Exploring the potential of critical mineral resources in Europe: Setting challenging and realistic targets

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The criticality index of mineral raw materials shifts much faster than the ability of the EU to meet the rapidly rising supply demand

The following 34 raw materials are proposed for the CRM list 2023:

2023 Critical Raw Materials (*new CRMs in italics*)			
aluminium/bauxite	coking coal	lithium	phosphorus
antimony	*feldspar*	LREE	scandium
arsenic	fluorspar	magnesium	silicon metal
baryte	gallium	*manganese*	strontium
beryllium	germanium	natural graphite	tantalum
bismuth	hafnium	niobium	titanium metal
boron/borate	*helium*	PGM	tungsten
cobalt	HREE	phosphate rock	vanadium
		*copper**	*nickel**

17 of them considered also as strategic

Within 12 years the number of CRM has tripled!
OK that new ones are added, but why are all the ones from 2011 and 2014still there!

Minerals that are assessed to be critical are those for which the EU,

- is not self-sufficient, and their supply needs to be someway secured
- is to great extent strongly import-dependent (geopolitical risk!),
- not has the capacity to domestically implement all-inclusive resilient technology value chains that enable energy and digital transition

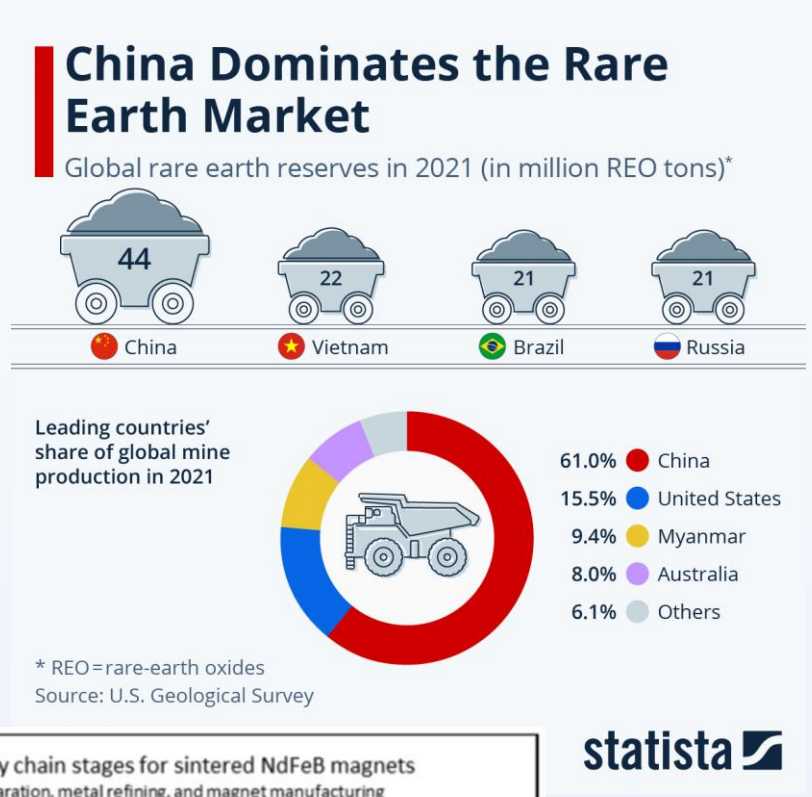
The main reasons are that,

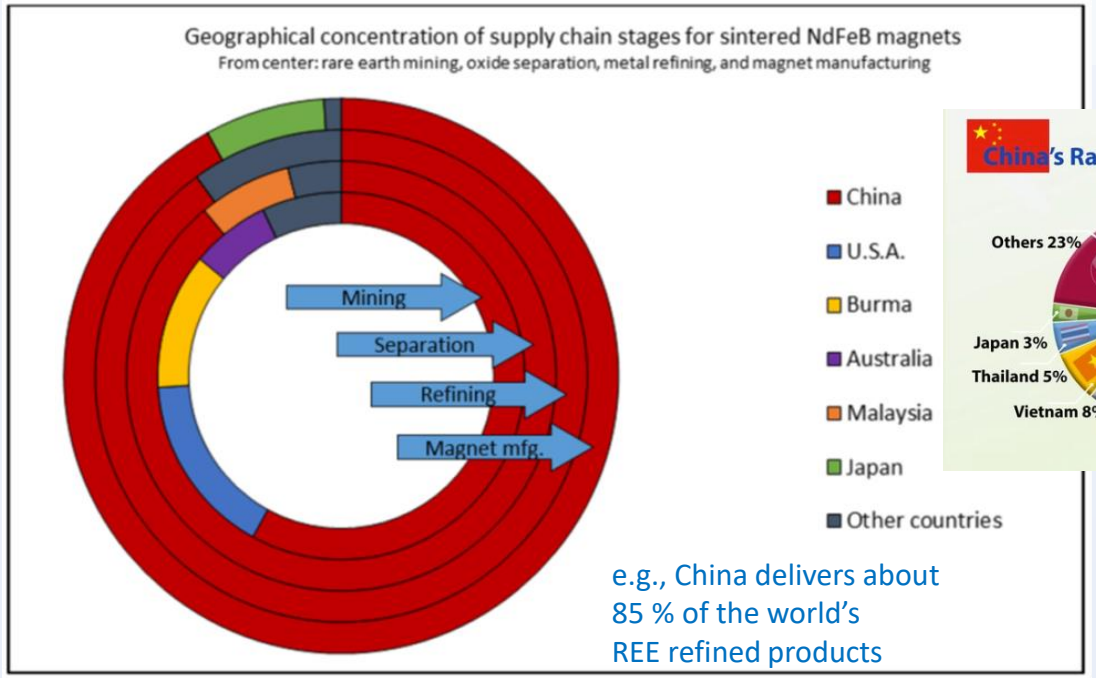
- certain minerals tend to be concentrated in a few places, sometimes in just one country, e.g., about 60% of the world's cobalt comes from the DRC, China is mining and supplying close to 60 % of REE minerals, but consuming also almost 70% of global REE
