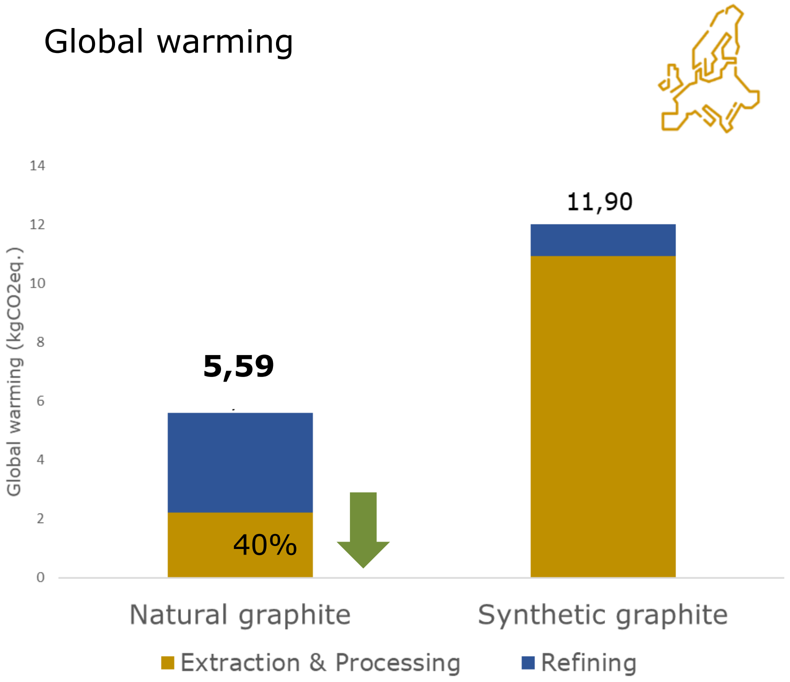
Global warming

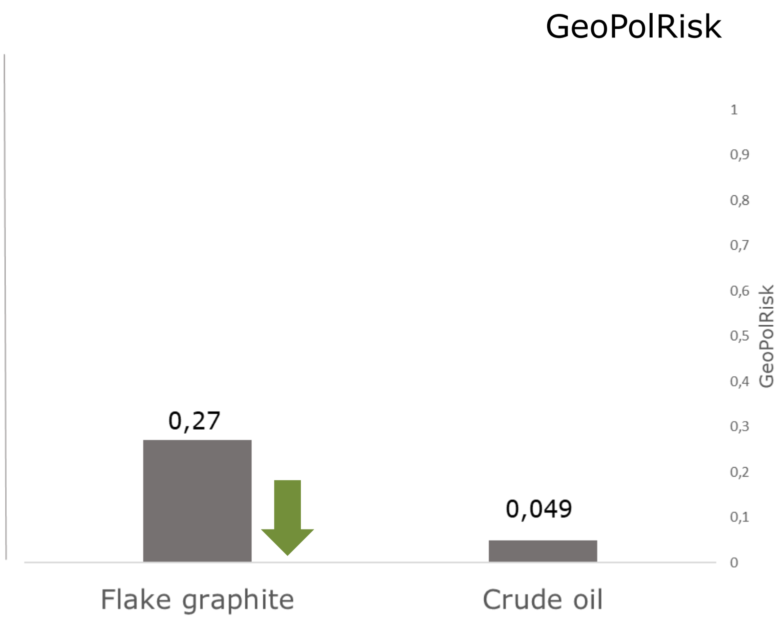


GeoPolRisk

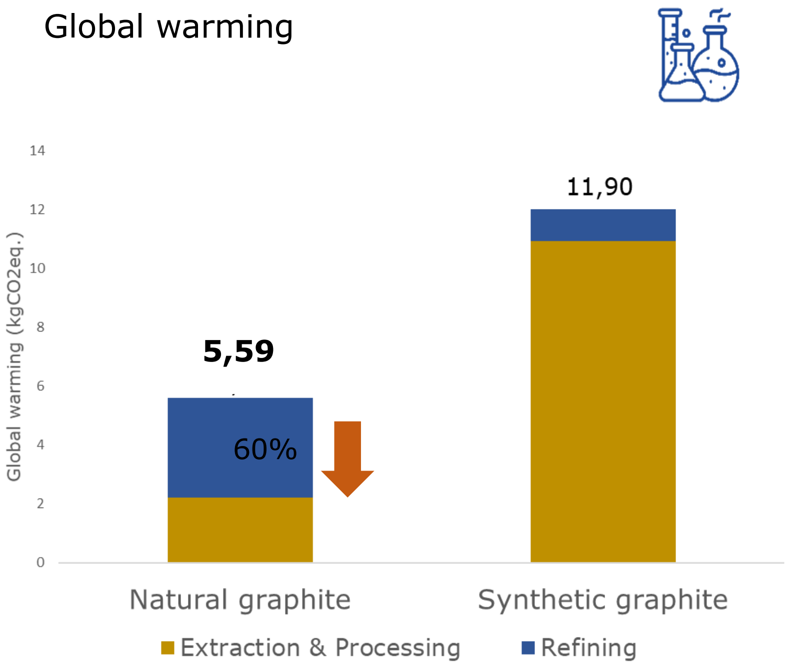


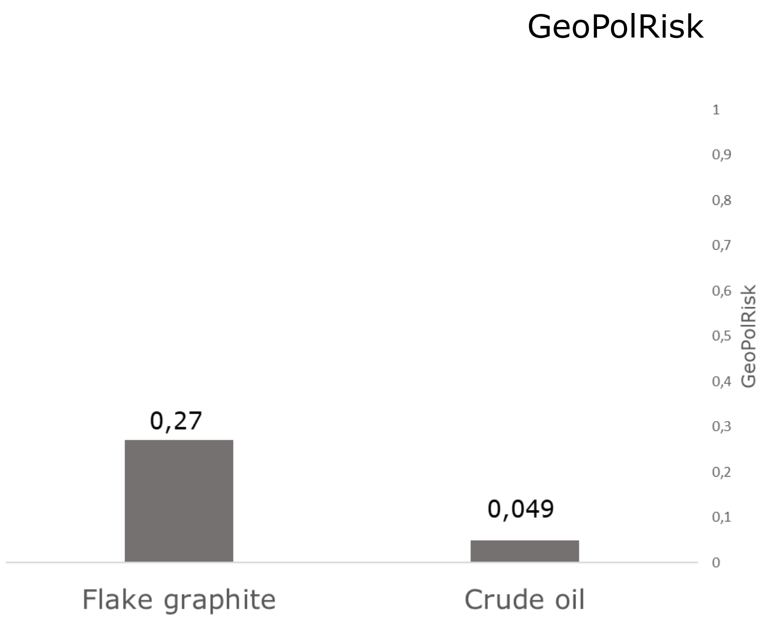
Trade-offs


Global warming
14
12
10
8
6
4
2
0
Global warming (kgCO2eq.)
5,59
40%
11,90
Natural graphite
Synthetic graphite
Extraction & Processing
Refining


GeoPolRisk
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
GeoPolRisk
0,27
0,049
Flake graphite
Crude oil

Trade-offs

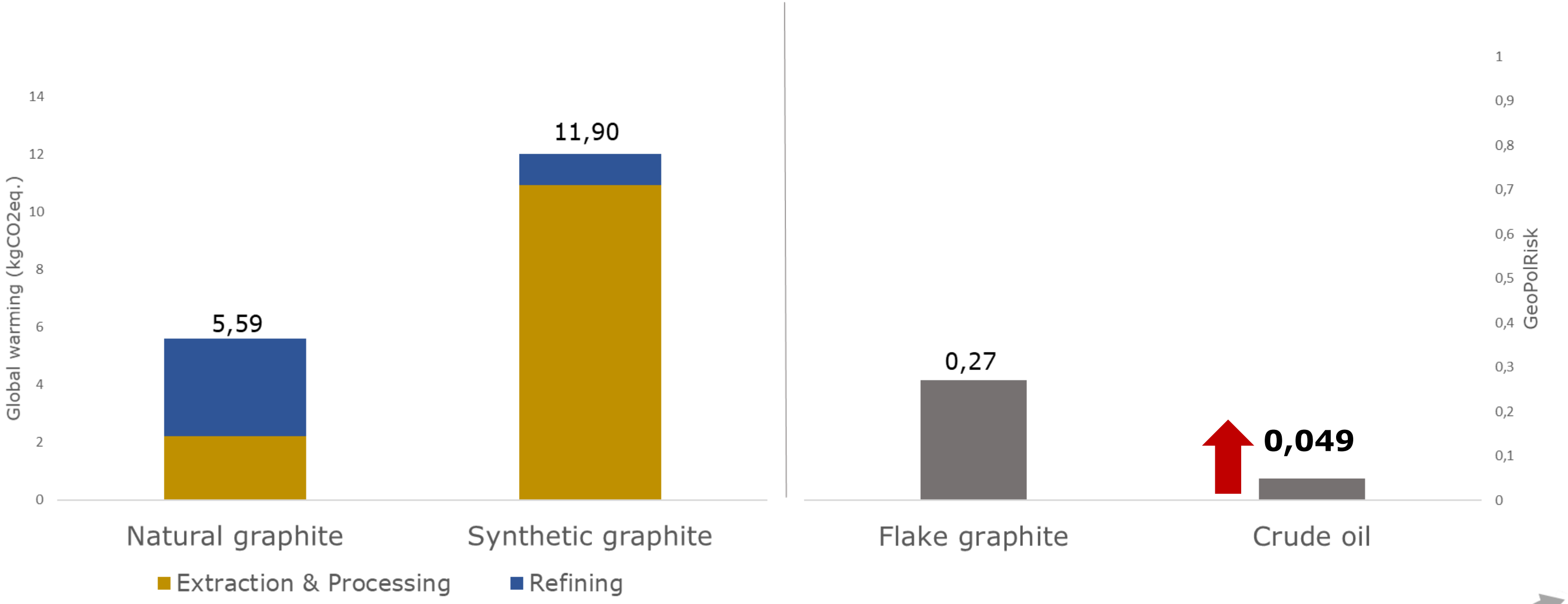

Global warming
Global warming (kgCO2eq.)
0
2
4
6
8
10
12
14
5,59
60%
11,90
Natural graphite
Synthetic graphite
Extraction & Processing
Refining


GeoPolRisk
0,27
0,049
Flake graphite
Crude oil
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
GeoPolRisk

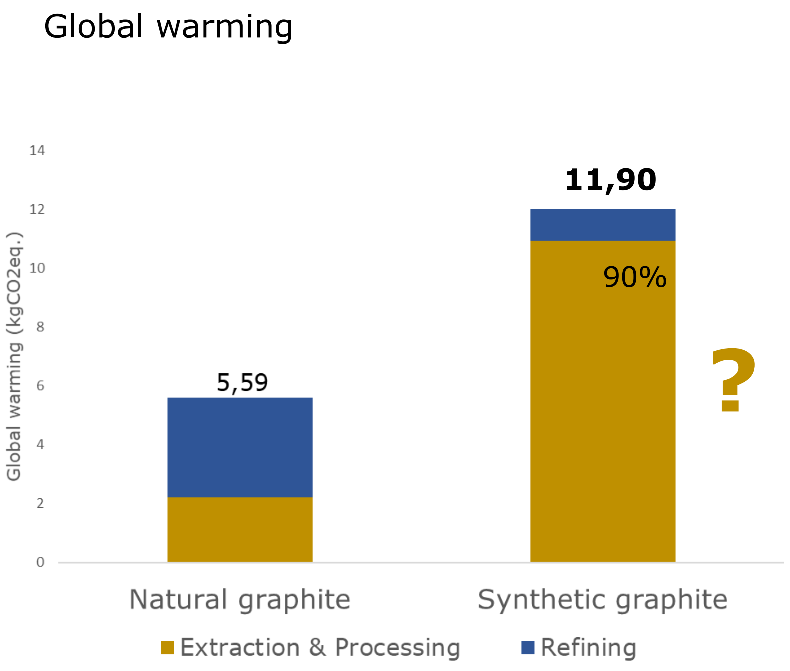
Trade-offs

Global warming

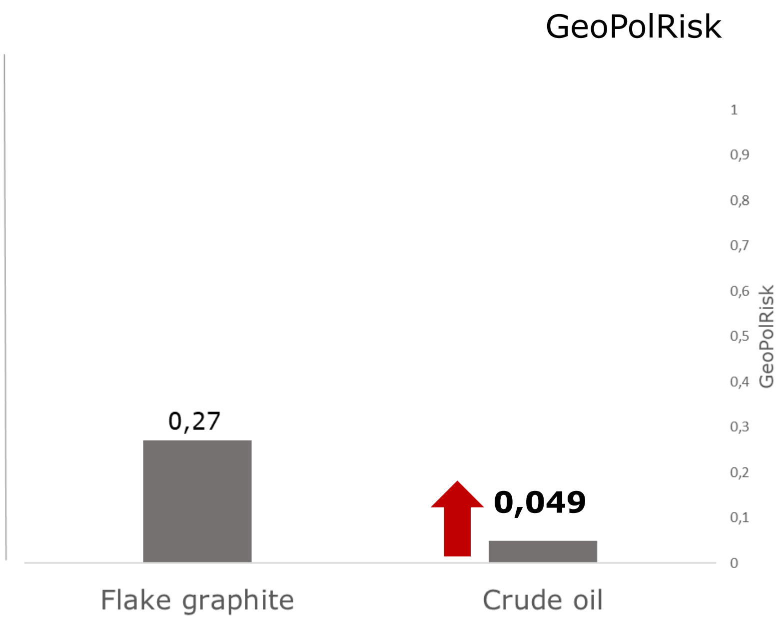
GeoPolRisk



Trade-offs

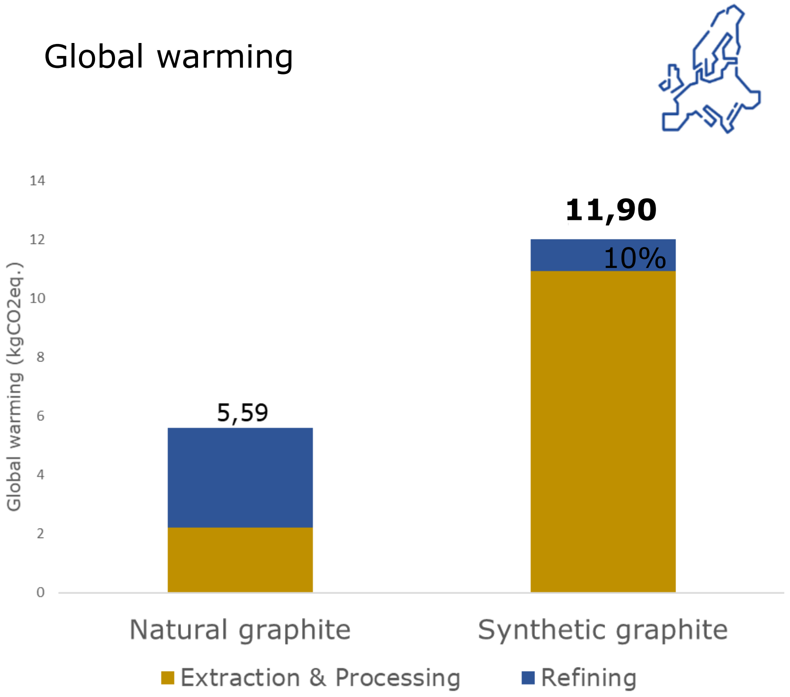


Global warming
Global warming (kgCO2eq.)
0
2
4
6
8
10
12
14
5,59
11,90
90%
?
Natural graphite
Synthetic graphite
Extraction & Processing
Refining



