Project Blue Forum
London

...in association with

mmta
Minor Metals trade association

PROJECT BLUE
CRITICAL MATERIALS AND
ENERGY TRANSITION INTELLIGENCE

Today's presentations…

Jack Bedder, Founder & Director – Project Blue

Setting the scene: the geopolitics of critical materials

Robert Baylis, Consultant – InnoEnergy

Minor metals: the enablers of high-performance batteries

Michael Husakiewicz, Trader – Lipmann Walton

How aerospace learnt to love Hafnium, Tantalum and Rhenium

Setting the scene:
The Geopolitics of Critical Materials

Dr Jack Bedder, Project Blue

Unsettling times…

HOW WILL GLOBAL TRENDS SHAPE CRITICAL MATERIAL SUPPLY CHAINS?

- Around the world, rhetoric and industrial policy related to critical materials are becoming more protectionist and more muscular.
- Are we at an inflection point for critical material supply chains?
- Is the era of 'global' critical material supply chains coming to an end, with a geopolitically charged realignment of sorts set to replace it?
- Or – despite these feeling like unsettling times – will it be business as usual for the foreseeable?

Critical materials and China…

FORGING A NEW PATH?

- Raw material strategy has until now driven by a thirst for economic growth, and other priorities including a desire to reduce dependence on oil, and a growing need to control pollution.
- For various reasons (not just industrial policy) China is unquestionably in a strong position regarding critical materials.
- Beijing now focused new priorities, centrally a re-shaping of its economy and society in line with its Vision 2035.
- For commodities, iron and steel are out, energy transition metals are in?
- Will China transition towards more cyclical consumer-driven growth? Can it? Does it want to?
- Stability and security are of high importance.
- Short term challenges are considerable (Taiwan, economy, property markets, “zero-COVID”).
- A changing China will change its position in the commodity sphere…

Critical materials and the USA…

FORGING A NEW PATH?

- In the West, the scale of the problem has become clear. When it comes to raw materials, mineral processing, and manufacture, most roads lead to China.
- The Inflation Reduction Act (IRA) is focussed mostly on the domestic economy but has huge implications for the world and will influence the geopolitics of climate change, energy transition and as a result commodity markets.
- The IRA is an industrial policy designed to re-shore certain clean-energy industries and nurture US competitors to Chinese companies at the same time.
- US policy is becoming more assertive and recent chip sanctions feel like an escalation.
- Material sourcing from free-trade partners creates some interesting dynamics.

Concluding thoughts…

CRITICAL MATERIAL SUPPLY CHAINS COULD CHANGE…

- “Friend-shoring”, “near-shoring” or “re-shoring” – shorter supply chains?
- New alliance-centred strategies?
- Security but also ESG/sustainability as a mechanism/justification for US-Sino decoupling?
- Techno-nationalism and data nationalism/sovereignty?

BUT WILL THEY?

- China and the USA are still hugely intertwined. Both markets are vast…
- Perhaps we initially see a high-cost strategy of duplicating supply chains.

Image courtesy of Roberto Bueno, TBB Photo Contest

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Minor Metals in batteries

MMTA / Project Blue LME Week Seminar

25th October 2022

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About EIT InnoEnergy

Who we are

A force to bring people and resources together

A catalyst and accelerator of the energy transition

Investing in people, technologies, businesses

Established 2010: supported by the EIT

Public-private partnership aiming for financial sustainability

Key InnoEnergy shareholders

+

Funded by the EU

Our goals

Energy security and safety of supply

Reduce costs in the energy value chain

Reduce CO_2 emissions
Encourage sustainable growth

Improve European competitiveness
Remove barriers to innovation

Create jobs

About EBA250

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A EUROPEAN VALUE CHAIN

Our goal:

Build a strong pan-European battery industry to capture a new market worth 250B€/year in 2025.

A UNIQUE OPEN ECOSYSTEM

An independent meeting place:

More than 600 members throughout the value chain have joined EBA250. The members come from the industrial, academic and financial worlds, from mining to recycling.

PROJECT-DRIVEN

Our actions' DNA:

Competitiveness, sustainability, significant impact, objective focus, urgency, concrete, project-driven, sharing, investment.

Selection of planned Battery Materials Projects in Europe (raw materials, active materials and recycling)

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TALGA
Graphite mine and possible anode production