- non-success of MS to elevate advanced exploration projects to mining. Governments and the EU invest public money to improving the economic geology knowledge base and to identifying critical minerals systems of high exploration potential, but the same governments do not act in the same way when it comes to granting mining permits. This means that the demand is always ahead of the available assets.

2011 (14)	2014 (20)	2017 (27)	2020 (30)
Antimony	Antimony	Antimony	Antimony
.	.	.	Bauxite
.	.	Baryte	Baryte
Beryllium	Beryllium	Beryllium	Beryllium
.	.	Bismuth	Bismuth
.	Borate	Borate	Borate
.	Chromium	.	.
Cobalt	Cobalt	Cobalt	Cobalt
.	Coking coal	Coking coal	Coking coal
Fluorspar	Fluorspar	Fluorspar	Fluorspar
Gallium	Gallium	Gallium	Gallium
.	.	Natural rubber	Natural rubber
Germanium	Germanium	Germanium	Germanium
Graphite	Graphite	Graphite	Graphite
.	.	Hafnium	Hafnium
.	.	Helium	.
Indium	Indium	Indium	Indium
.	.	.	Lithium
.	Magnesite	.	.
Magnesium	Magnesium	Magnesium	Magnesium
Niobium	Niobium	Niobium	Niobium
Platinum group metals	Platinum group metals	Platinum group metals	Platinum group metals
.	Phosphate rock	Phosphate rock	Phosphate rock
.	.	Phosphorus	Phosphorus
.	.	Scandium	Scandium
.	Silicon	Silicon	Silicon
.	.	.	Strontium
Tantalum	.	Tantalum	Tantalum
.	.	.	Titanium
Rare earth	Light rare earth	Light rare earth	Light rare earth
	Heavy rare earth	Heavy rare earth	Heavy rare earth
Tungsten	Tungsten	Tungsten	Tungsten
.	.	Vanadium	Vanadium

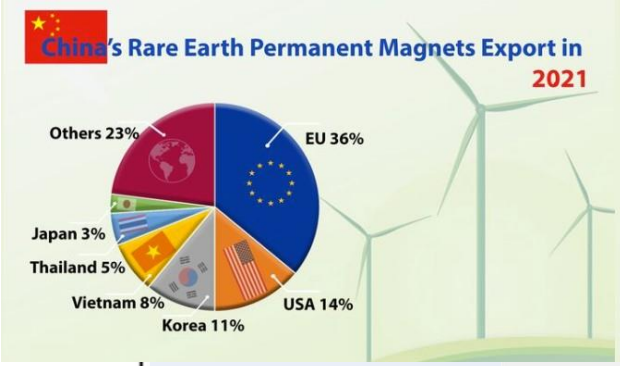
Full-scale battery and magnet minerals value chains under Chinese dominance