GeoPolRisk
0,27
0,049
Flake graphite
Crude oil
GeoPolRisk
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1

Trade-offs



Global warming
Global warming (kgCO2eq.)
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10%
Natural graphite
Synthetic graphite
Extraction & Processing
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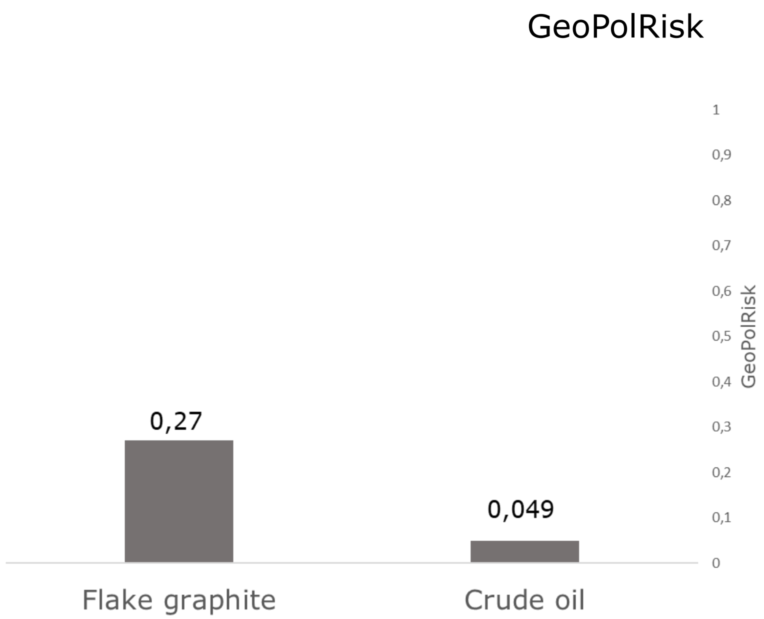


GeoPolRisk
GeoPolRisk
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0,27
0,049
Flake graphite
Crude oil

Conclusions

- The decarbonization of the mobility sector is around the corner | Increasing demand for battery-grade graphite
- Climate emergency | Argument to promote the production of natural graphite
- Effect on the supply of certain raw materials | Increasing supply risk for oil
- Carbon tunnel vision | Need to include and consider other impact categories
- The direct comparison is limited

Thank you for your attention!

aina.mas-fons@u-bordeaux.fr

CARESTER
Your partner for Rare Earths

CAREMAG
MAGNETS RECYCLING BY CARESTER

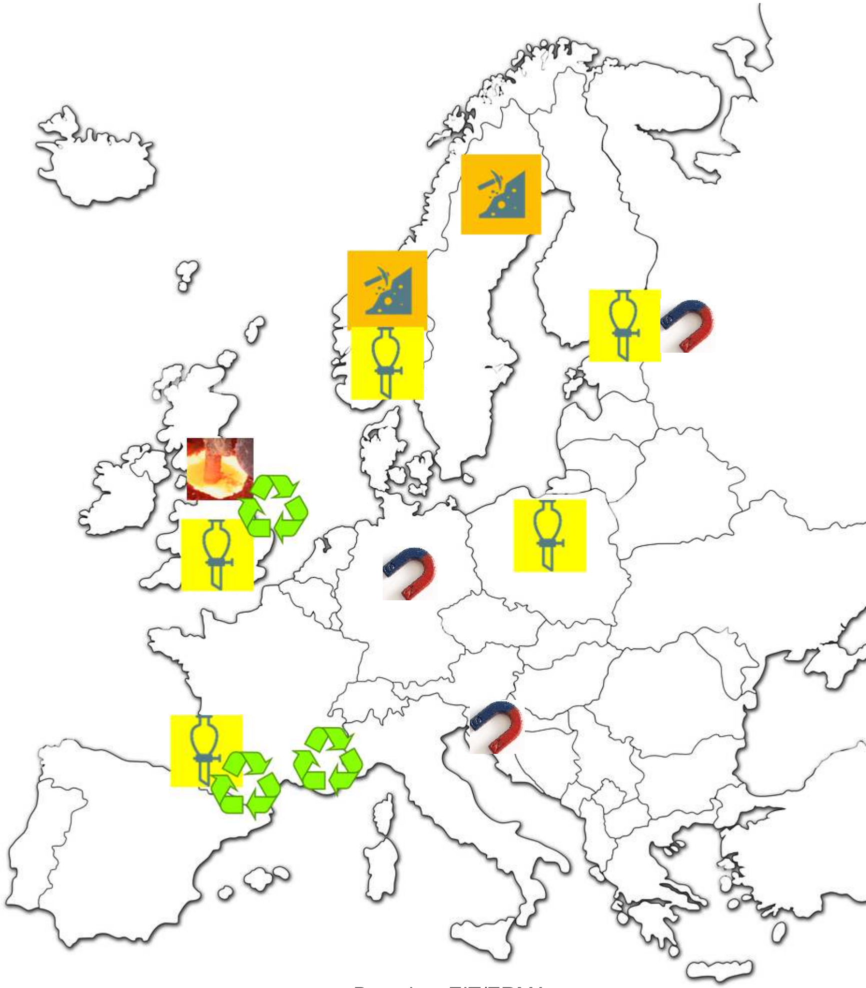
THE REVIVAL OF THE FRENCH RARE EARTH INDUSTRY

IRTC 2023 Lille 02/15-02/16 2023

Alain ROLLAT

SEVERAL INDUSTRIAL UNITS ARE UNDER DEVELOPMENT IN EUROPE ALONG THE RE VALUE CHAIN

- **Mining:** Sweden, Norway
- **Separation:** UK, Norway, Poland, Estonia, France
- **Metal making:** UK (debottlenecking)
- **Magnets making:** Estonia, Germany (debottlenecking), Slovenia (debolltlenecking)
- **Recycling from End of Life Magnets:** France, UK



Based on EIT/ERMA source

CARESTER

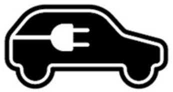
CAREMAG IS A KEY PART OF THE RE EUROPEAN INDUSTRY REVIVAL

Based on EIT/ERMA source

A new company, Caremag, dedicated to magnets recycling has been created in November 2020

RE Mine → Hydromet Plant → PURE REO → Metalworking company → Magnet manufacturer → Final use Equipment for energy tran=ition → END LIFE → Desmantling company → LOST MAGNETS



Permanent magnets contain 30% to 34% of Rare Earths

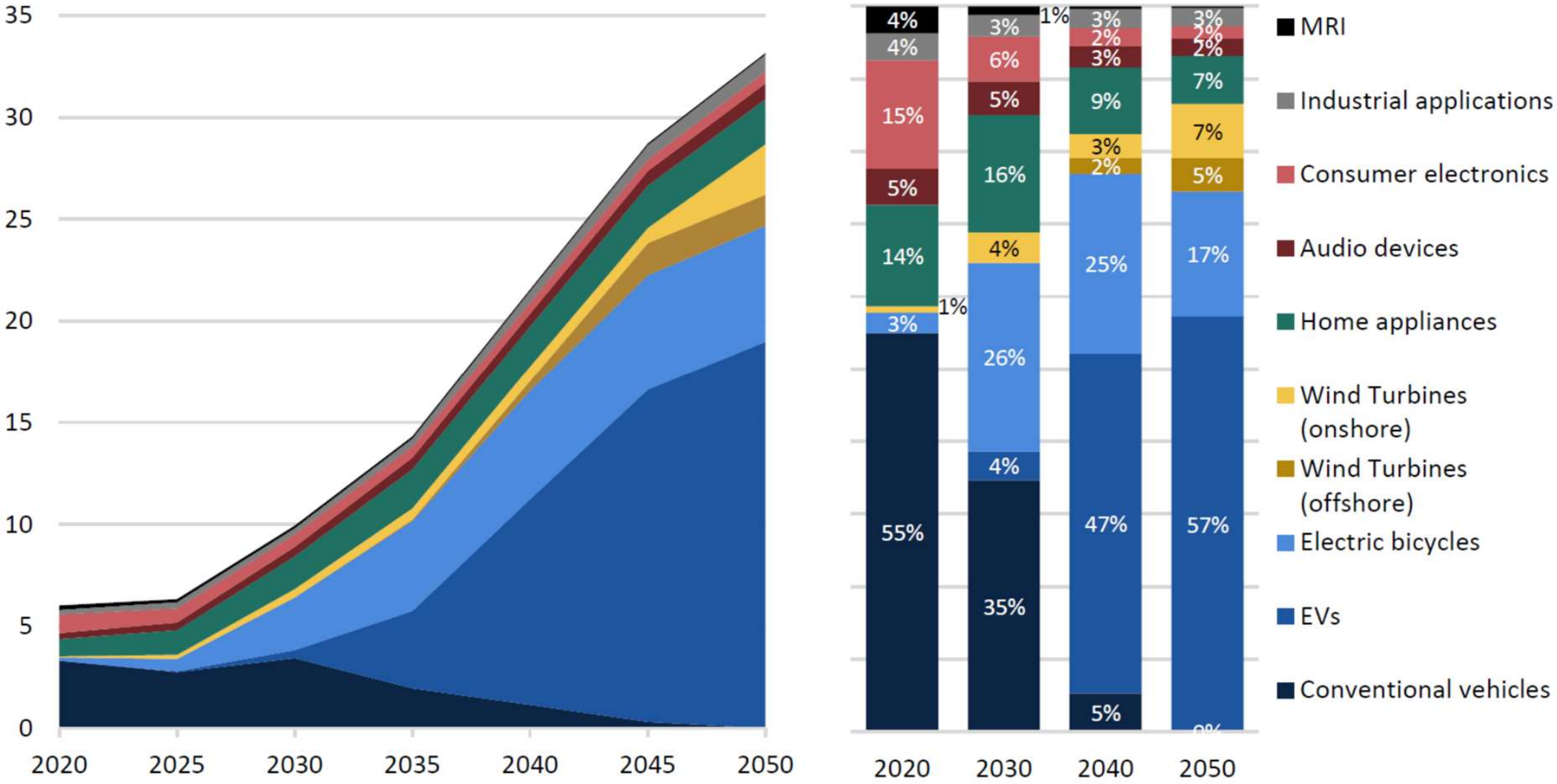
Urban Mining

CAREMAG

RECYCLAGE DES AIMANTS PAR CARESTER

CAREMAG: RECYCLED RARE EARTHS ARE ACCESSIBLE FROM NOW

EoL NdFeB magnet recycling potential in the EU from selected applications (KT)



Size of the deposit

Source: CEPS In depth analysis, December 2022

- **5000t of EoL magnets are accessible from now. Our target is to capture 20% of that.**
- **It will reach 25000t in 2045 (#9000t REO) mainly due to the EVs growth**

➢ **Caremag is already buying end of Life Magnets**

CAREMAG : AN INNOVATIVE PYRO-HYDROMETALLURGICAL PROCESS WITH PATENTS FILLING IN PROGRESS

Capacity: 1000t/y of EoL + 1000t/y of scraps

Milled NdFeB magnets

Thermal treatment

Targets :
- Improve Fe removal
- Limit the energy consumption
- Facilitate the gas treatment

Patent filled

Oxidized magnets

Nitric acid dissolution and filtration

Targets :
- Limit the acid consumption
- Improve the RE+B/Fe selectivity

Fe oxi-hydroxide residue

✓ **Possible valorization for water treatment**

Nitrate solution

Boron purification by Solvent Extraction

Targets :
- Obtain a commercial Borax product
- Get a RE solution with B< 10ppm

2 Patents filled

RE nitrate solution
REO = 700 T/Y
→ To RE SX

Borax
B = 20 T/Y
→ To Market

CAREMAG IS A KEY PART OF THE RE EUROPEAN INDUSTRY REVIVAL

Based on EIT/ERMA source

TOWARDS A HEAVY RARE EARTHS SEPARATION HUB

- ✓ All the market studies show the necessity of opening new RE mines.
- ✓ Most of the current RE mining projects are based on deposits containing mainly Light Rare Earths (LRE) minerals with low Heavy Rare Earths (HRE) content.
- ✓ These projects include a LRE separation unit focused on Pr and Nd purification while the HRE are usually not separated and produced as a concentrate. The reason for such a choice is economic. For most of these companies a HRE separation unit would lead to a long pay-back due to the low HRE content of their deposit.
- ✓ In the end, all these HRE concentrates will be sold as a mixed HRE to the companies having a HRE separation unit and currently only Chinese companies have these capacities

- ✓ The consequence of this situation is paradoxical. At the same time when the western companies develop their independency from China for the Pr and Nd supply, they reinforce their dependency on China for Tb and Dy supply.

Carester intends to propose to these companies a HRE Hub able to treat their HRE concentrate and give them back the pure rare earths they need, in particular Tb and Dy.

A HRE HUB SUITABLE FOR ANY TYPE OF HRE COMPOSITIONS

2 types of HRE concentrates with very different REE distributions

- **HRE concentrate from LRE minerals: Monazite & Bastnasite**

In Monazite and Bastnasite minerals SEG (Sm, Eu, Gd) represent more than 80% of the HRE

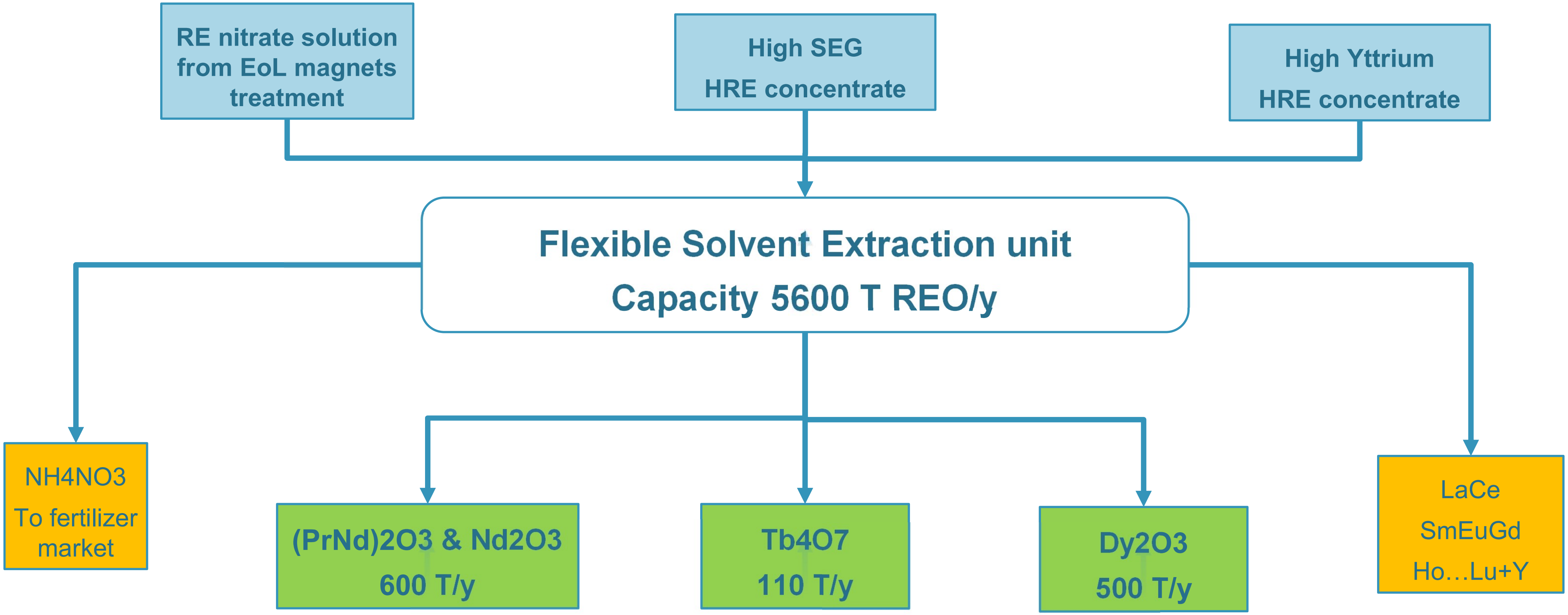
- **HRE concentrate from HRE minerals: Xenotime & Ionic Clays**