REVOLT (Northvolt)
Full-scale Recycling Plant

BASF
Cathode material plant

NORTHVOLT
Cathode Production

HYDROVOLT
Recycling Plant

ELKEM
Pilot plant for synthetic graphite

VOLKSWAGEN, Salzgitter
Recycling Pilot Plant

Vulcan Energy
Lithium from Brine

Lithium de France
Lithium from geothermal brine and Li-refinery

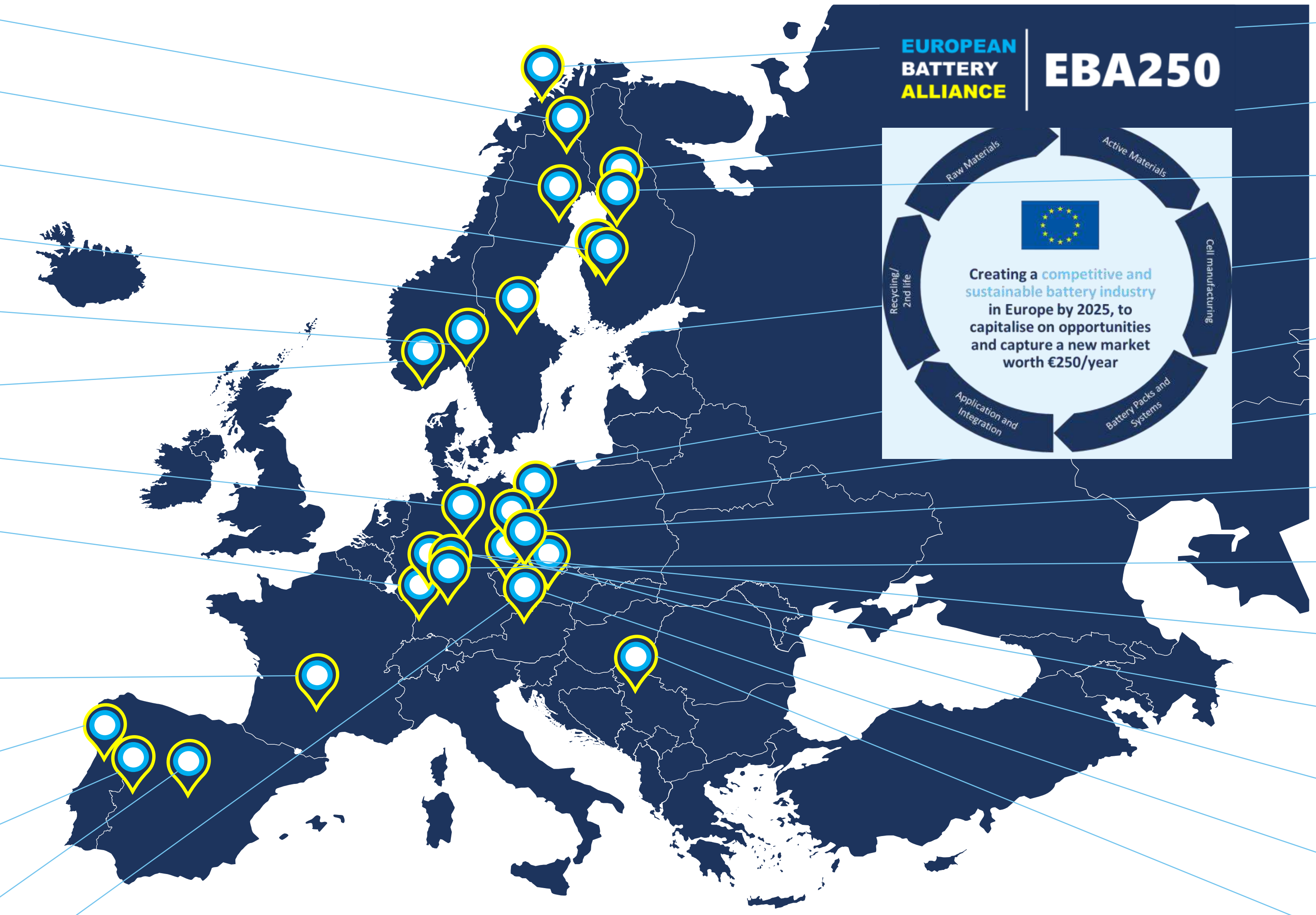
SNAM/Honda
Recycling Project
Announced

SAVANNAH RESOURCES
Lithium Mine

SAN JOSÉ
Lithium Mine

INFINITY
Lithium Mine

European Lithium
Lithium Mine



MRC SKALAND
Graphite mine and possible anode production

KELIBER
Lithium Mine

UMICORE/KOKKOLA
Cobalt and Nickel Production

Fortum, BASF and Nornickel Recycling Center

Umicore, Nysa
Cathode Material Plant

BASF, Schwarzheide
Cathode Material Plant

Rock Tech Lithium
Lithium Refinery

AMG Lithium
Lithium Refinery

Promobius
Recycling Plant

Pure Battery Technologies
Processing of battery materials

Cinovec
Lithium mine

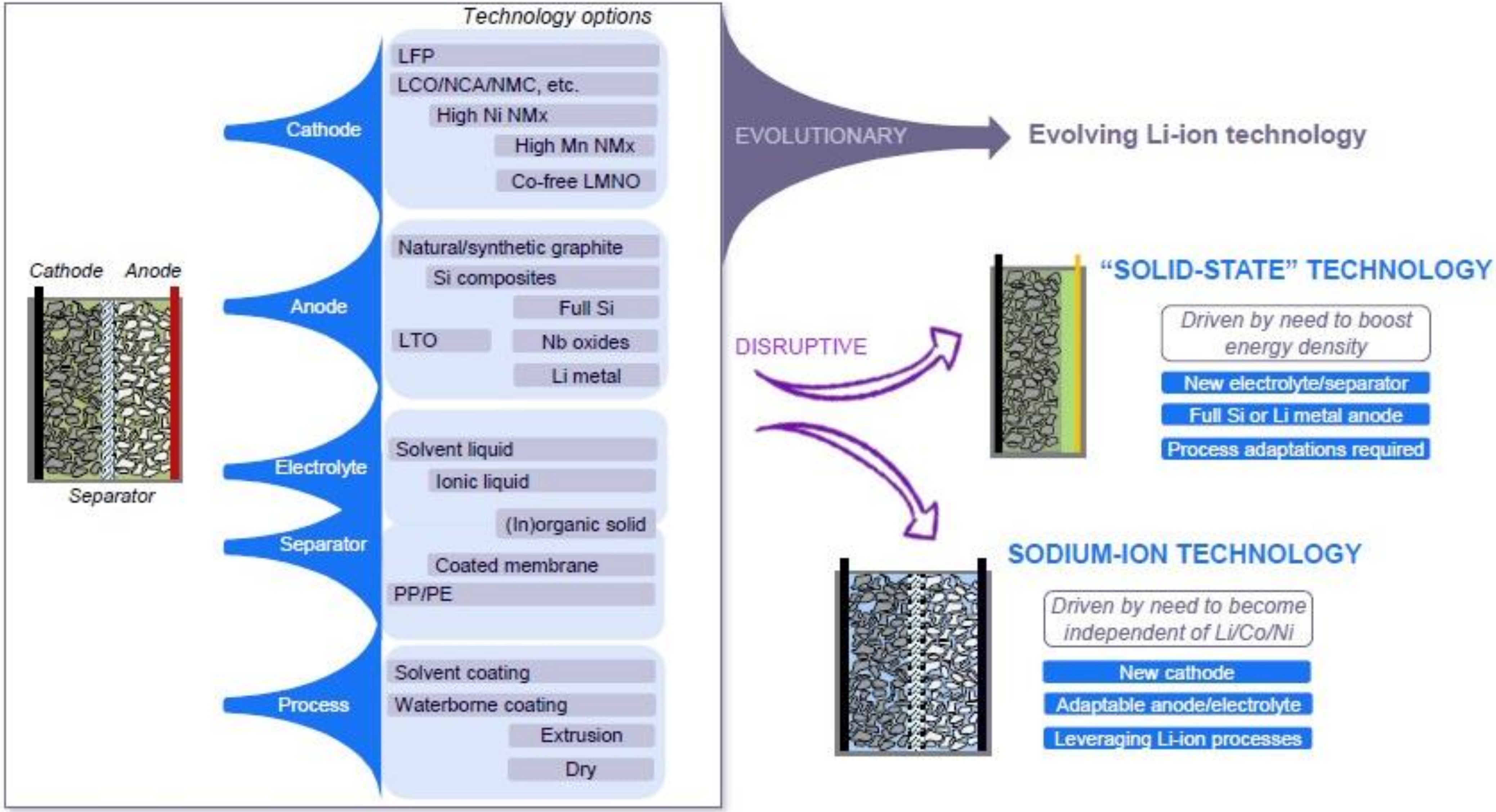
EURO MANGANESE
Manganese from tailings

Rio Tinto, Jadar
Lithium Mine

Mining projects for battery raw materials
Active materials projects (precursor, cathode and anode production)
Recycling facilities for Li-Ion batteries