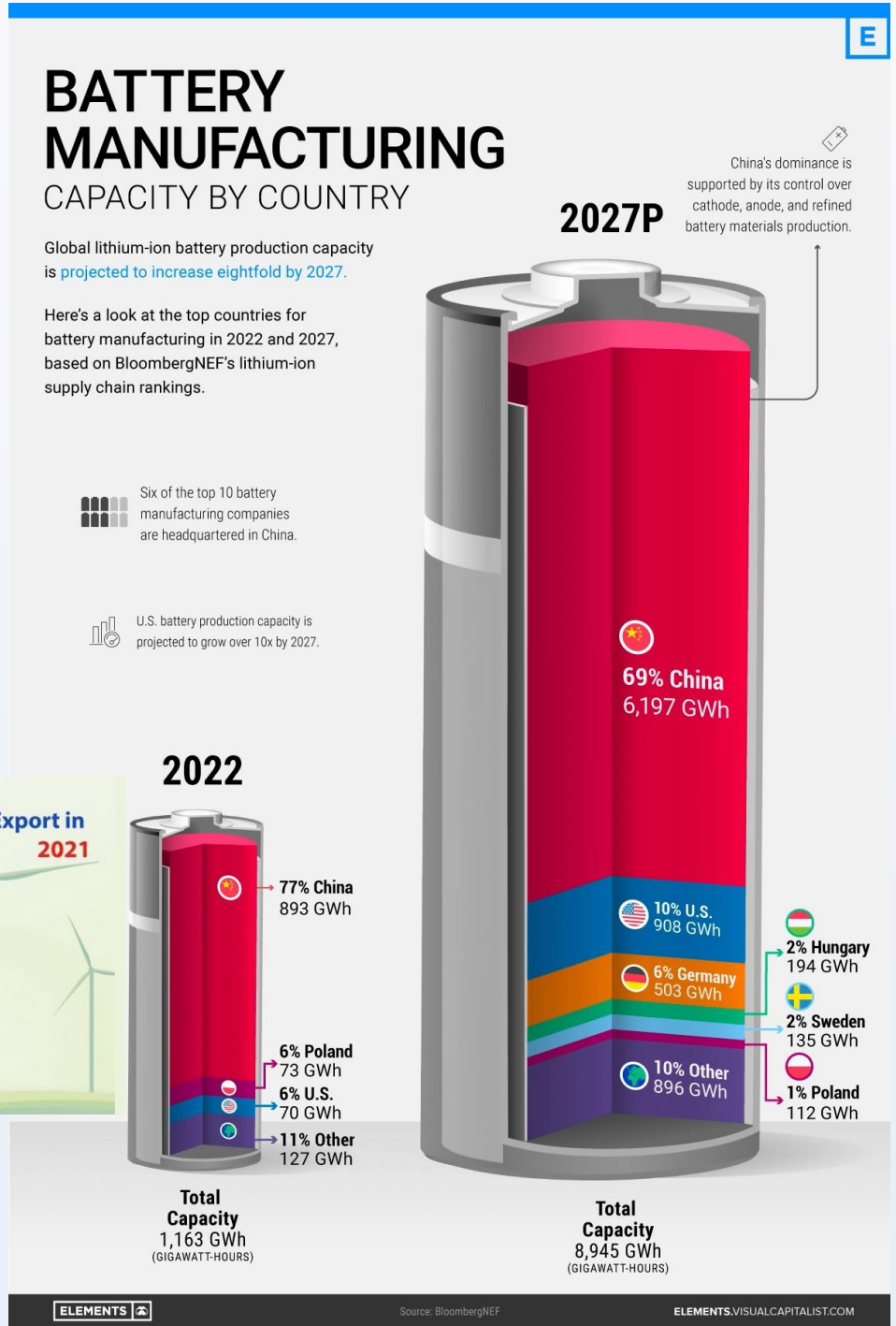
Li-batteries and Nd-magnets are the most vulnerable technologies for EU. Import dependence on Li, Co, REE minerals may develop into a major bottleneck in production planning of the 16 Li-battery factories to be operational in the EU, by 2030





e.g., China delivers about 85 % of the world's REE refined products





Challenging targets of CRMA

Better late than never!