In Xenotime and Ionic clays minerals Yttrium alone represents more than 60% of the HRE

We need to design a process able to deal with these 2 types of RE composition

	Typical LRE deposits		Typical HRE deposits	
Country	USA	Australia	Brazil	Australia
Company	MCP	Lynas	Serra Verde	Northern Minerals
Deposit	Mountain Pass	Mount Weld Central zone	Pela Ema	Browns range
Bearing mineral	Bastnasite	Monazite	Ionic ore	Xenotime
	%/HREO	%/HREO	%/HREO	%/HREO
Sm2O3 / Eu2O3 / Gd2O3	**90.8%**	**86.1%**	17.7%	9.6%
Tb4O7 / Dy2O3	3.4%	5.4%	9.0%	11.2%
Ho2O3 / Er2O3 / Tm2O3 / Yb2O3 / Lu2O3	0.6%	0.4%	11.4%	14.5%
Y2O3	5.2%	8.0%	**62.0%**	**64.6%**

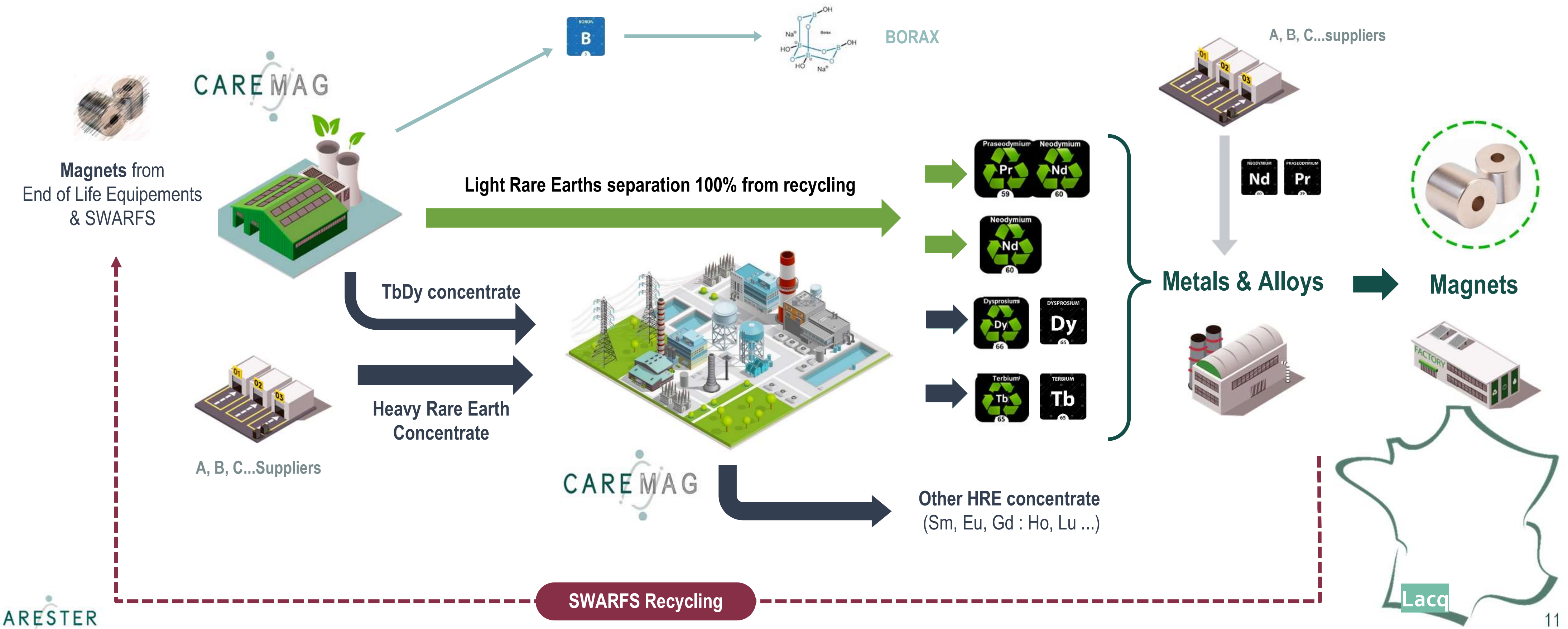
A HRE HUB SUITABLE FOR ANY TYPE OF HRE COMPOSITIONS



- ✓ The flexible separation unit is a Carester proprietary process
- ✓ No waste waters are released, all the liquid effluents are valorized as NH_4NO_3 solution in the fertilizer market.

CAREMAG : A KEY MILESTONE TO BUILD A EUROPEAN ECOSYSTEM, WITH RECOGNISED INDUSTRIAL EXPERIENCE AND EFFICIENT TECHNOLOGIES IN EACH STEP

CAREMAG & THE « MAGNET VLLEY »



CARESTER

« As far as the future is concerned, it is not a matter of foreseeing it, but of making it possible»

Antoine de Saint-Exupéry

CARESTER

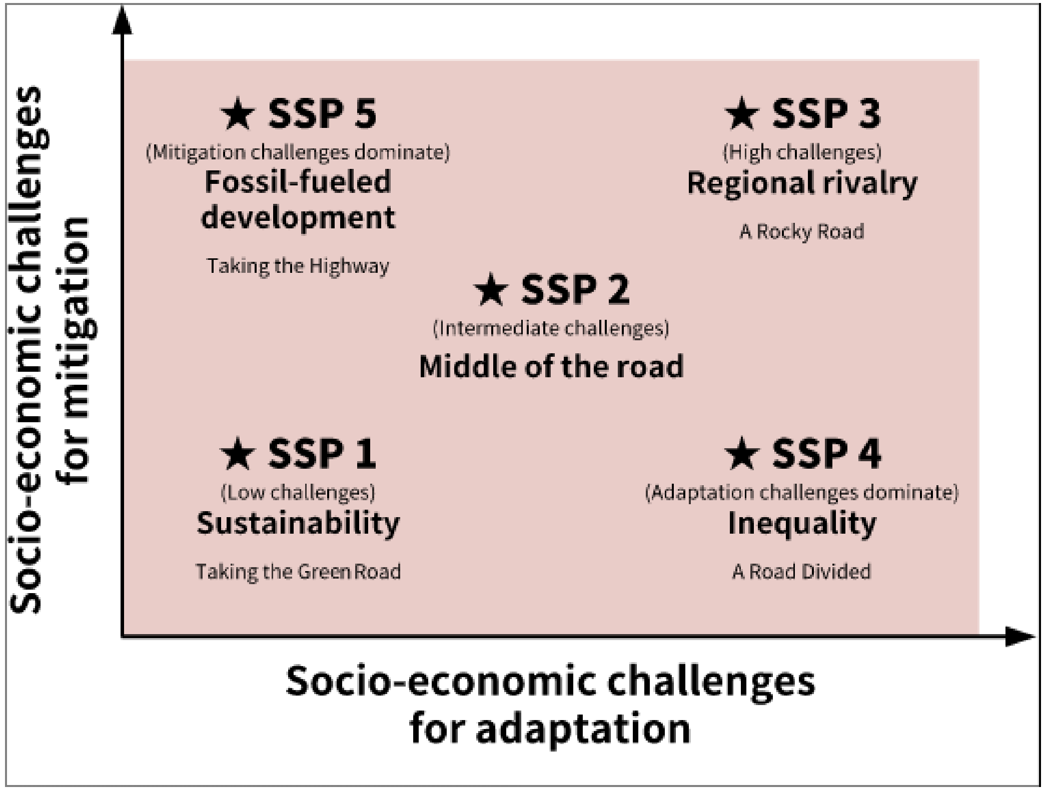
Your partner for Rare Earths

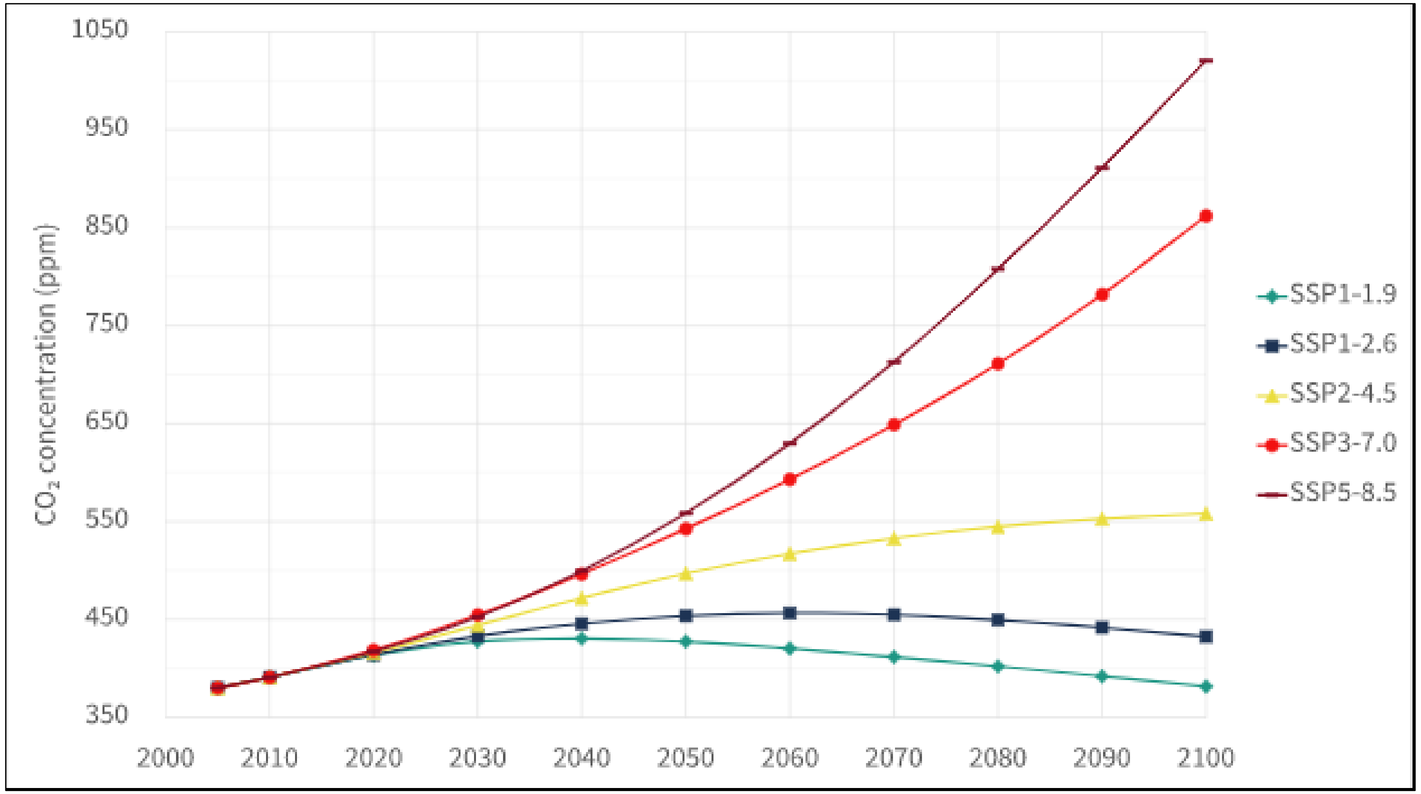
Acting for our children

Developing bottom-up understanding of primary copper supply under the shared socio-economic pathways

Stephen Northey – UTS Institute for Sustainable Futures, Australia
Damien Giurco – UTS Institute for Sustainable Futures, Australia
Stefan Pauliuk – University of Freiburg, Germany
Mohan Yellishetty – Monash University, Australia

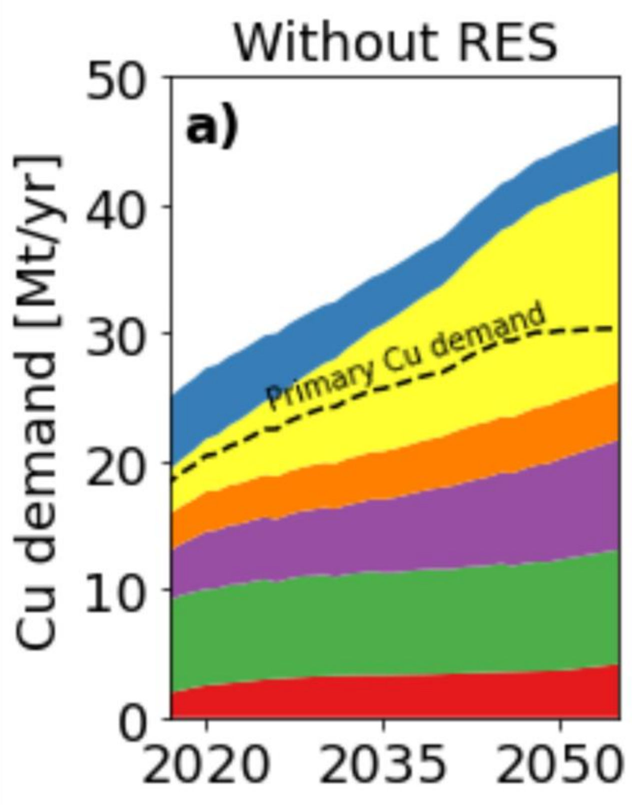
Shared Socio-economic Pathways (SSPs)