Part of EBA BIP Portfolio

Lithium-ion battery technology roadmap



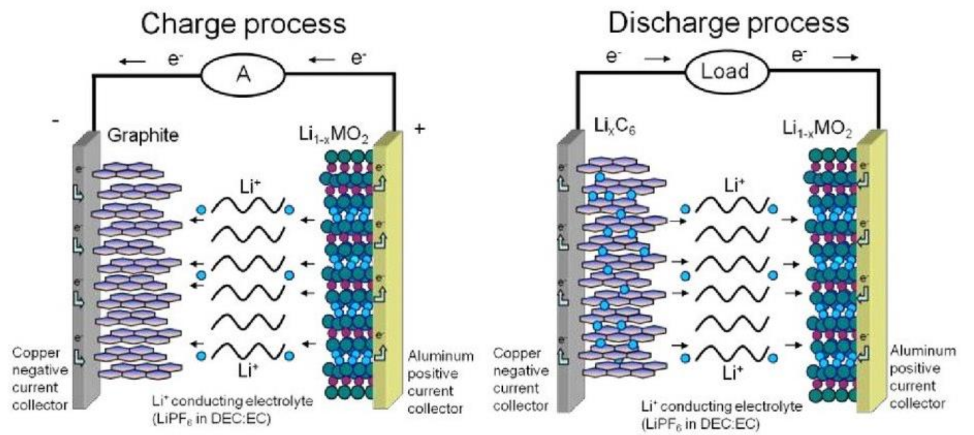
Sources: Arthur D Little

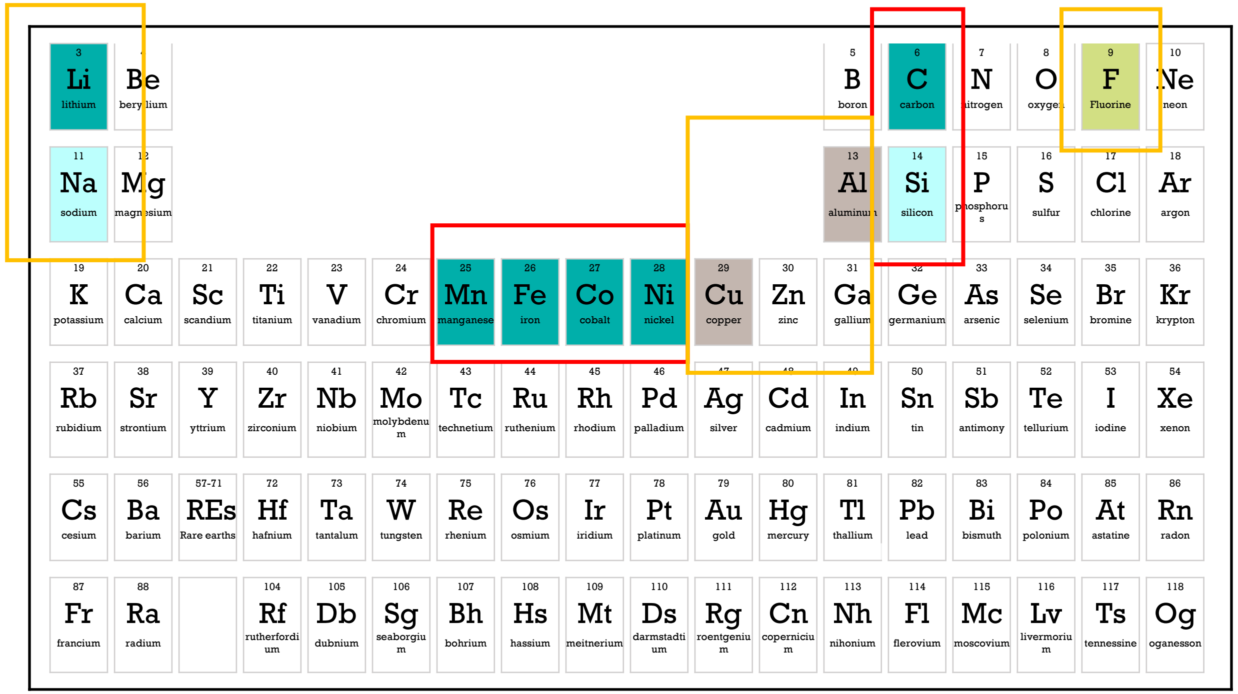
Lithium, manganese, iron, cobalt, nickel, copper, aluminium and carbon are the **building blocks** of today's Li-ion batteries

+ **Cathodes** need to be:
  + An efficient oxidizing agent
  + Stable in contact with electrolyte

- **Anodes** need to:
  - Be an efficient reducing agent
  - Have high coulombic output
  - Be conductive

± **Both** need to offer:
  ± Stability
  ± Useful working voltage
  ± Ease of fabrication
  ± **Low cost**
  ± Safety

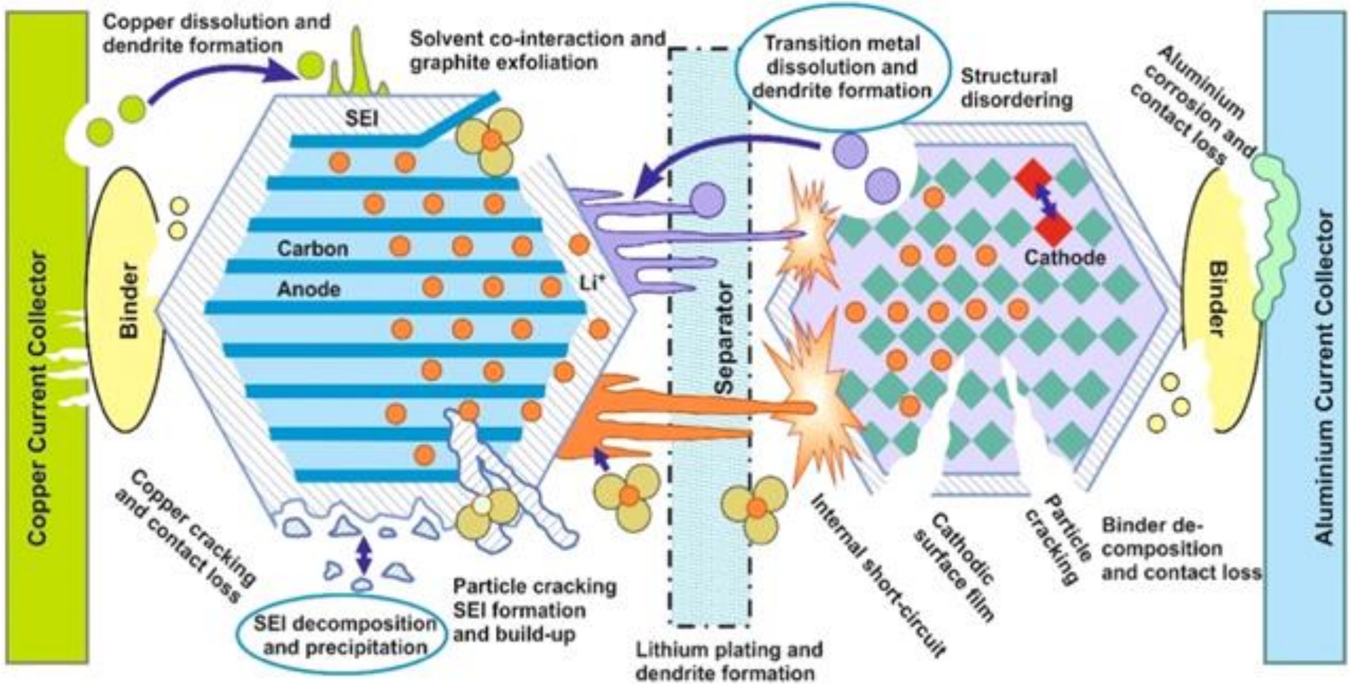




Sources: University of Washington (https://depts.washington.edu/matseed/batteries/MSE/components.html)

These building blocks have been modified for varying cell uses and performance, however **they remain weak in the cell internal environment**

Degradation in Li-ion cells is caused by a large number of physical and chemical mechanisms, which affect the different components of the cells: the electrodes, the electrolyte, the separator and the current collectors
= power and capacity fading



Loss of lithium inventory (LLI):
- Surface film formation (SEI)
- Decomposition reactions
- Lithium plating

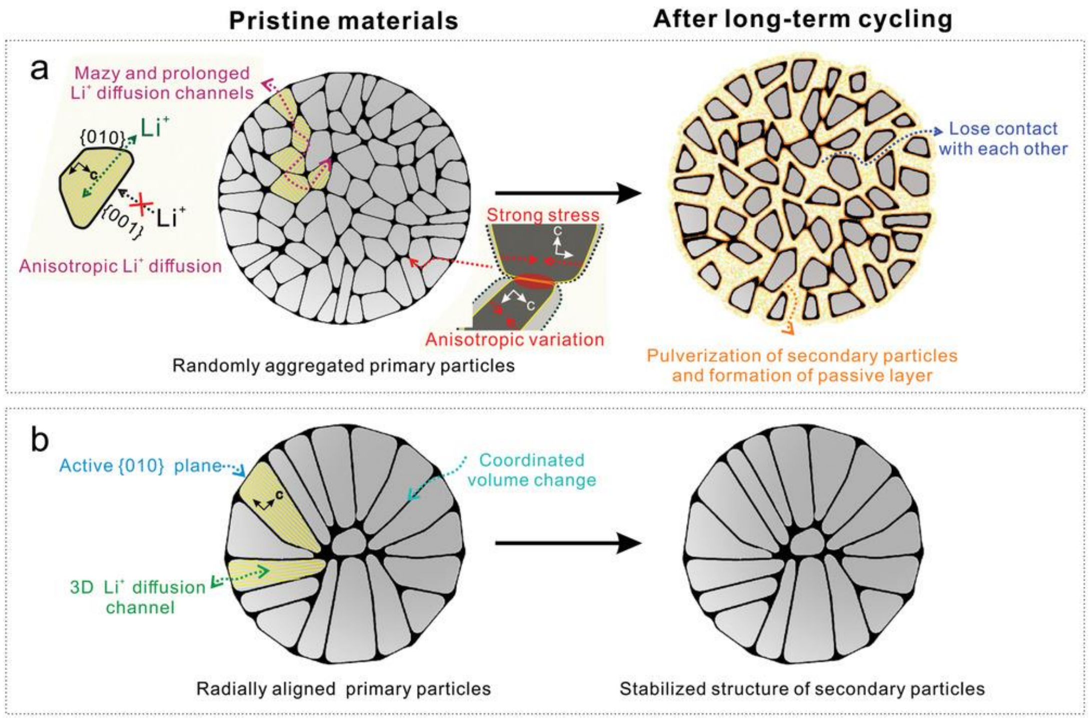
Loss of active material –ve (LAMNE):
- Particle cracking
- Loss of electrical contact
- Resistive surface layers