The first public political statement by the EC (Council & Commission) that the EU needs to secure the supply of CRM and the domestic implementation of relevant strategic value chains!

I really hope CRMA will prove to be the right platform to start doing things in a more effective and practical way!

Would 2030 be a turning point for greener EU economy?

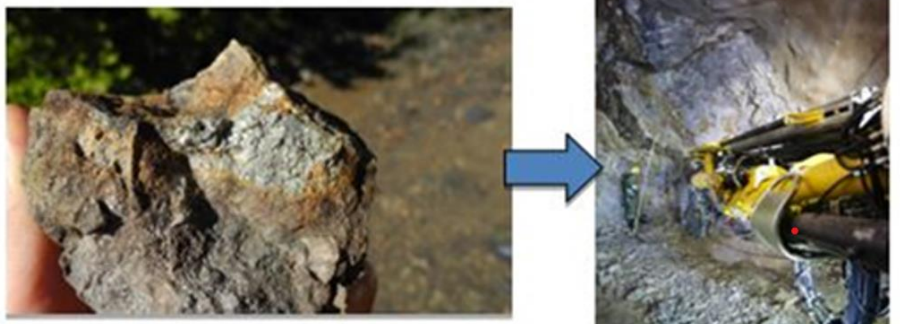
- Mineral intensity issues, in relation to Green Deal targets to be achieved by 2030, e.g., cut greenhouse gas emissions by at least 55%.
- The EU electric automotive penetration of 7-8 m cars annually. By 2030, more battery and magnet minerals will be needed, if car makers are to hit these very ambitious production targets.
- Lithium demand has risen very strongly in the last few years, and it is expected to go higher, especially as the planned battery giga factories appear to be coming online in the next 12 to 36 months.
- According to CRMA, by 2030 10% of the Union's consumption of strategic mineral raw materials should be mined in the EU
- In fact, 2030 is only seven years away. Just about 10 years or so, is about the amount of time it takes to bring a new mine into production. To consider also that 1% of mineral occurrences found will become a mine!
- **So, the central question is where all these battery and magnet minerals needed will come from? Would EU manage to reach the 10% target?**

“Critical” need for highly capital- and resource-intensive mineral exploration

- Increasing the degree of self-sufficiency from 2-3% to 10% in 2030 means a 300-400% increase in domestic production in 7 years!
- That's about the time it takes on average to get a permit in place.
- Massive efforts and an increase in investment in exploration to at least an equivalent degree are required if we are to even come close to that degree of self-sufficiency!
- Of course, we need to apply innovative and sustainable approaches, using breakthrough technologies, in that way improving the economic efficiency and obtaining information that could not be obtained by the conventional methods

Exploration should always consider minerals value chains progression

Upstream | Midstream | Downstream



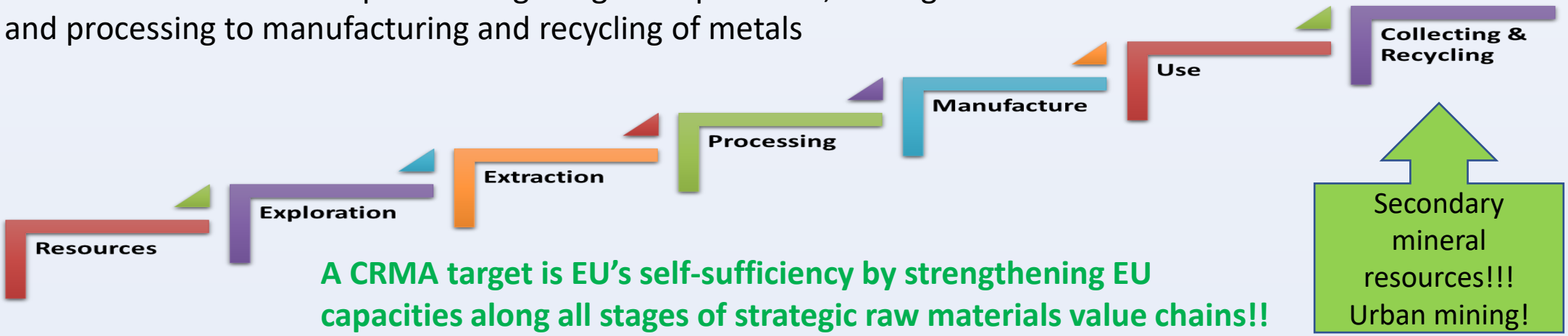
Li-battery

Lithium, Cobalt Graphite, Nickel, Manganese, Vanadium

Electric car

Neodymium, Dysprosium, Copper, Aluminium, Magnesium

The mineral value chain spans from geological exploration, mining and processing to manufacturing and recycling of metals