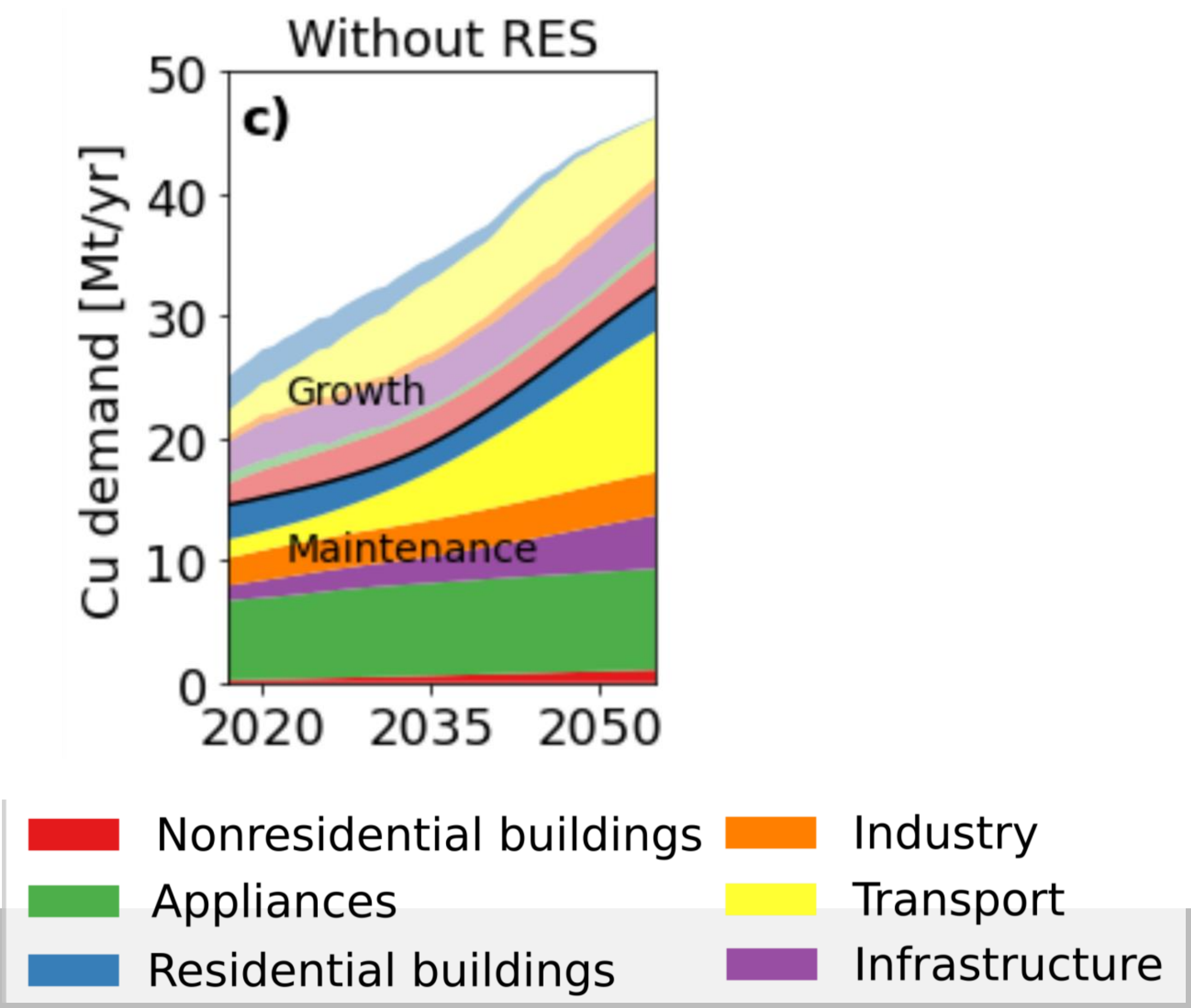




https://tntcat.iiasa.ac.at/SspDb/

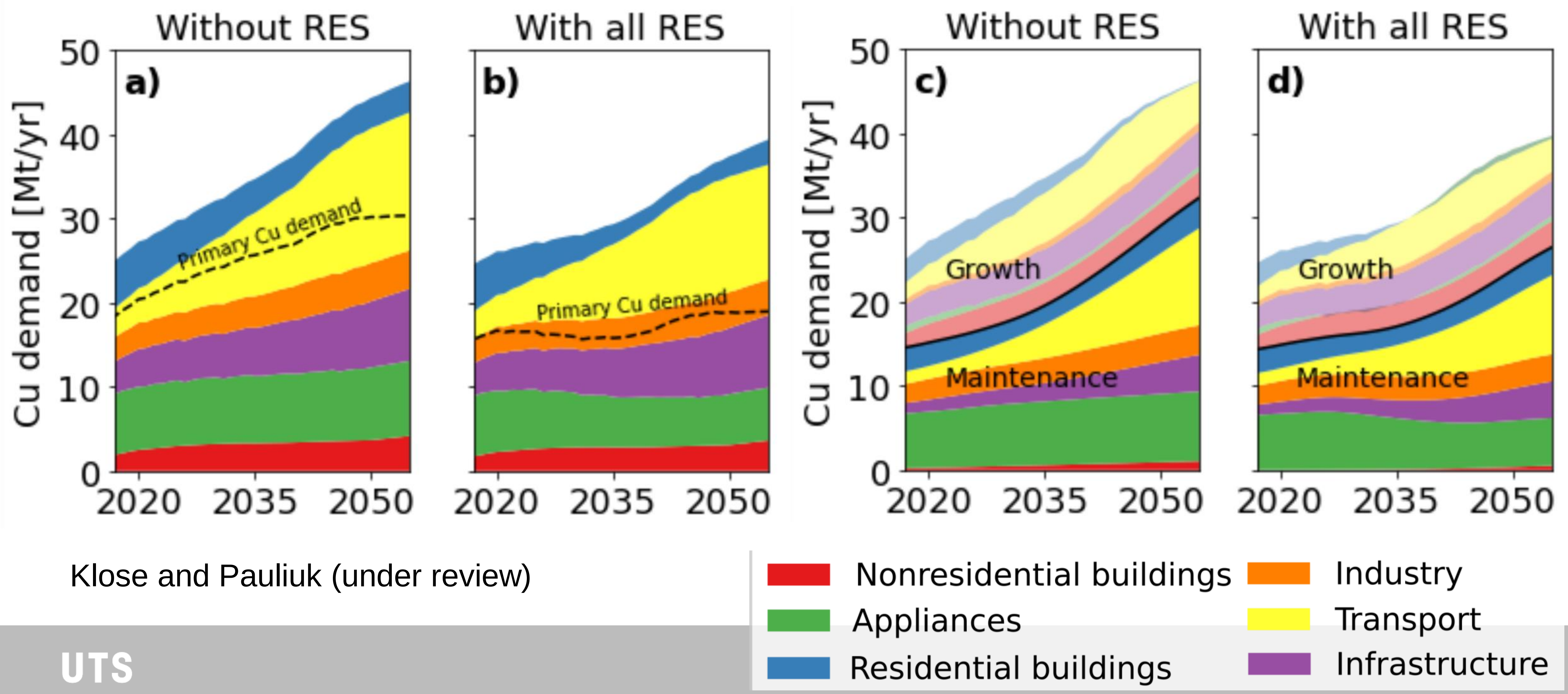
SSP 2.6 - Copper demand is expected to grow rapidly





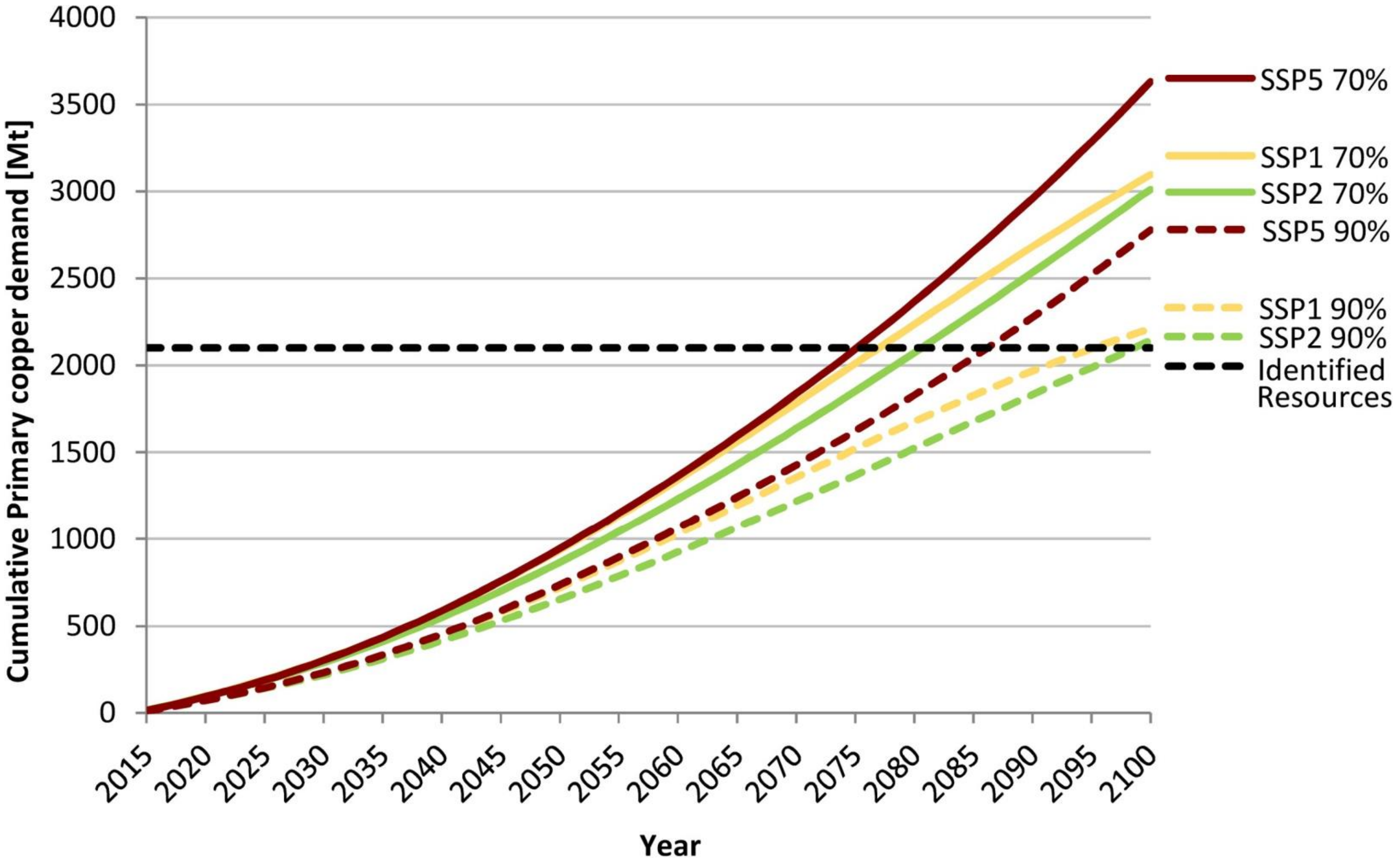
Klose and Pauliuk (under review)

Resource efficiency strategies may reduce demand growth



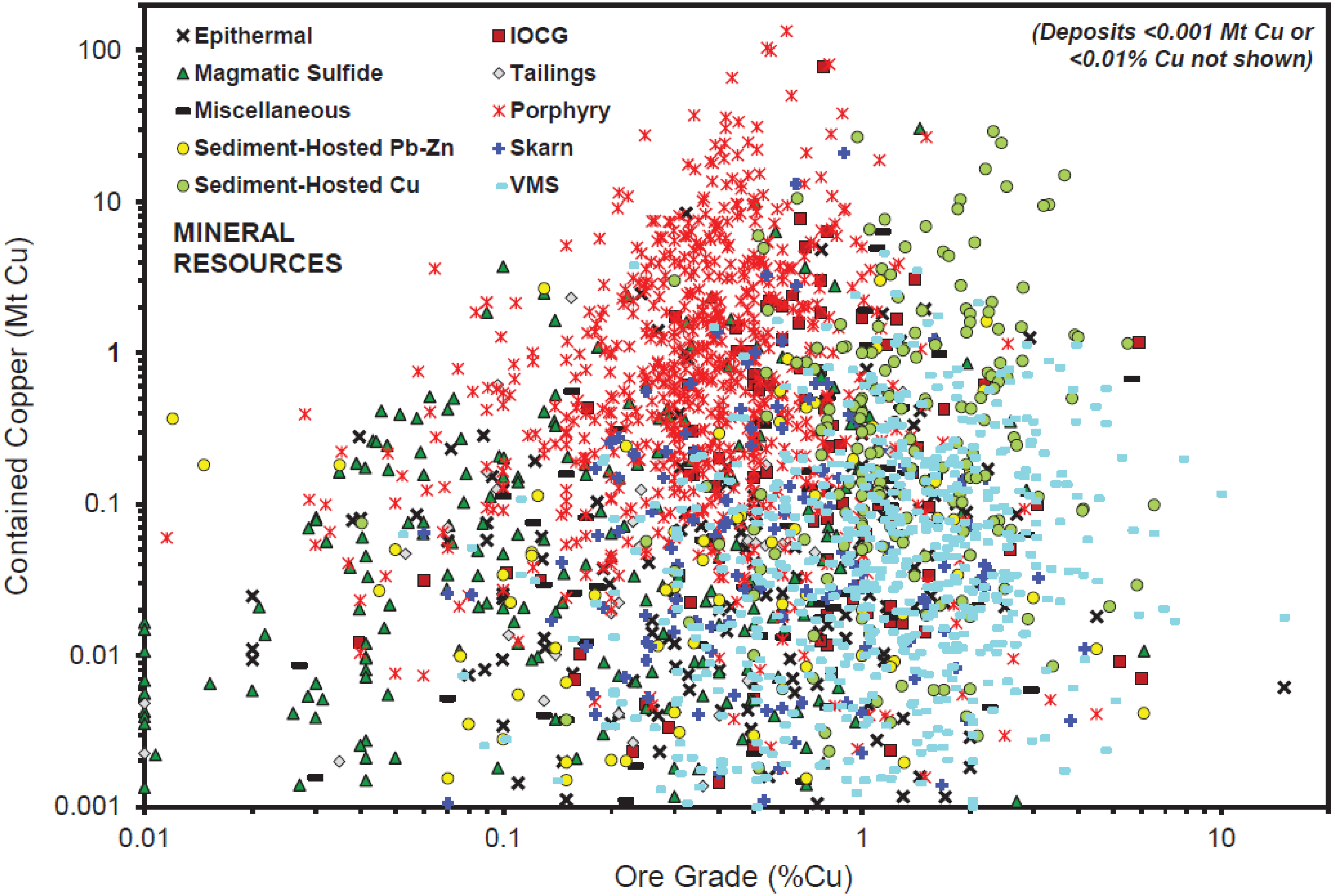
Klose and Pauliuk (under review)

Overtime cumulative primary copper demand will start to exceed identified resources



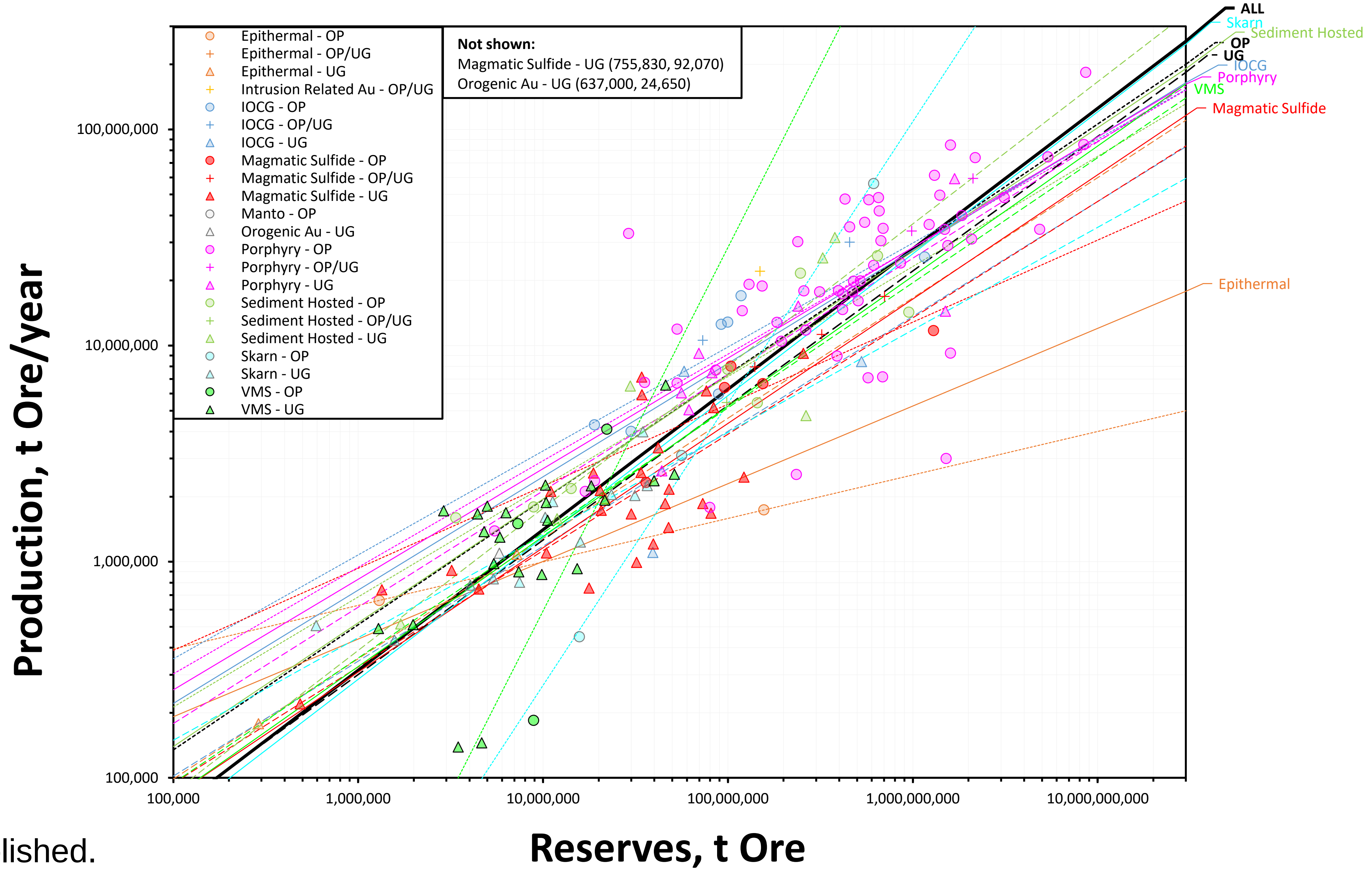
Schipper et al. (2020). Res. Cons. & Rec. 132: 28-36.