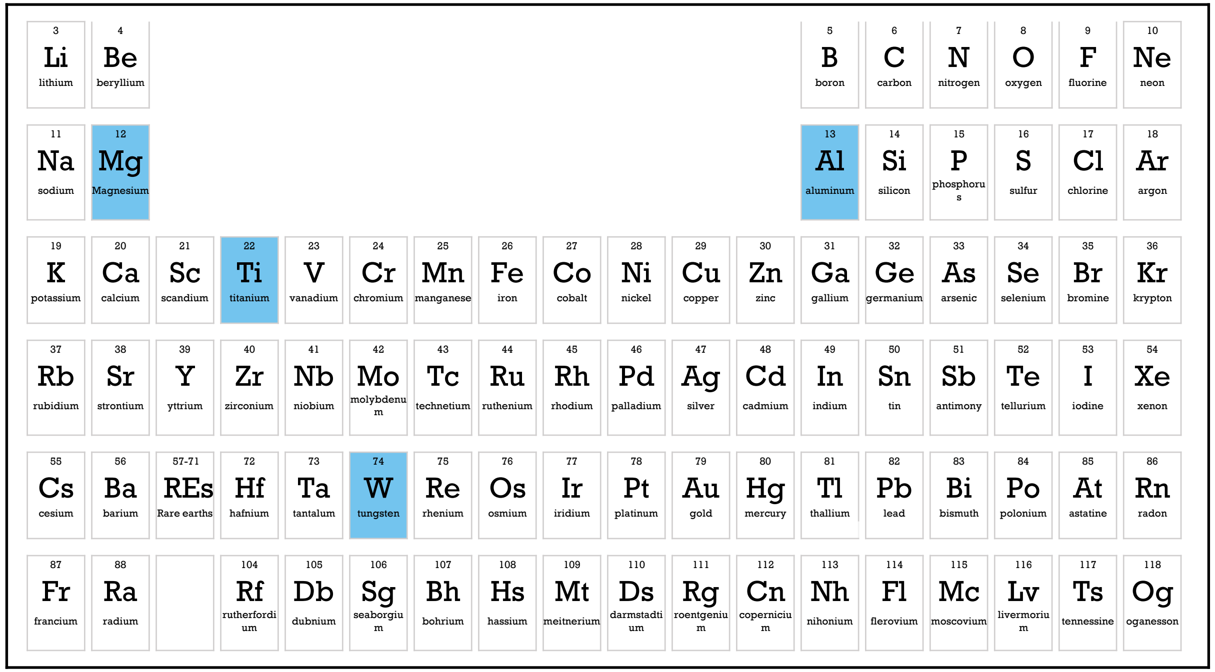
Loss of active material +ve (LAMPE):
- Structural disordering
- Particle cracking
- Loss of electrical contact

Sources: Degradation diagnostics for lithium ion cells (https://www.sciencedirect.com/science/article/pii/S0378775316316998)

Cathode material physical properties, including morphology and primary particle orientation are inherited from precursor material

Starlike feature is responsible for various battery benefits, including better Li+ conductivity and improved mechanical strength during cycling





Sources: Umicore (Kokkola Material Week 2021); Advanced Energy Materials (https://onlinelibrary.wiley.com/doi/10.1002/aenm.201803963)

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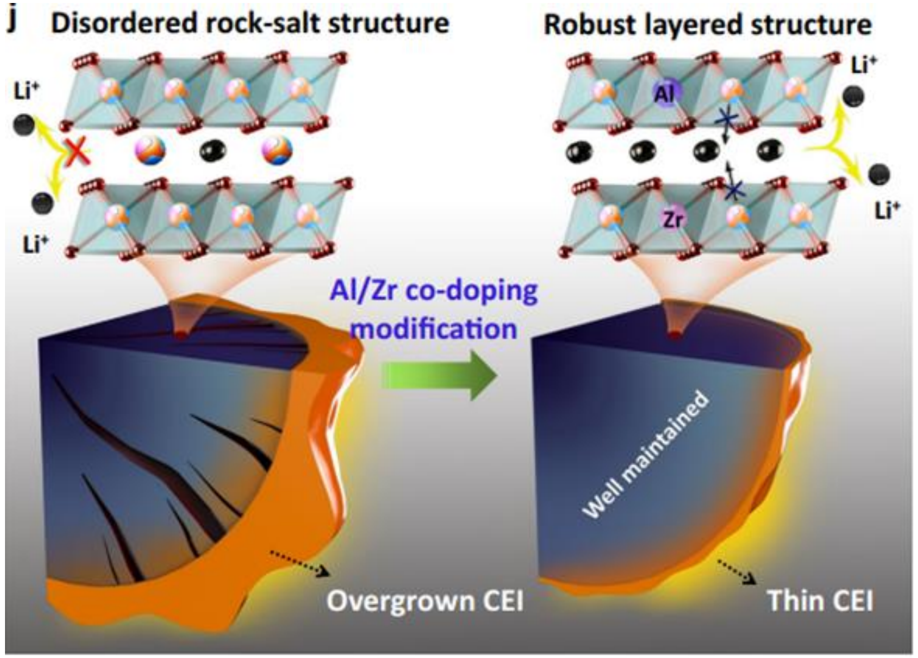
Structural instability detrimentally affects the battery performance during cell cycling

The synergistic effect of Al/Zr co-doping improves the Li+ mobility, relieves the internal strain, and suppress the Li/Ni cation mixing upon cycling at high cut-off voltage



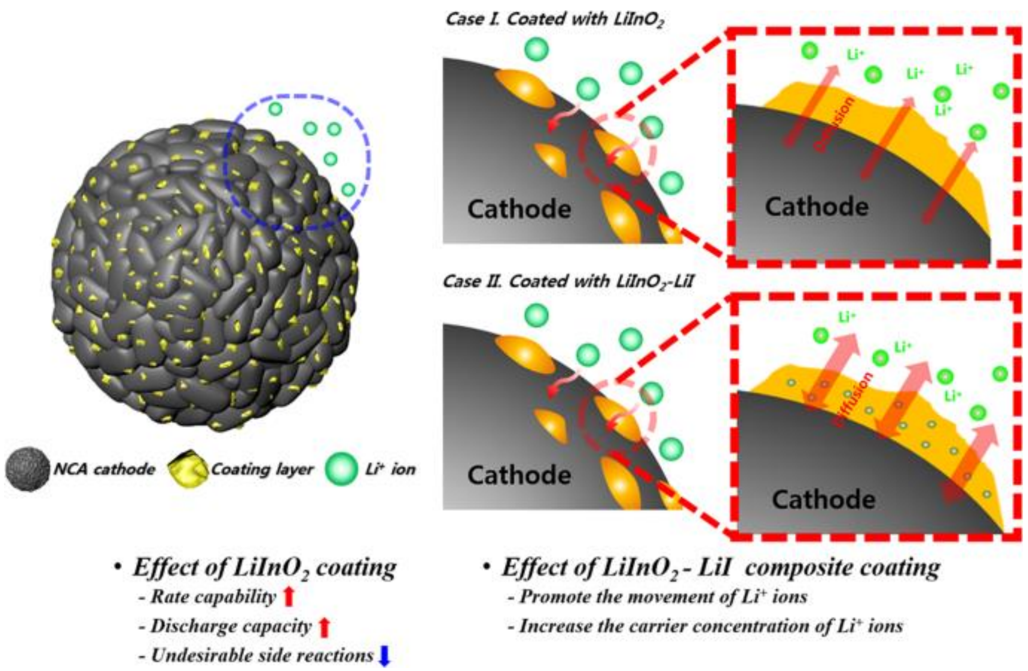
3 Li lithium	4 Be beryllium											5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
11 Na sodium	12 Mg magnesium											13 Al Aluminum	14 Si silicon	15 P phosphorus	16 S sulfur	17 Cl chlorine	18 Ar argon
19 K potassium	20 Ca calcium	21 Sc scandium	22 Ti Titanium	23 V vanadium	24 Cr chromium	25 Mn manganese	26 Fe iron	27 Co cobalt	28 Ni nickel	29 Cu copper	30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	35 Br bromine	36 Kr krypton
37 Rb rubidium	38 Sr strontium	39 Y yttrium	40 Zr Zirconium	41 Nb niobium	42 Mo molybdenum	43 Tc technetium	44 Ru ruthenium	45 Rh rhodium	46 Pd palladium	47 Ag silver	48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon
55 Cs cesium	56 Ba barium	57-71 REs Rare earths	72 Hf hafnium	73 Ta tantalum	74 W tungsten	75 Re rhenium	76 Os osmium	77 Ir iridium	78 Pt platinum	79 Au gold	80 Hg mercury	81 Tl thallium	82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium		104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson

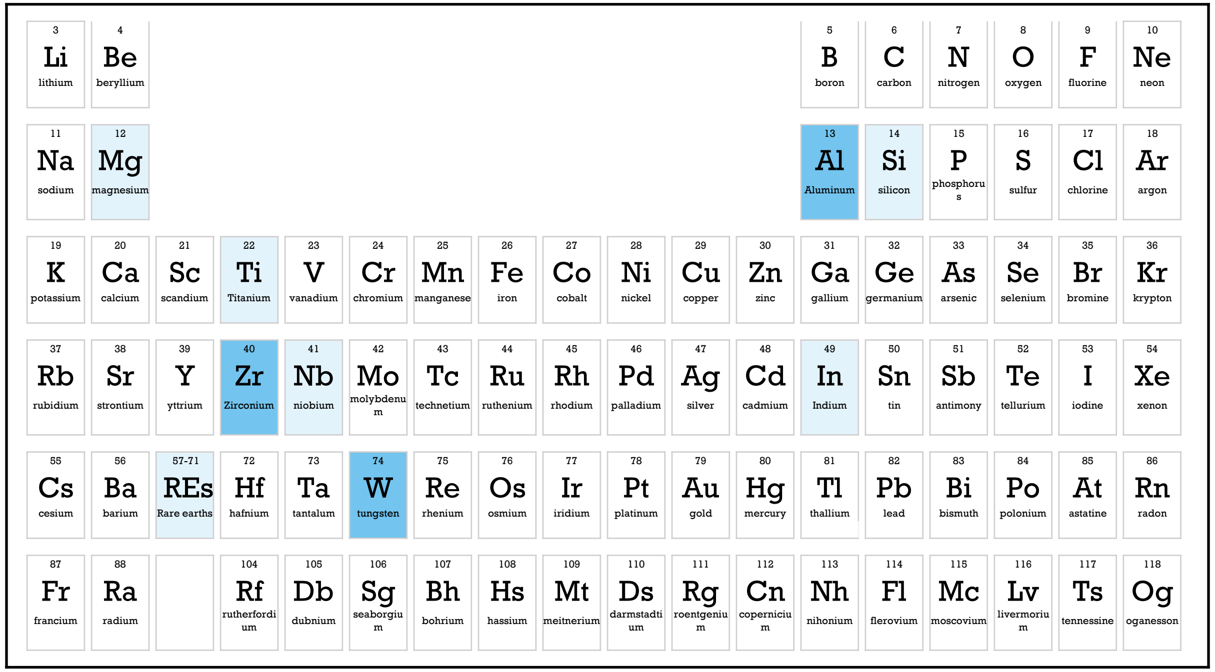
Source: Enabling high energy lithium metal batteries (https://www.nature.com/articles/s41467-022-30020-4.pdf?proof=t)

Coatings enhance the Li-ion diffusion and conductivity, and help prevent against electrolyte degradation

Cathodes tend to react with the electrolytes and undergo surface modifications accompanied by performance and life cycle degradation

Surface coatings have been widely implemented as a measure to improve stability, electrochemical performance, and to prevent detrimental surface reactions