Can our annual rate of primary copper increase to meet these demand scenarios ?



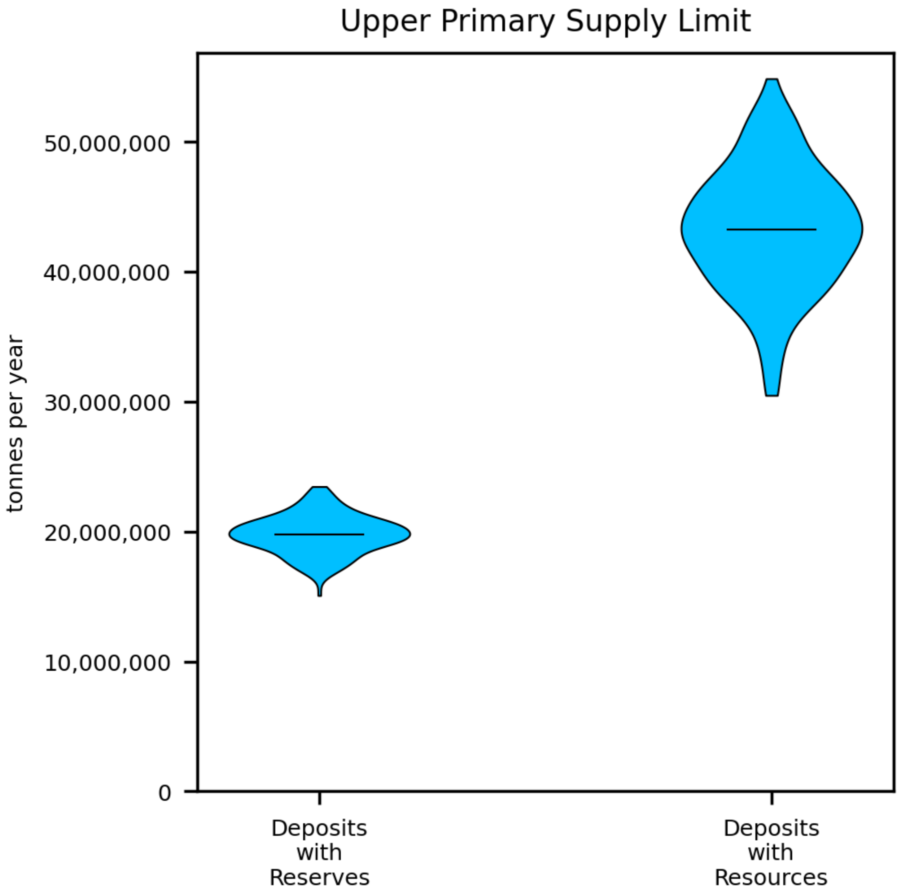
2301 deposits
Known Reserves: ~640 million tonnes
Known Resources: ~3,000 million tonnes

Mudd & Jowitt (2018). Economic Geology 113(6): 1235-1267.



Unpublished.

Mining all known copper deposits simultaneously would only get you so far

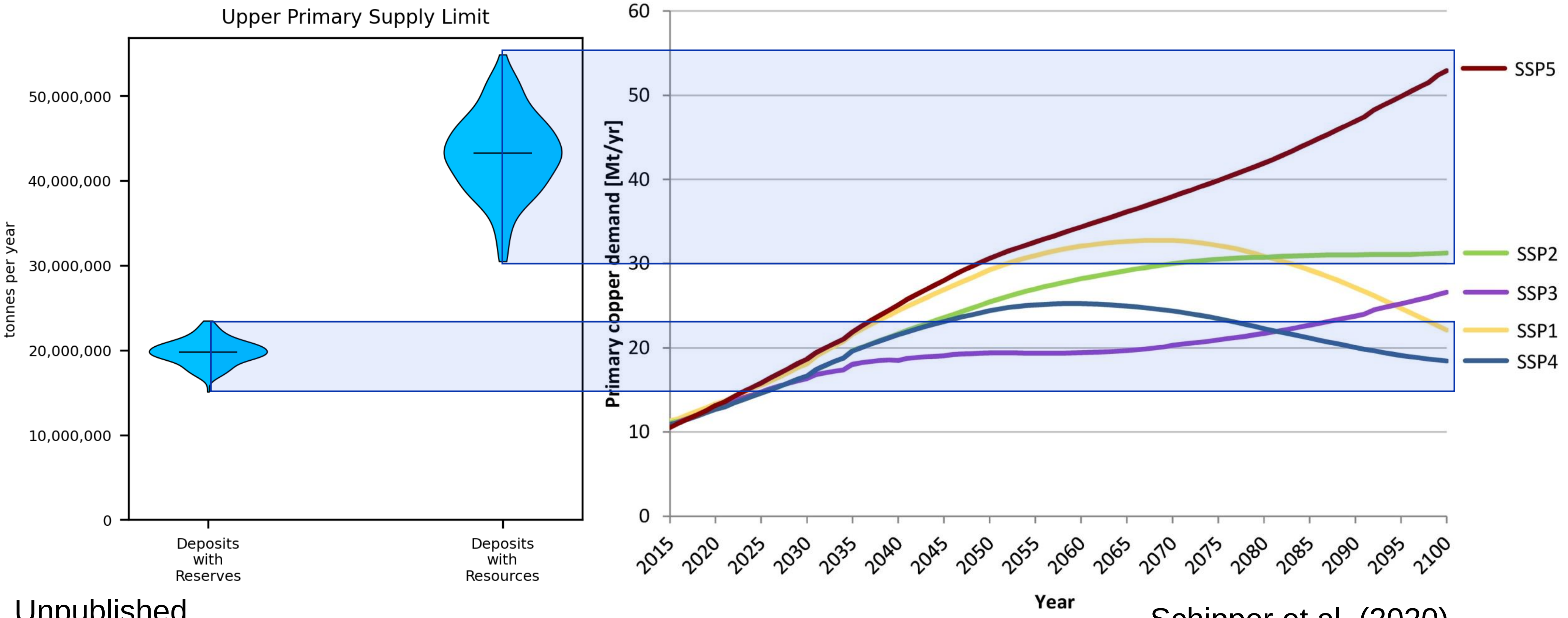


Deposits with Resources ~ 50 million tonnes per year

Deposits with Reserves ~ 24 million tonnes per year

Unpublished.

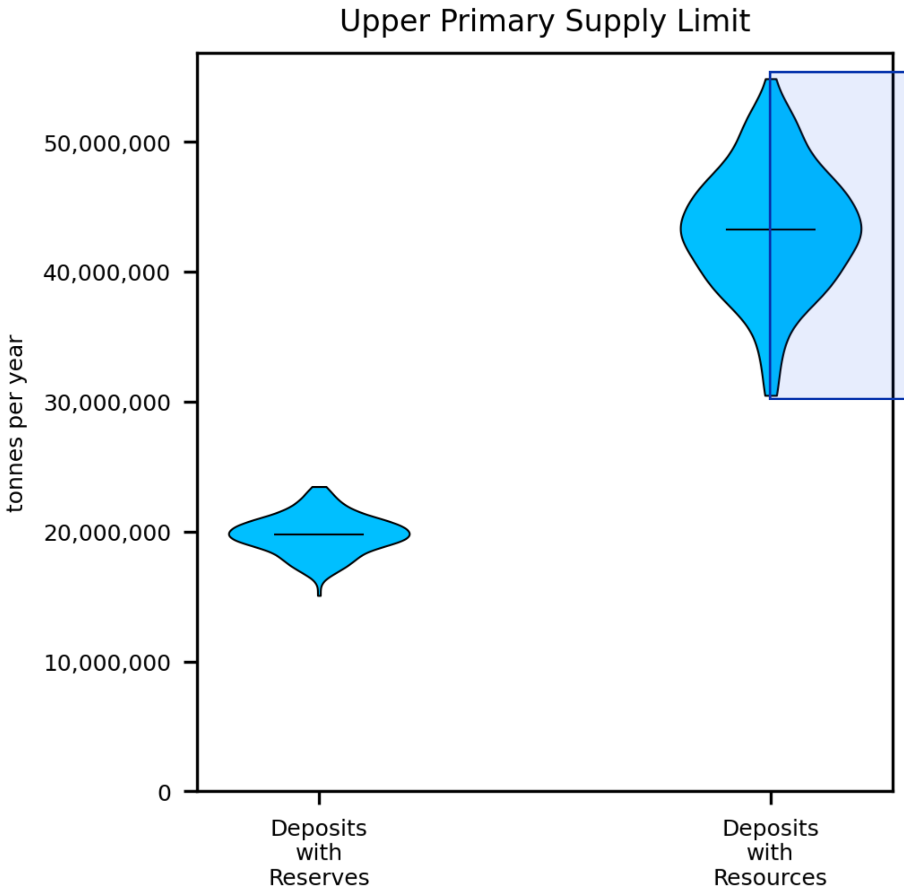
Recycling rates exceeding 90% are required to constrain all SSPs below supply limit of known deposits



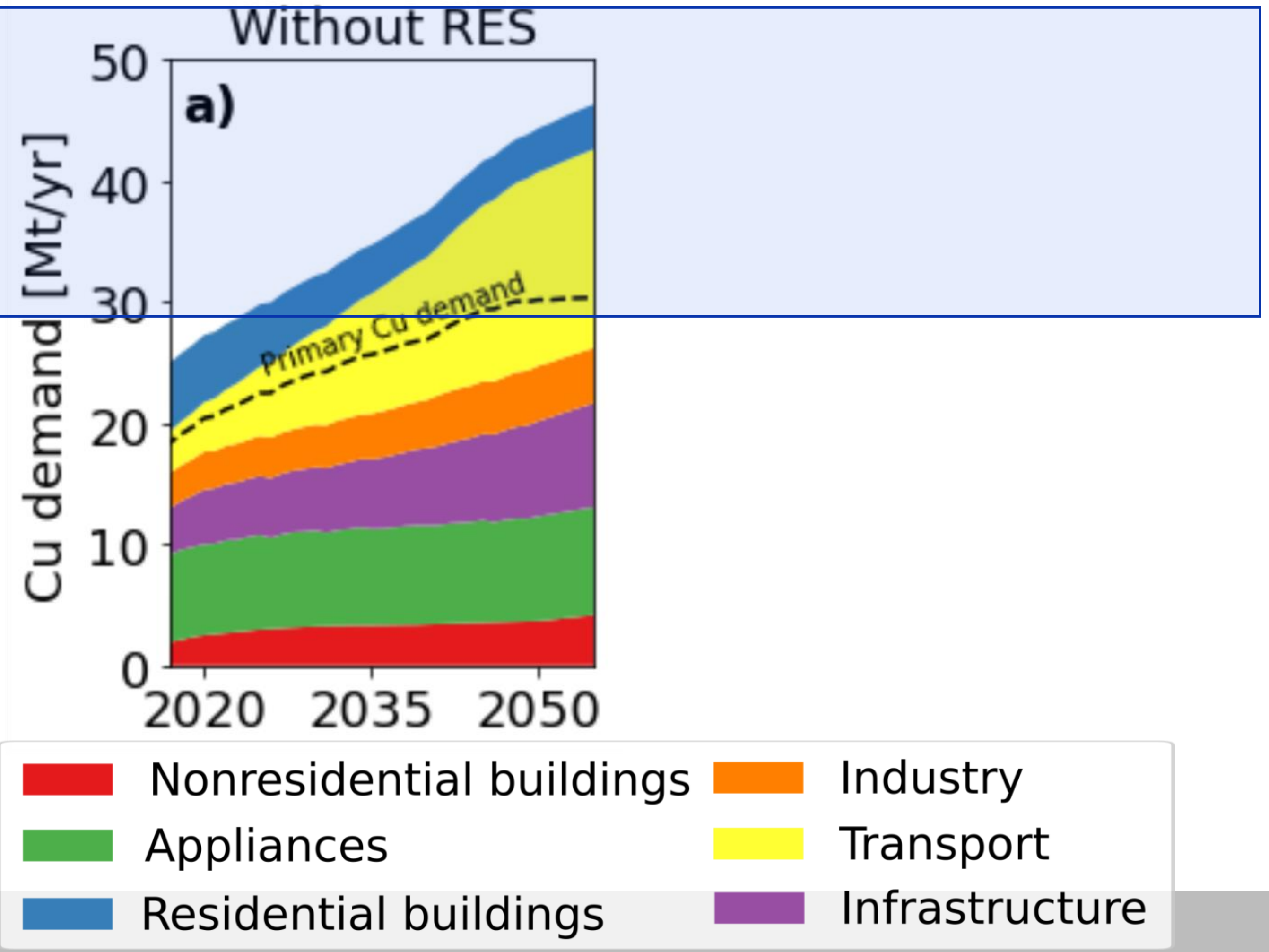
Unpublished.

Schipper et al. (2020)

SSP 2.6



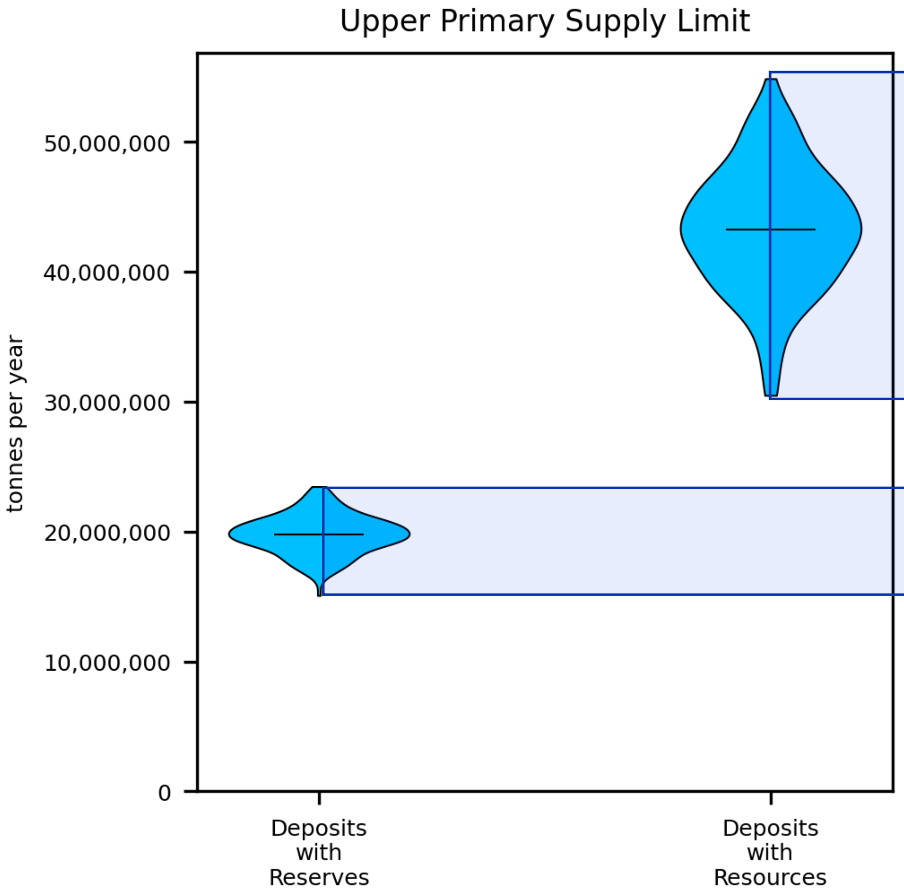
Unpublished.



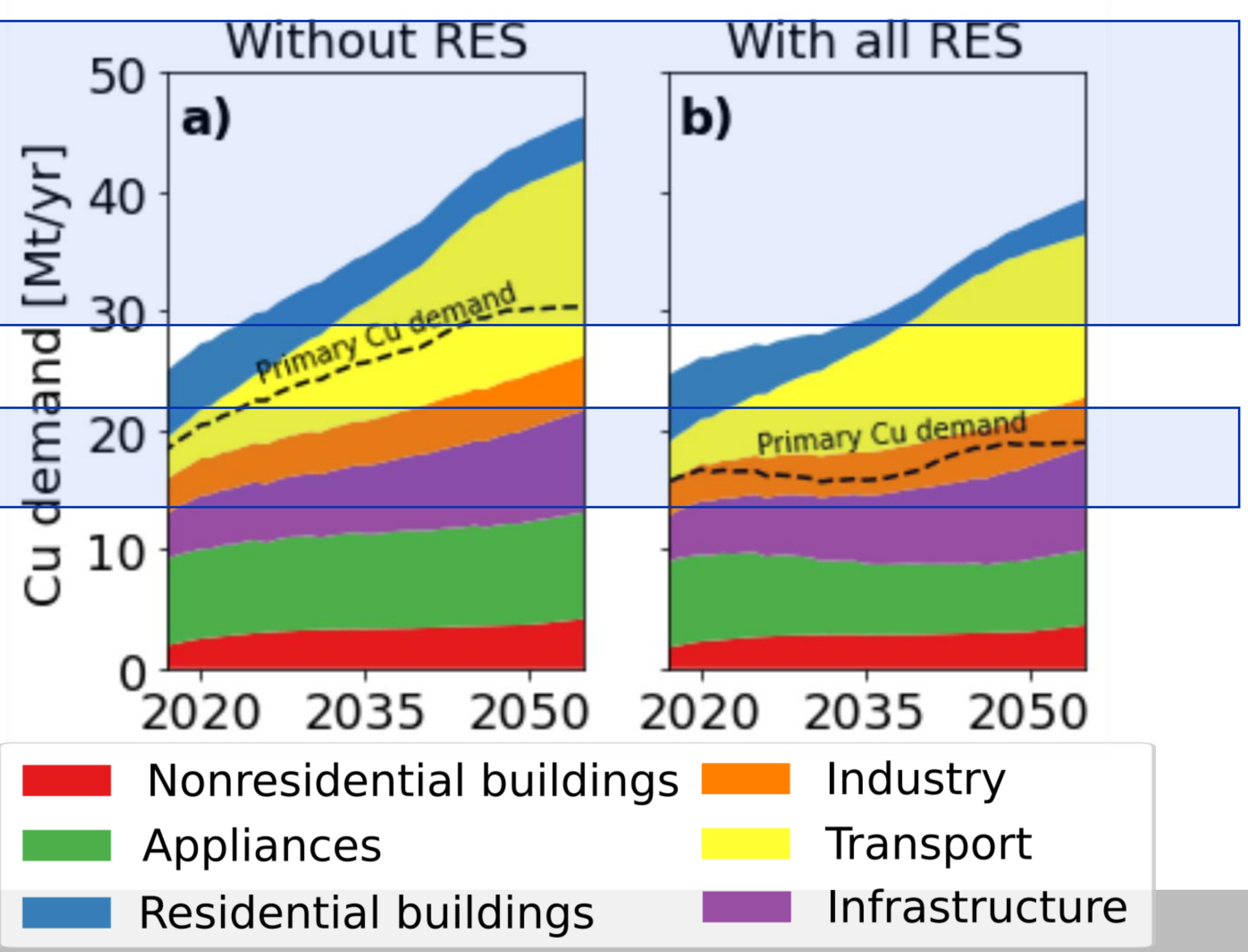
Klose and Pauliuk (Under Review)

Deposits with reserves may be sufficient to meet supply **IF** strong material efficiency strategies are implemented

SSP 2.6

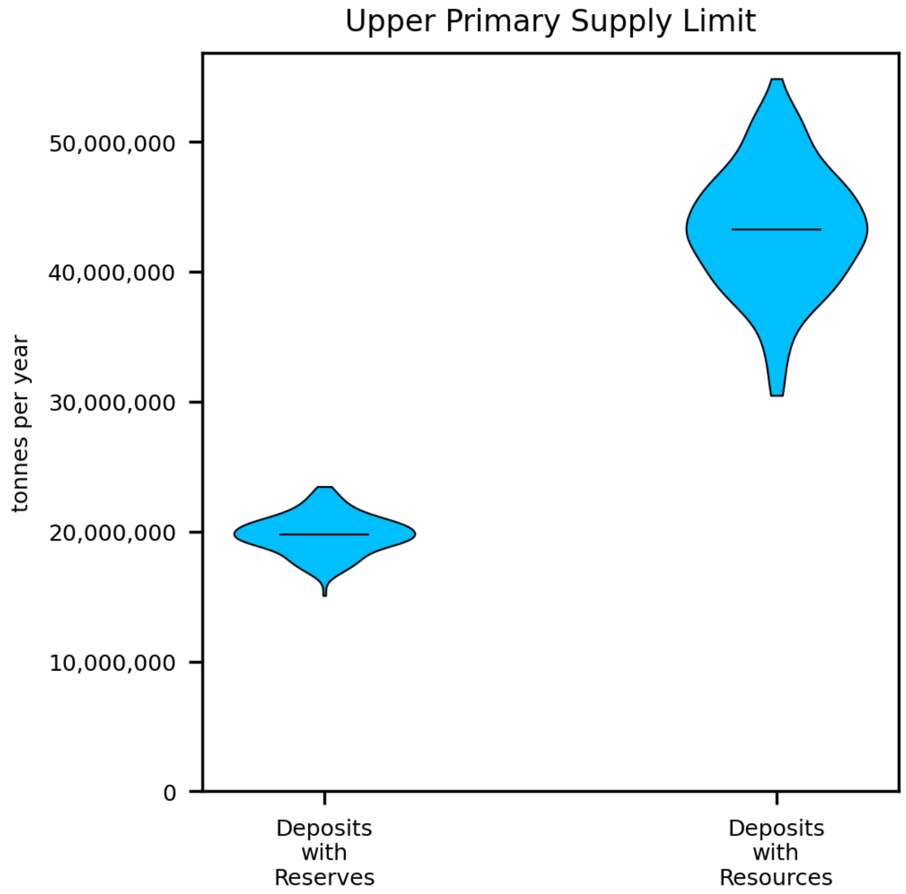


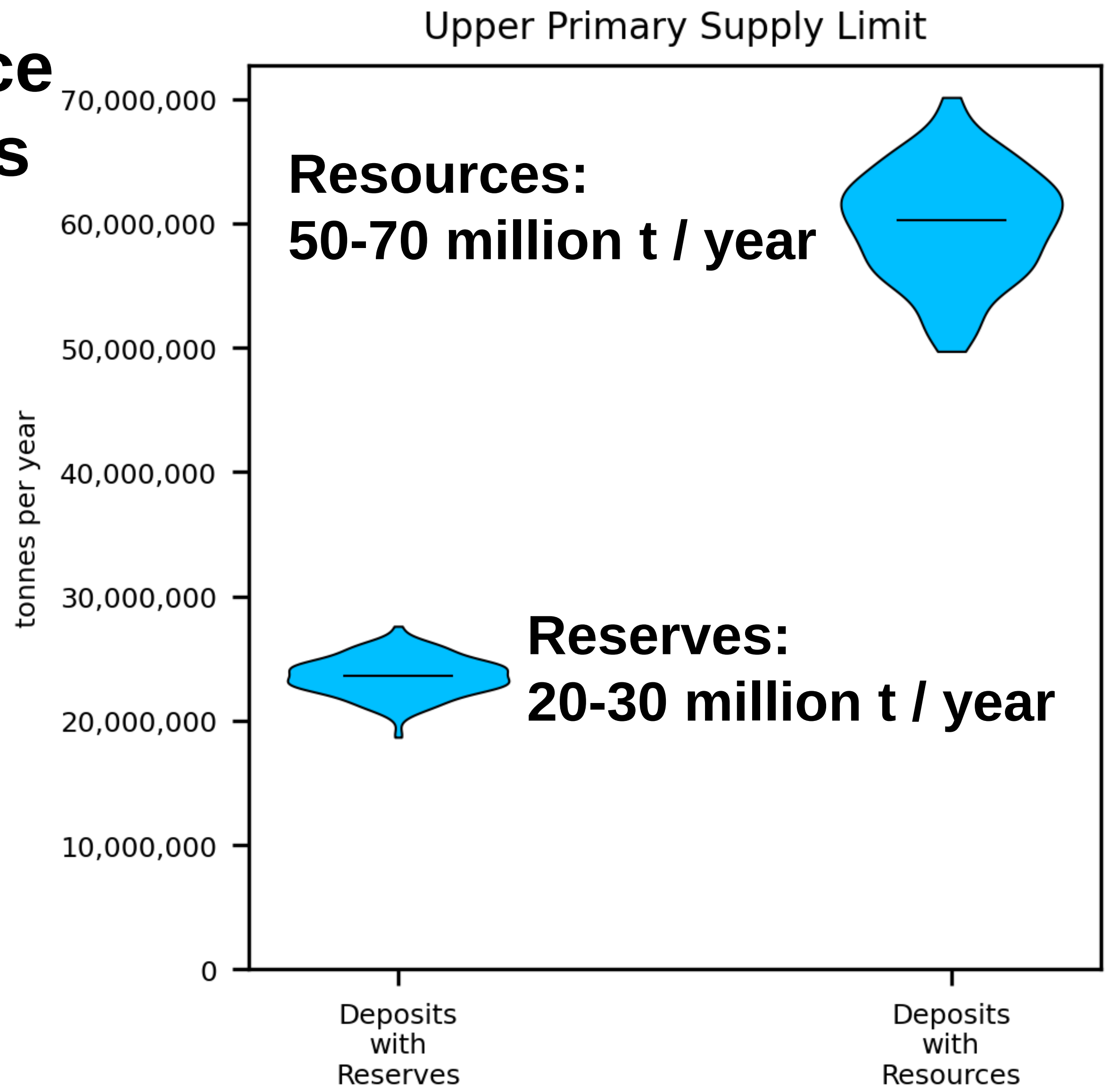
Unpublished.



Klose and Pauliuk (Under Review)

Doubling the Reserve & Resource of Undeveloped Copper Deposits

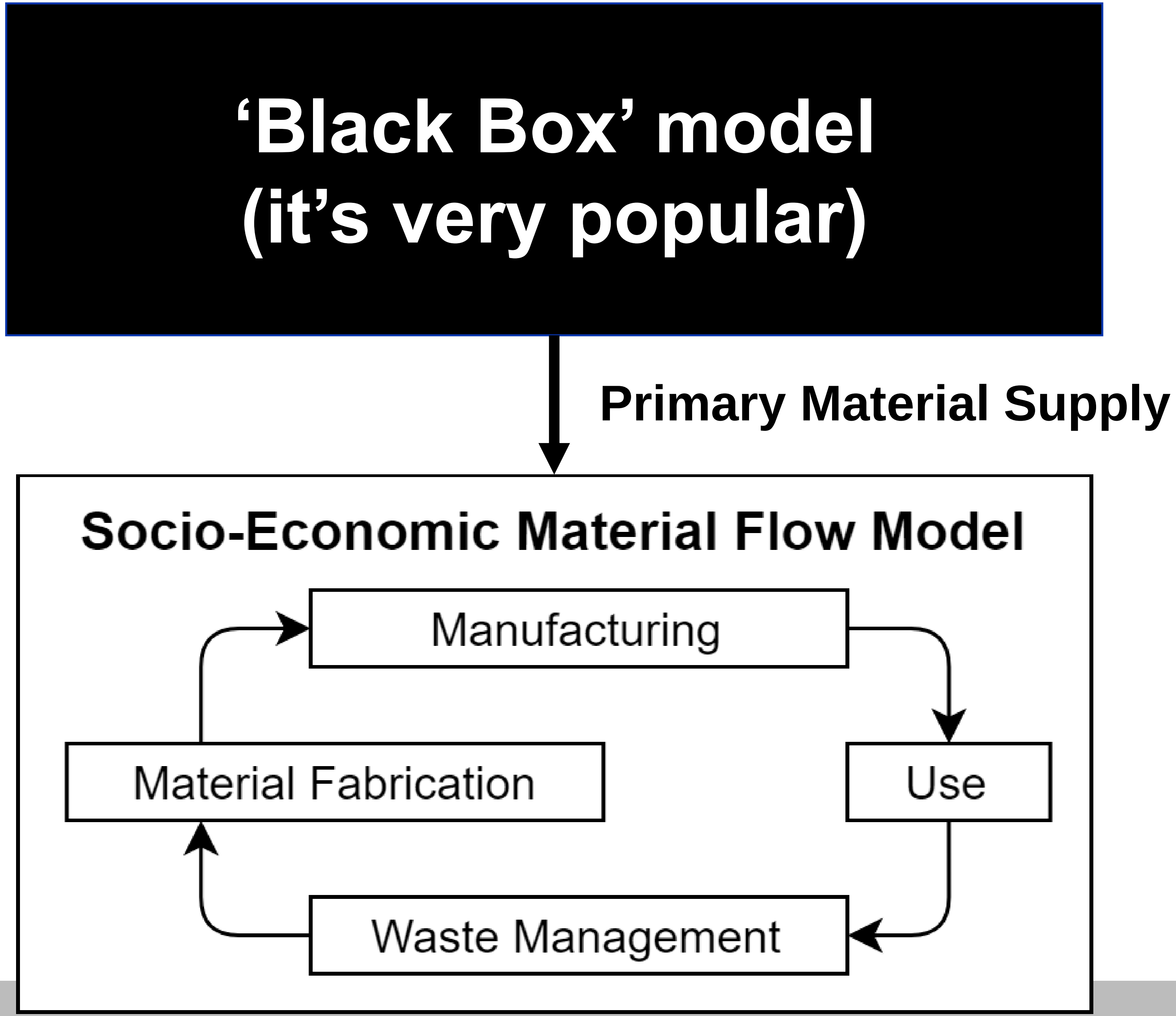




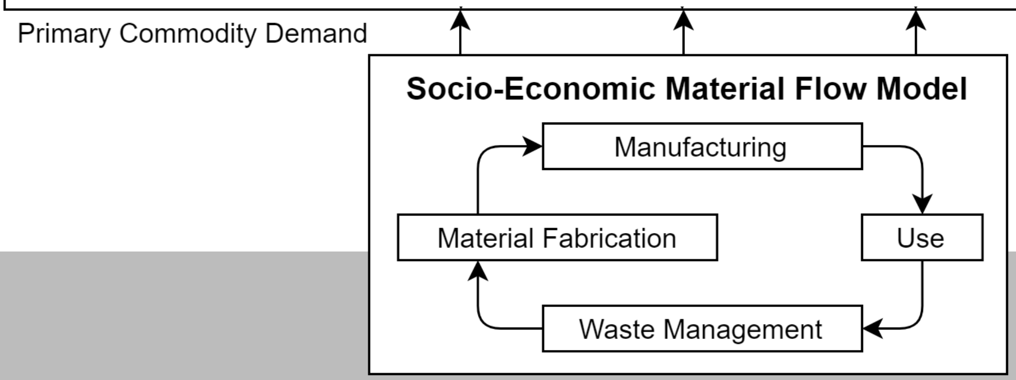
Unpublished.