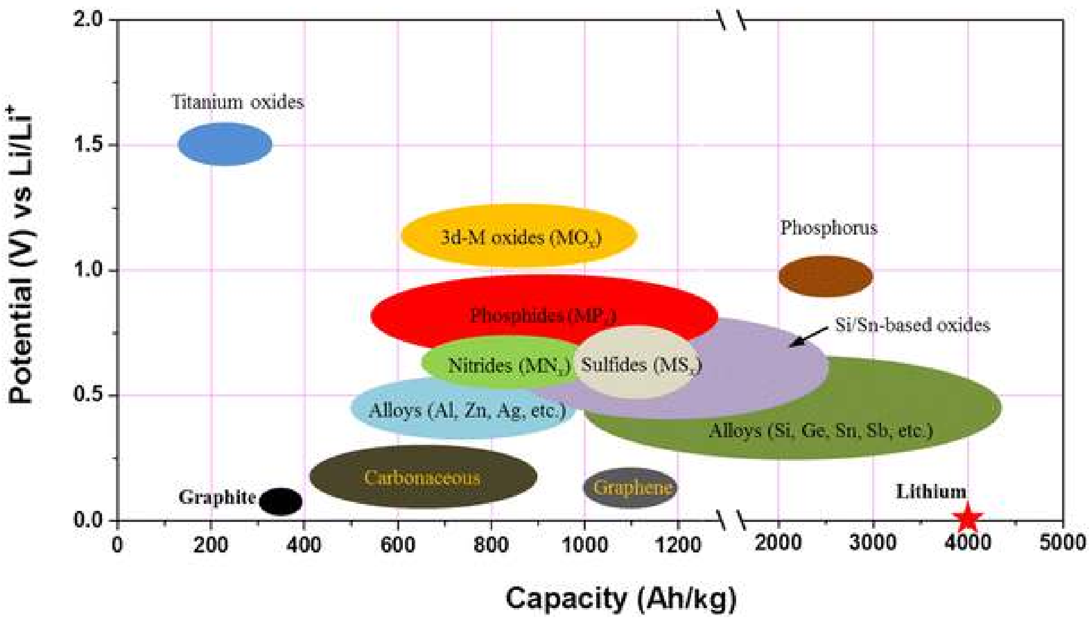


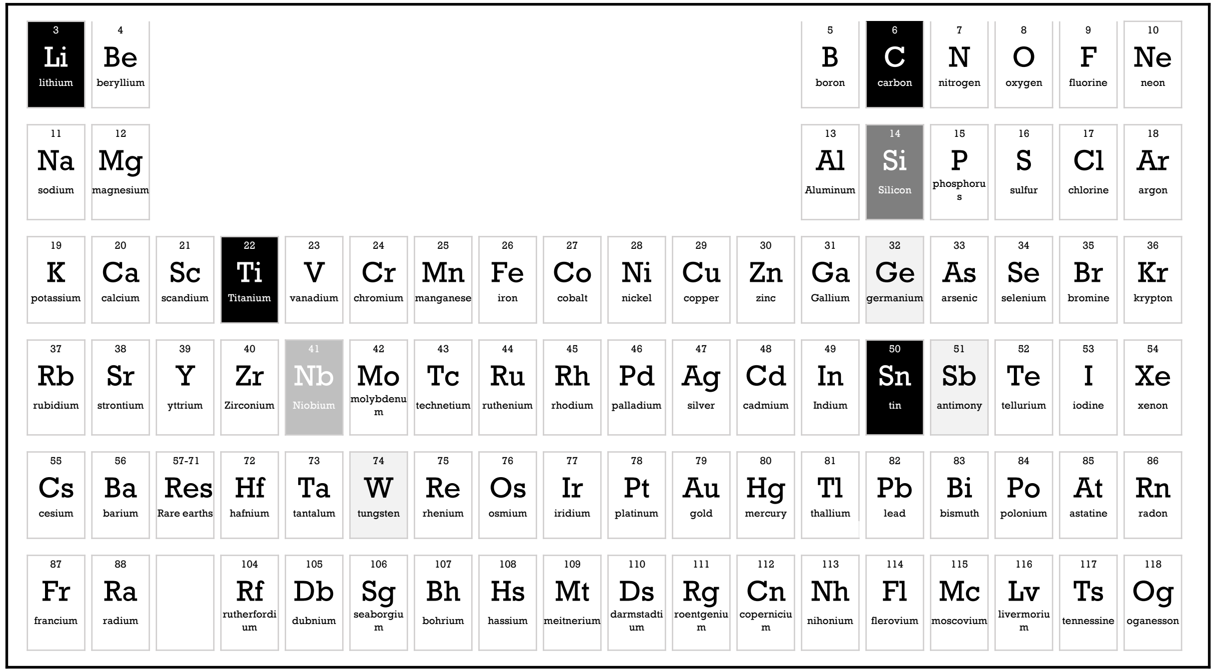


Source: Cathode coating using LiInO2-LiI composite for stable sulfide-based all-solid-state batteries (https://europepmc.org/article/med/31147595)

Alloys and metals show high capacity compared to carbon; swelling has hitherto limited silicon adoption but nano-materials are the step-change

Titanates and now niobates (oxides) have emerged due to high theoretical capacity and impressive electrochemical performance (fast charge, low temperature performance)





Source: High-Performance Anode Materials for Rechargeable Lithium-Ion Batteries (https://link.springer.com/article/10.1007/s41918-018-0001-4/figures/2)

Evolving LIB cathode and anode chemistry has increased the range of minor metal uses, albeit some have faded in importance

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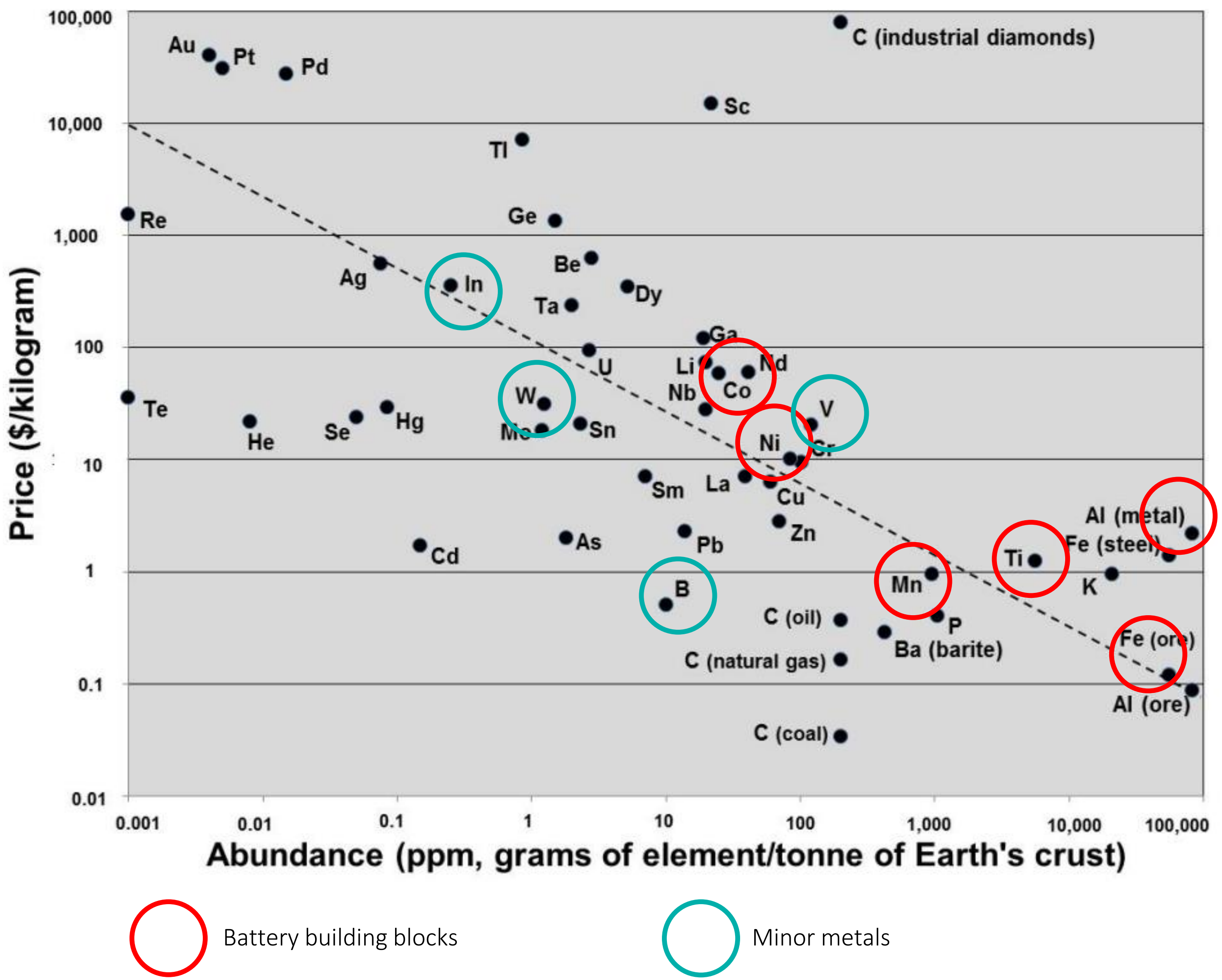
	1st GEN	2nd GEN	Current	Future
CAM	Polycrystaline (heterostructure) Doped/coated	Polycrystaline (microstructure) Doped/coated	Single crystal (monostructure) Doped/coated	Disordered rock salt ? ?
Anode	Carbons (Flake/amorphous/synthetic) LVO	Carbons +SiO_2 Alloys LTO	Carbon +>SiO_2 LNbO	Silicon Lithium Niobates?
Metals	Cobalt/Nickel Manganese Vanadium Aluminium	~~Tin~~ Titanium Silicon Tungsten	Niobium Lithium (metal) Zirconium Boron	Silicon Lithium ? ?

Improvement in electrolyte formulations has also impacted coating/dopant use

Abundance/price is a limiter to minor metal uptake in batteries, while form and IP protection keeps discussion out of the public domain

- Dopants and coatings are added in salt form (e.g. $M.SO_4$ $M.NO_3$), therefore commonly traded forms may not appear to be directly used
- The most common dopant/coating (Al & Mg) are large volume markets, even in chemical form
- More specialised coating and dopant element use (Zr, W, B), being a more secret sauce, is less widely discussed
- Future technology IP is closely held



Source: Colorado School of Mines

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Outlook for minor metals in aerospace