Okay, maybe copper supply and demand can be balanced in 2050

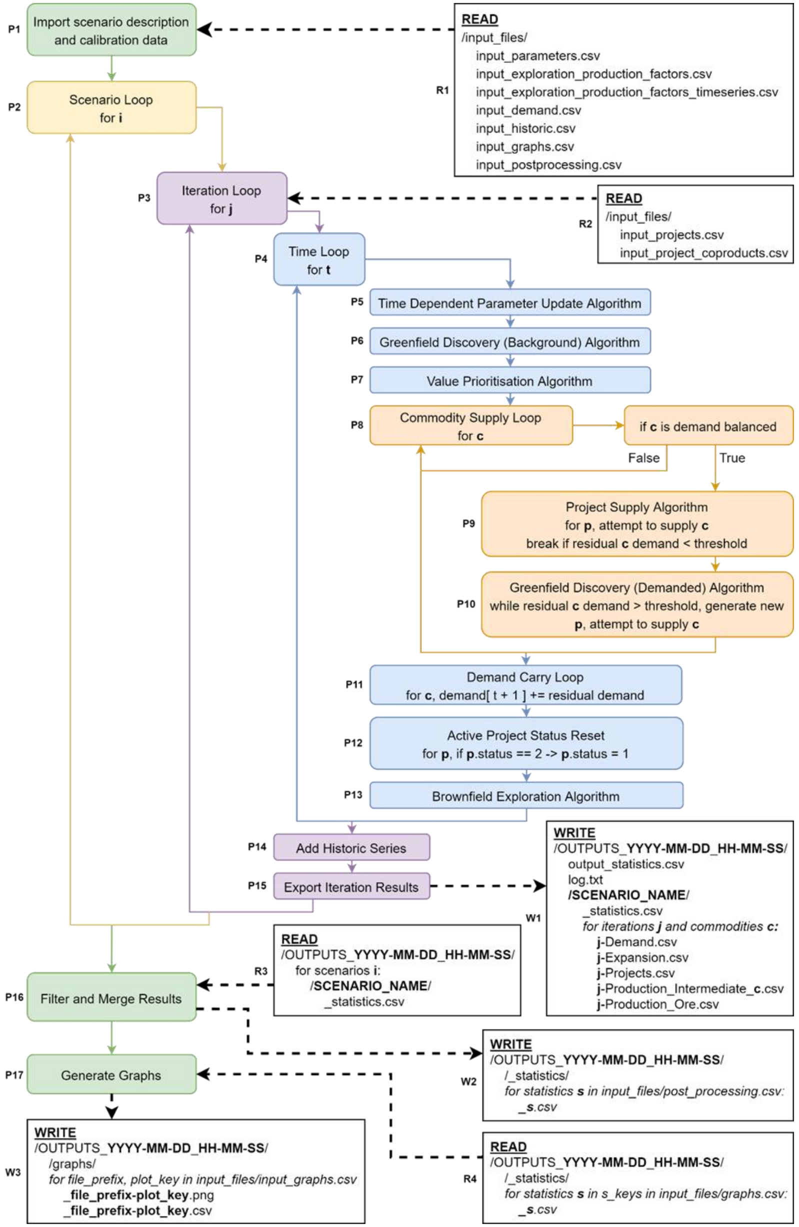
But what about the timing of exploration and supply?


‘Black Box’ model
(it’s very popular)
Primary Material Supply
Socio-Economic Material Flow Model
Manufacturing
Use
Waste Management
Material Fabrication

Primary Exploration, Mining and Metal Supply Scenario (PEMMSS) model

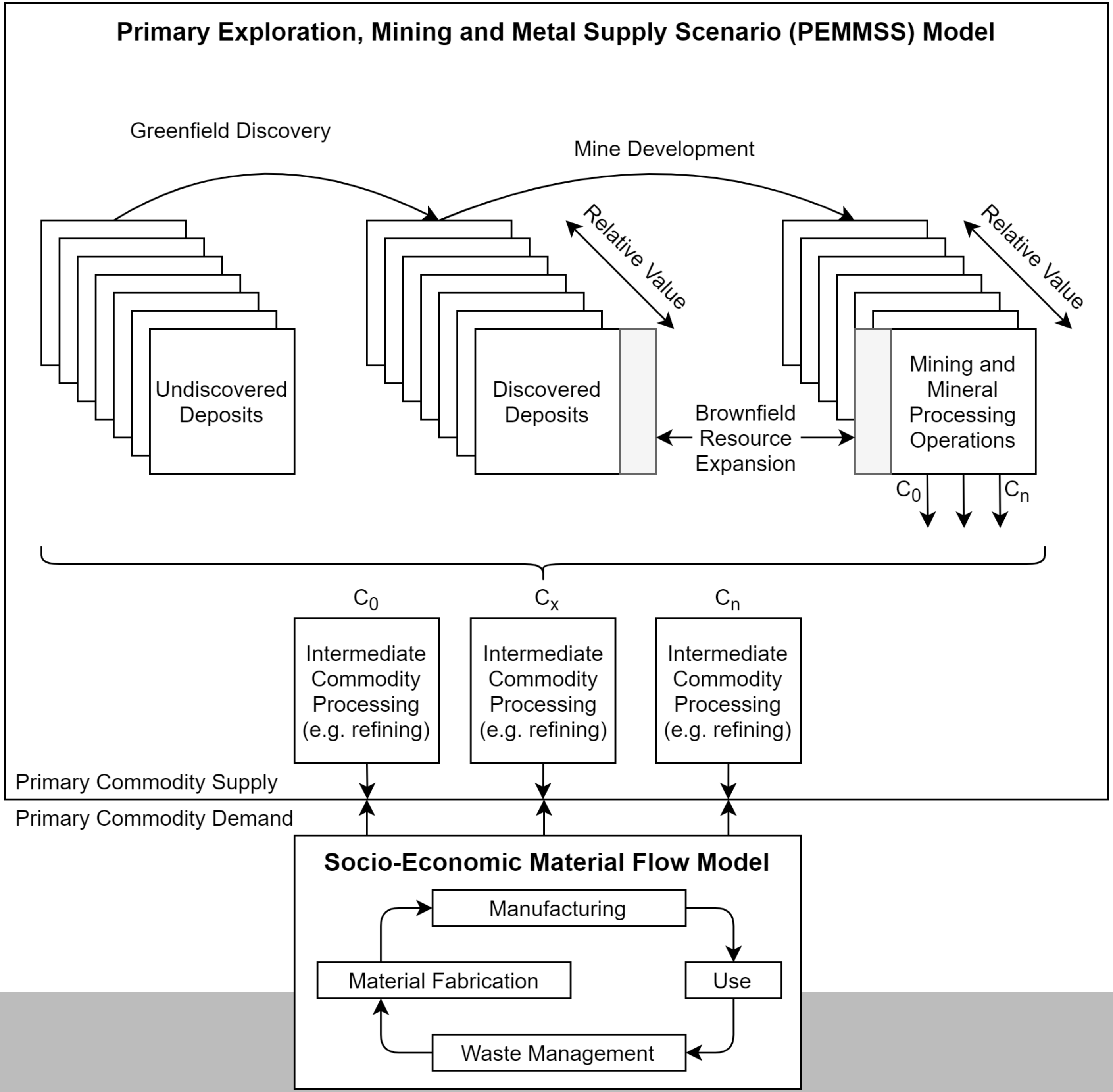


UTS



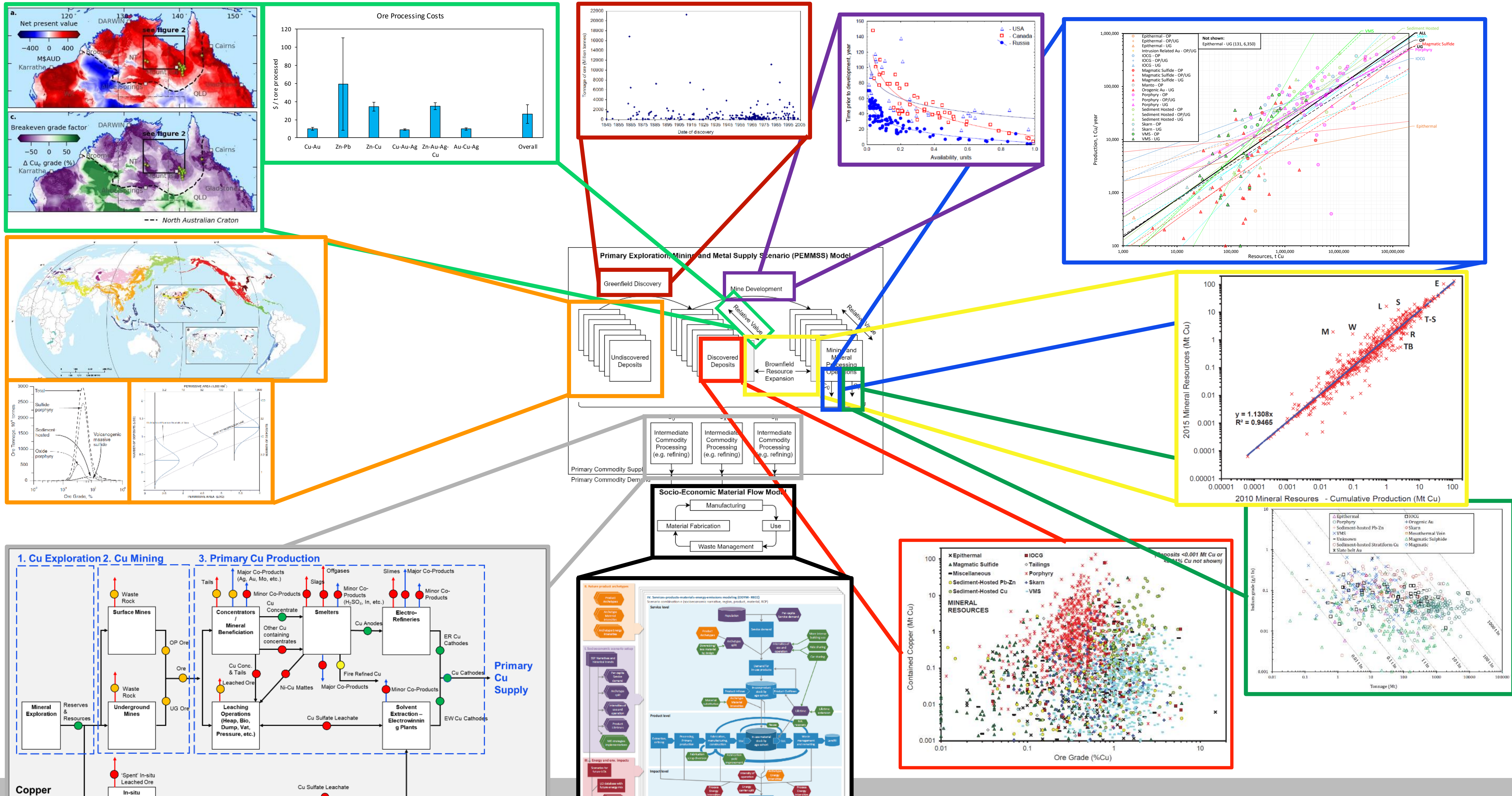
pemmss.py

```python
# Background greenfield discovery
# P6
if parameters['greenfield_background'][i] > 0:
    for gb in range(parameters['greenfield_background'
        projects.append(deposit.resource_discovery(fac

# Priority Ranking Algorithm
# P7
if parameters['priority_active'][i] == 1:
    # Sort then prioritise existing mines
    projects.sort(key=lambda x: x.value['ALL'])
    projects.sort(key=lambda x: x.status, reverse=True
else:
    projects.sort(key=lambda x: x.value['ALL'])

# Commodity Supply-Demand Balance Algorithm
# P8
for c in demand:
    if demand[c]['balance_supply'] == 1:

        # Project Loop
        # P9
        for project in projects:
            # break loop if residual demand less than
            if demand[c][year_current] <= demand[c]['d
                break
```

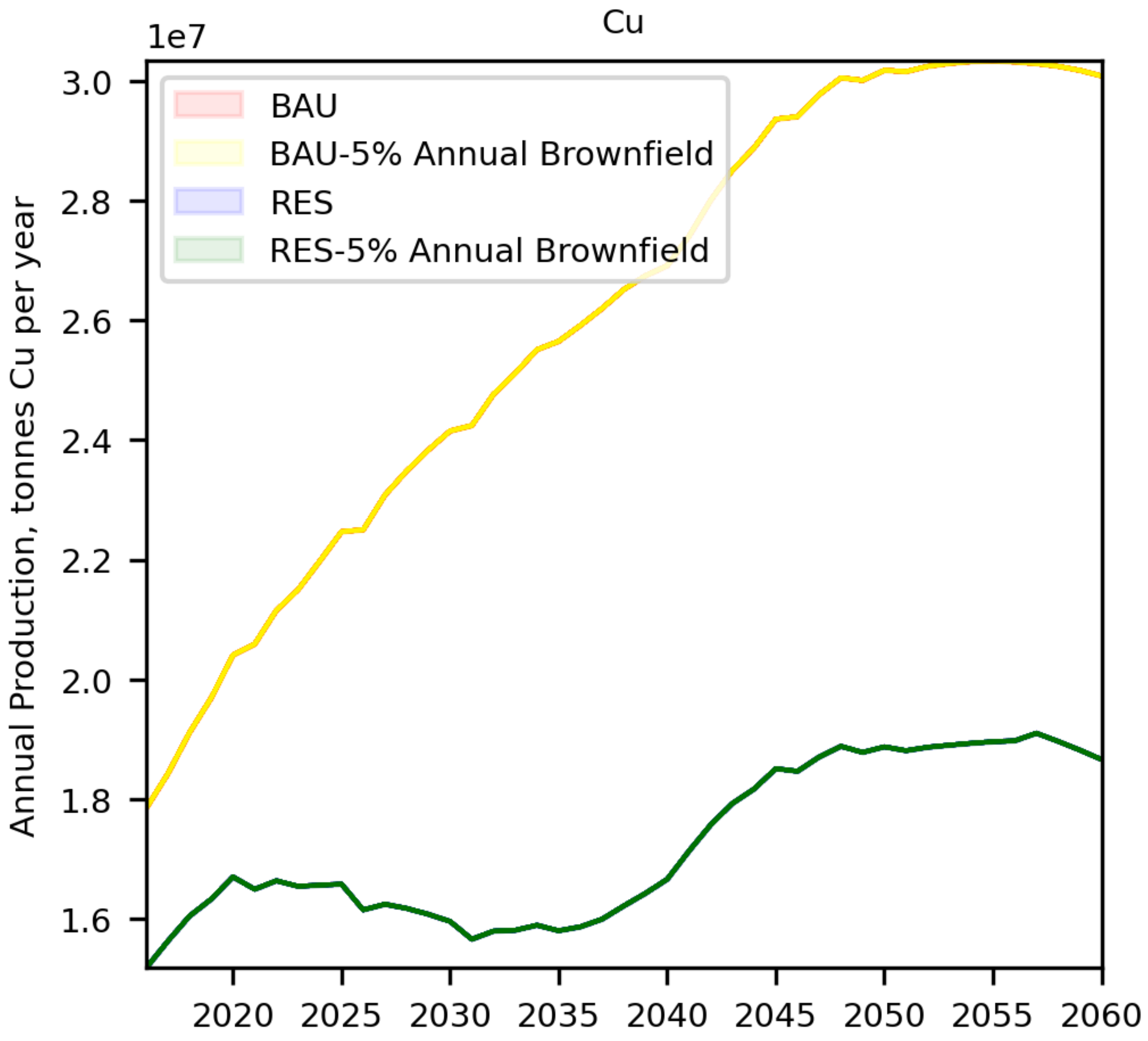

Primary Exploration, Mining and Metal Supply Scenario (PEMMSS) Model
Greenfield Discovery
Mine Development
Relative Value
Relative Value
Undiscovered Deposits
Discovered Deposits
Brownfield Resource Expansion
Mining and Mineral Processing Operations
C_0
C_n
C_0
C_x
C_n
Intermediate Commodity Processing (e.g. refining)
Intermediate Commodity Processing (e.g. refining)
Intermediate Commodity Processing (e.g. refining)
Primary Commodity Supply
Primary Commodity Demand
Socio-Economic Material Flow Model
Manufacturing
Material Fabrication
Use
Waste Management

UTS

Calibrating for Copper

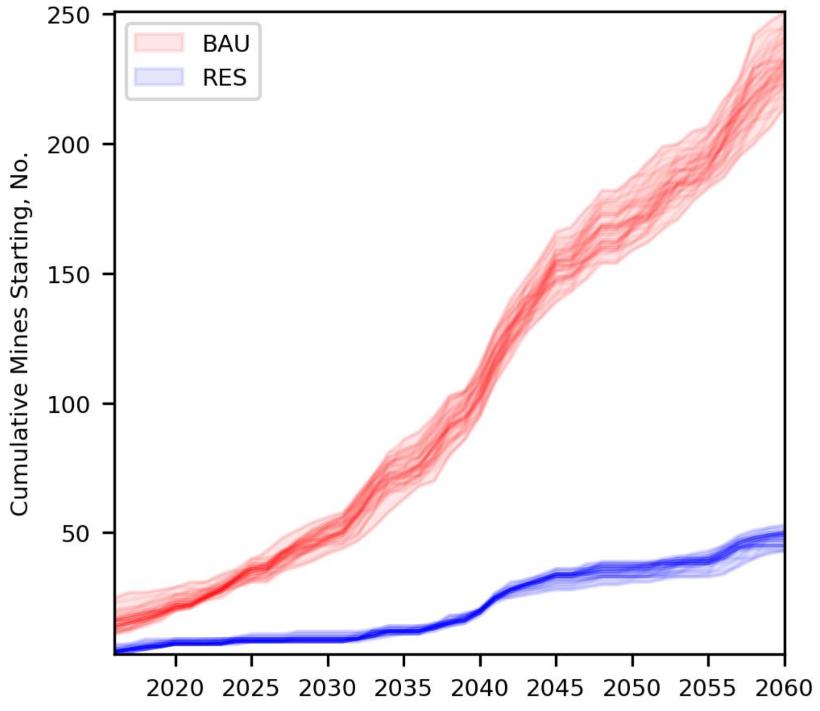


SSP 2 RCP 2.6

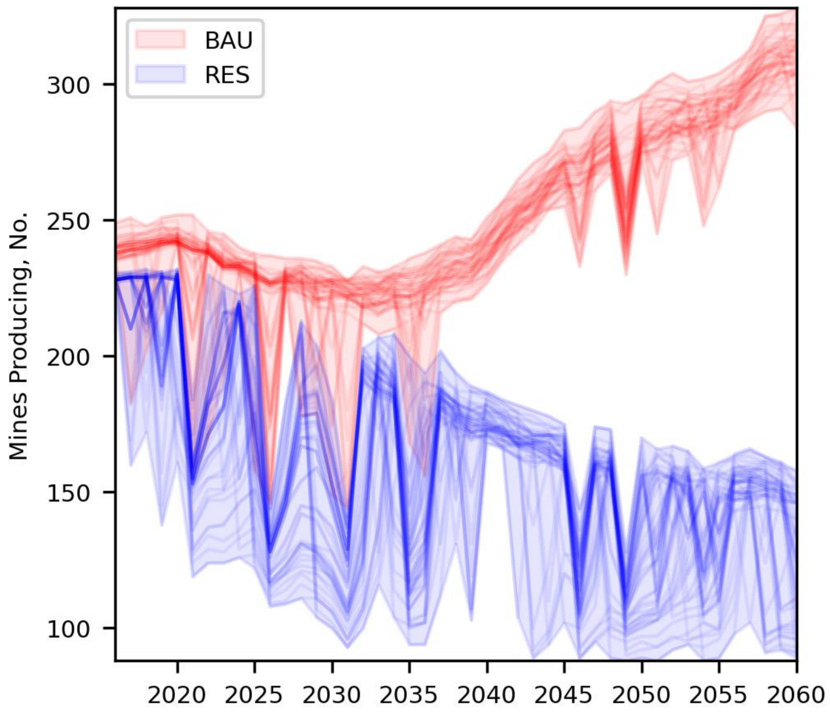

Cu
1e7
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
Annual Production, tonnes Cu per year
BAU
BAU-5% Annual Brownfield
RES
RES-5% Annual Brownfield
2020
2025
2030
2035
2040
2045
2050
2055
2060

SSP 2 RCP 2.6

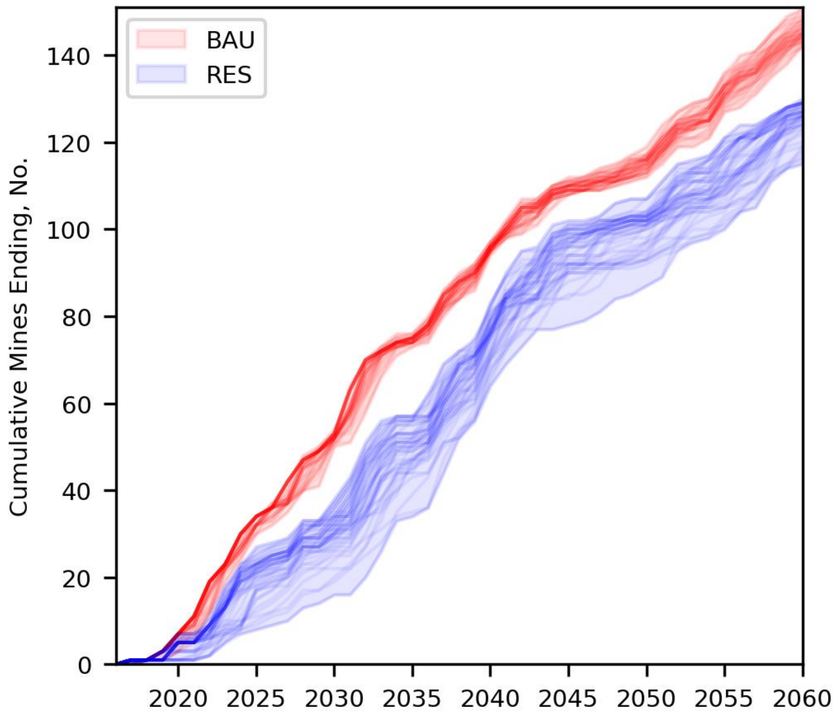
New Mines Required



Mines Producing



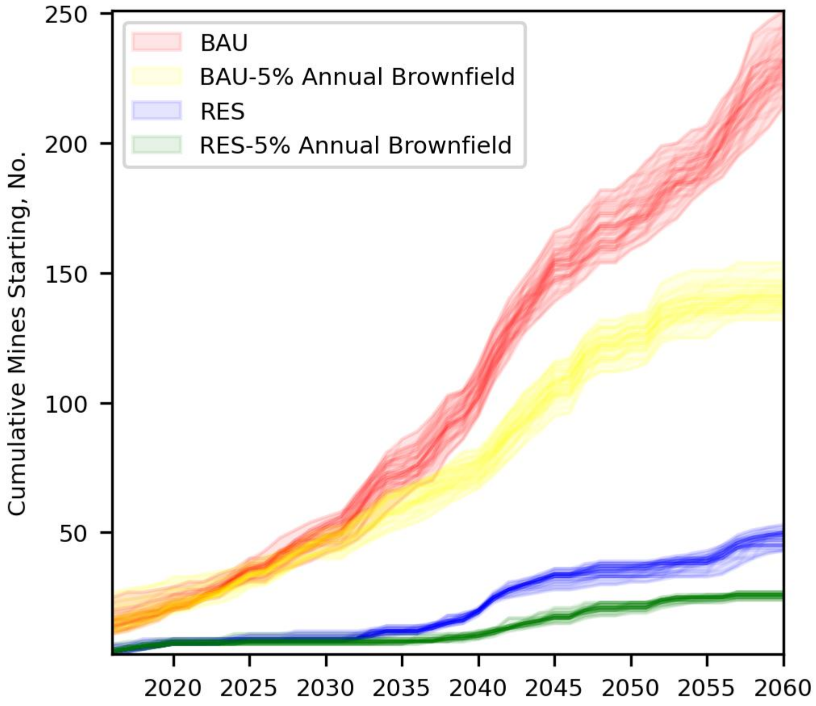
Mine Closures



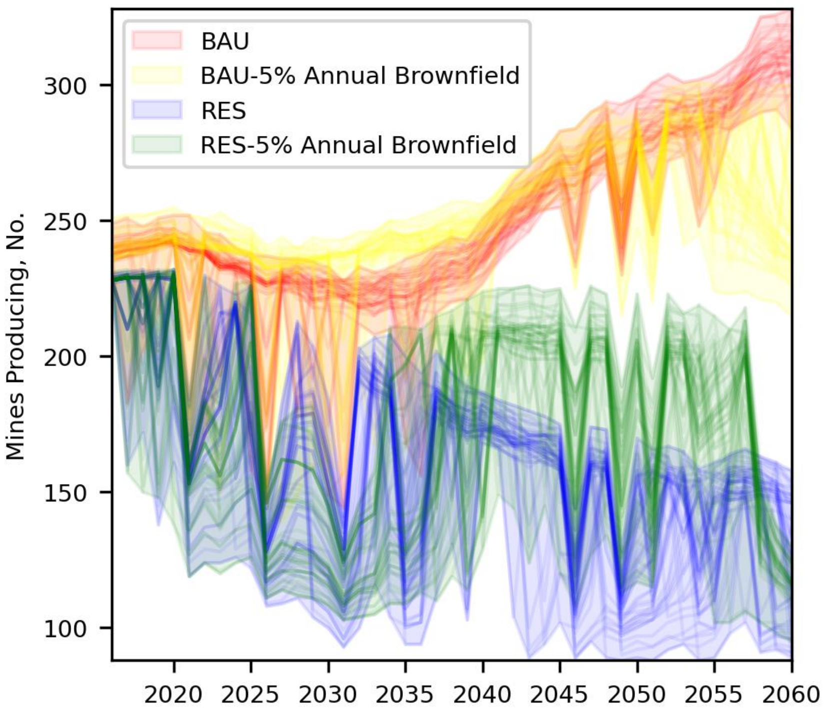
Unpublished and Preliminary. Subject to Change.

SSP 2 RCP 2.6

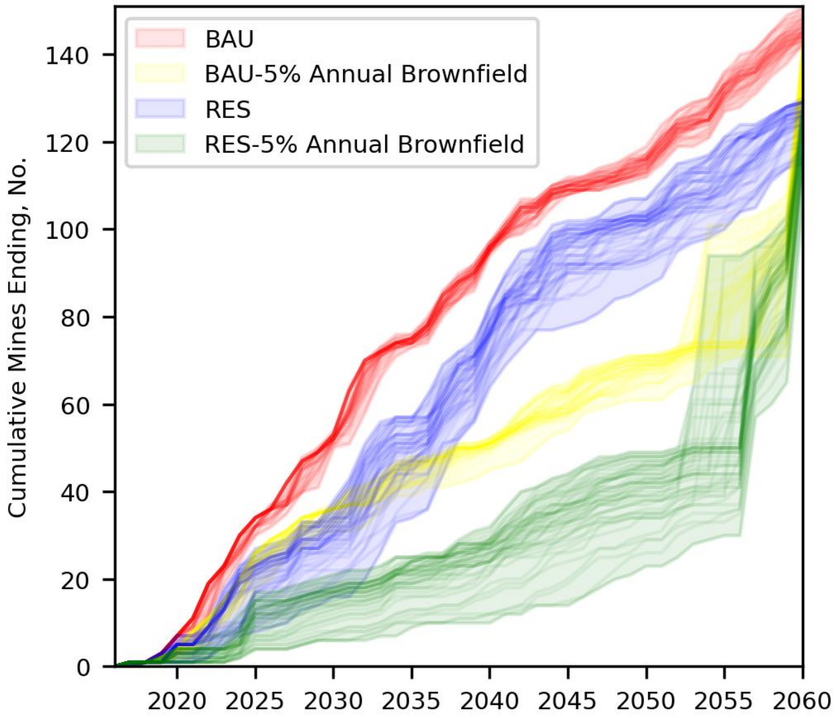
New Mines Required



Mines Producing



Mine Closures



Unpublished and Preliminary. Subject to Change.

Conclusions

Demand scenarios for the shared socio-economic pathways (SSPs) are a thing

Known deposits can probably scale supply for a while

Long term significant exploration success will be required, maybe higher prices as well

Thankyou

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