How aerospace learnt to love Hafnium, Tantalum and Rhenium…

…but how supply chains may not return the favour

by Michael Husakiewicz,
Director at Lipmann Walton & Co Ltd

AS9120 &
ISO 9001 Accredited

Lipmann Walton & Co Ltd – founded in 1953

Traders and stock-holders in minor metals

- Zirconium, Hafnium, Rhenium, Tantalum
- Niobium, Titanium, Vanadium, Tungsten

- Nickel & Cobalt alloys

- Thallium, Tellurium, Calcium, Germanium
- Rare Earth Metals, Rare Earth Magnet Scrap

by Michael Husakiewicz,
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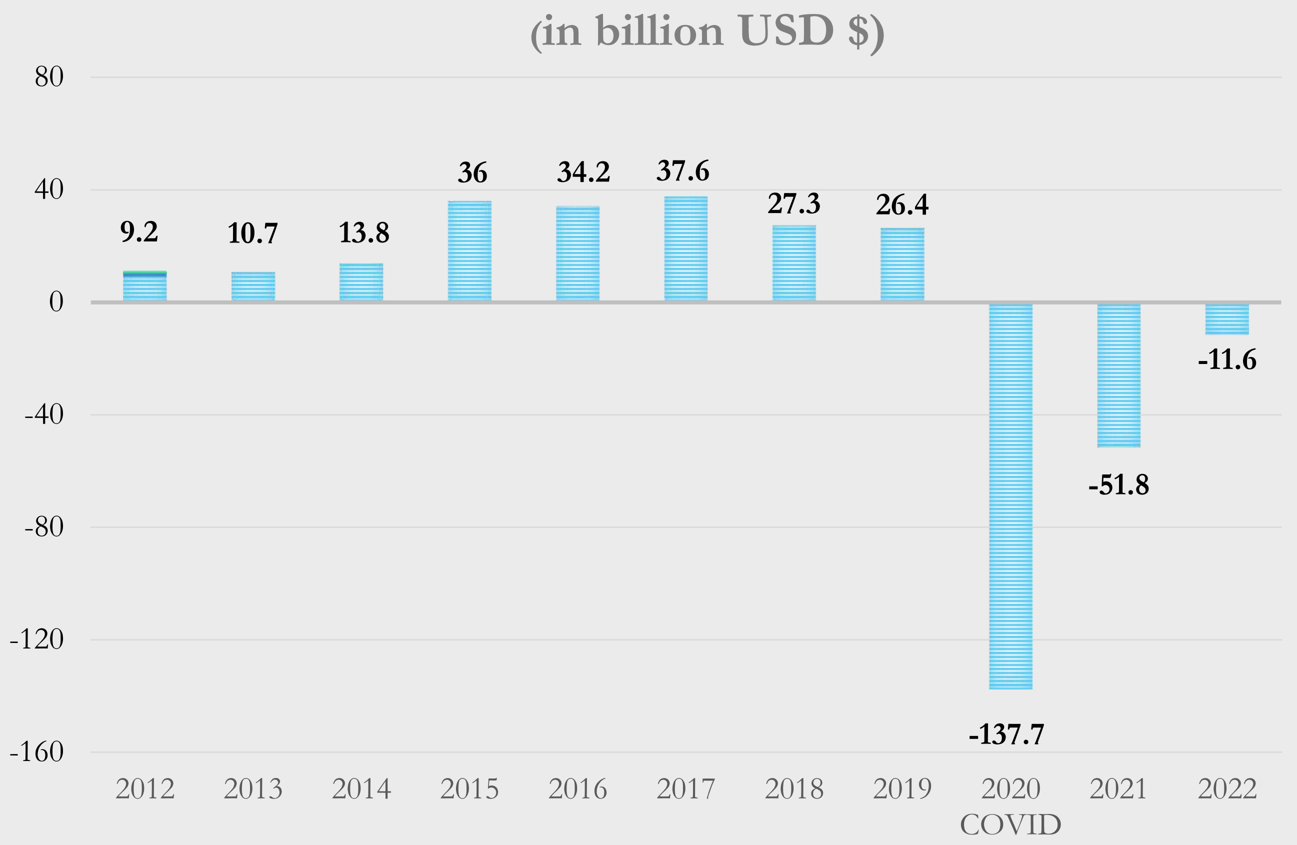
Net profit of commercial airlines worldwide 2012-2022



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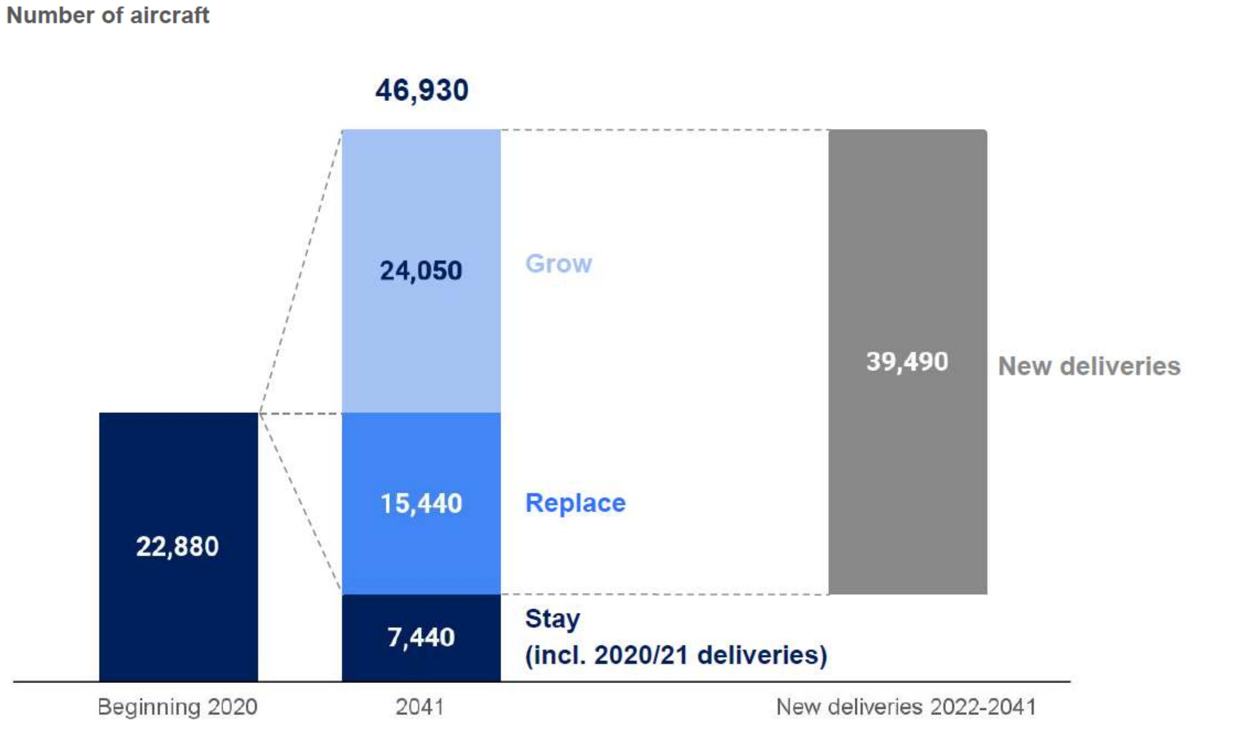
Demand for ~39,500 new passenger & freighter aircraft

Source: Airbus GMF
Notes: Passenger aircraft above 100 seats & freighters with a payload above 10t



Global Market Forecast 2022

AIRBUS

Outlook for minor metals in aerospace

Rhenium pellets

Hafnium crystal bar

Tantalum cut solids

It is a precarious task to predict the future after so many forecasts have been wrong. Only a fool would try to guess metal price next year and beyond.

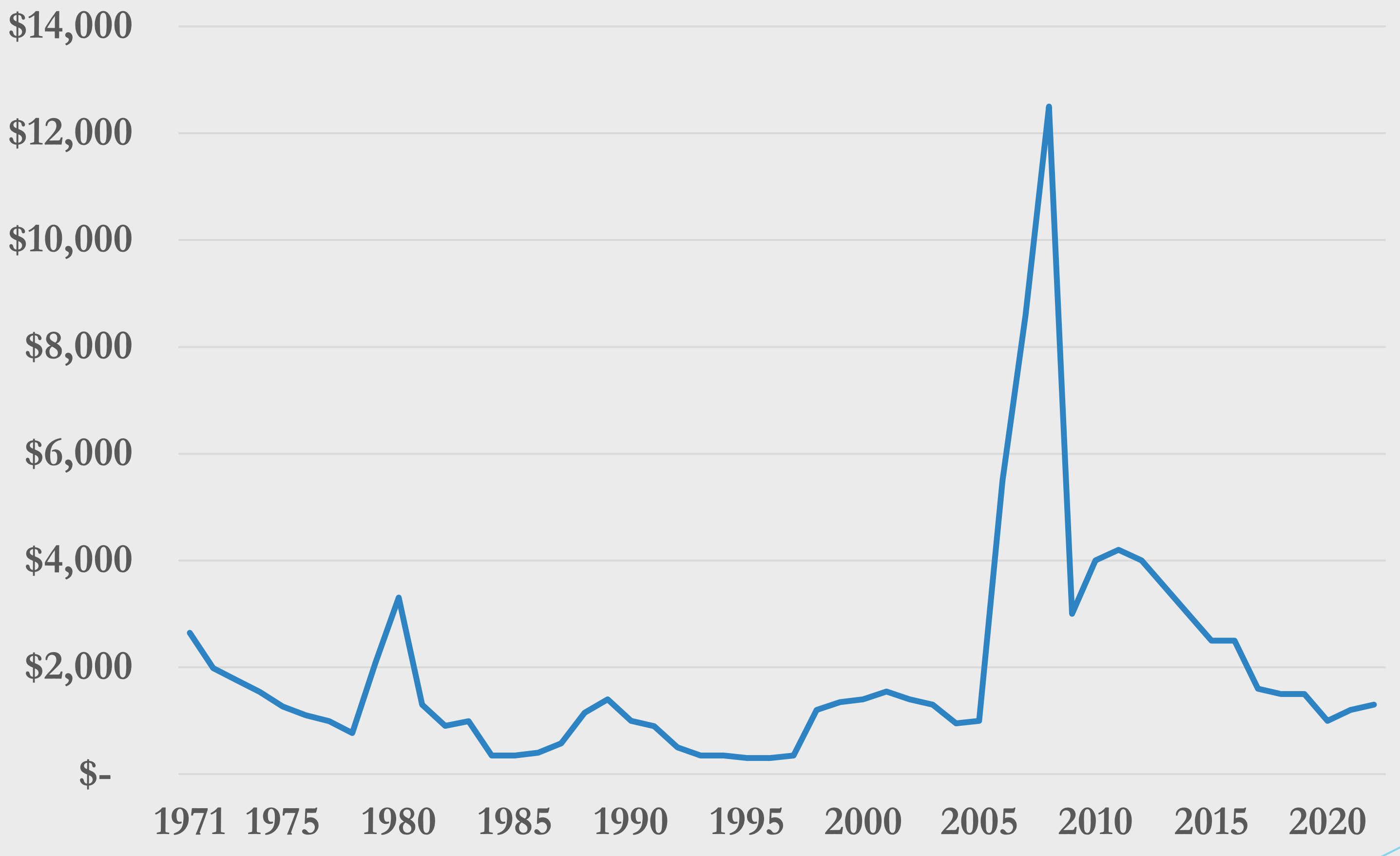
I proceed.

Let's start with Tantalum…

Lipmann Walton
& CO LTD

October 2022

Rhenium average prices $/kg



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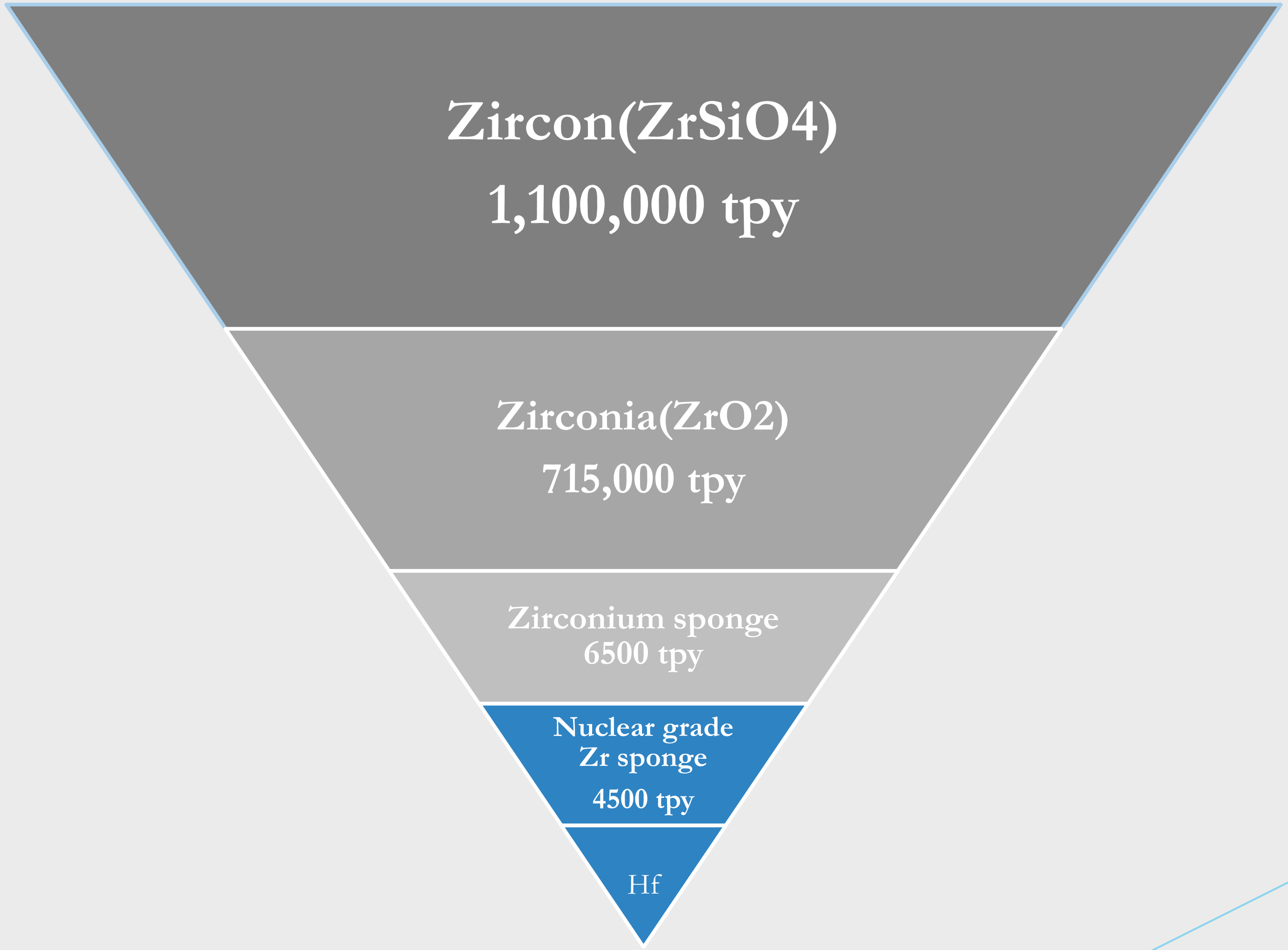
Hafnium


Zircon(ZrSiO4)
1,100,000 tpy
Zirconia(ZrO2)
715,000 tpy
Zirconium sponge
6500 tpy
Nuclear grade
Zr sponge
4500 tpy
Hf

Industrial Gas Turbines and Jet Engines are the main Super Alloy applications

Alloy	Cr (%)	Co (%)	Mo (%)	W (%)	Ta (%)	Al (%)	Ti (%)	Hf (%)	Ni (%)
GTD 111	14	9.5	1.5	3.8	3	3	5	**0.15**	Bal.
Rene 108	8.4	9.5	0.5	9.5	3	5.5	0.7	**1.5**	Bal.
Rene 125	8.9	10	2	7	3.8	4.8	2.5	**1.5**	Bal.
Rene N5	7	7.5	1.5	5	6.5	6.2		**0.15**	Bal.
Rene N6	4.2	12.5	1.4	6	7.2	5.8		**0.15**	Bal.
Rene 142	6.8	12	1.5	4.9	6.4	6.1		**1.5**	Bal.
MAR M247	8.2	10	0.6	10	3.0	5.5	1.0	**1.5**	Bal.

Conclusion & Questions

by Michael Husakiewicz,
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