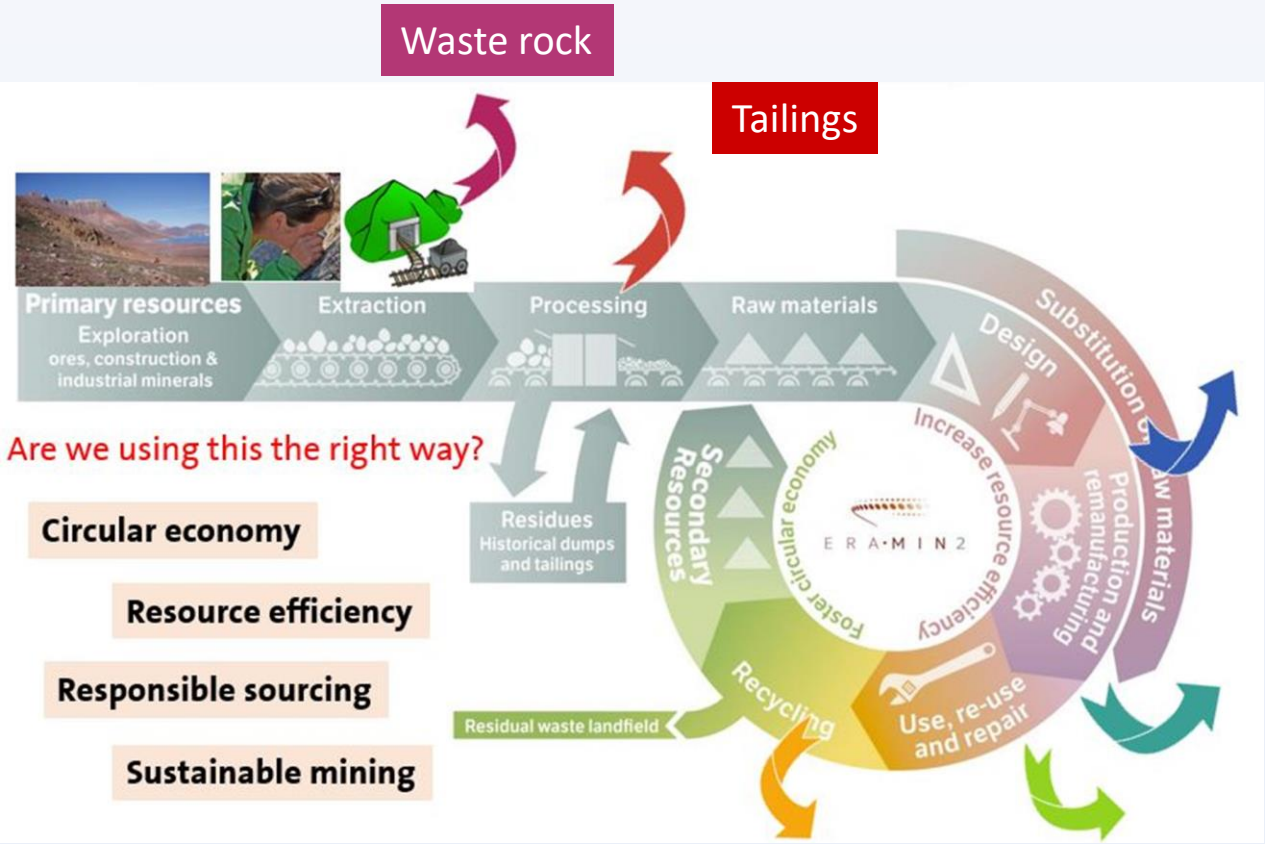
A CRMA target is EU's self-sufficiency by strengthening EU capacities along all stages of strategic raw materials value chains!!

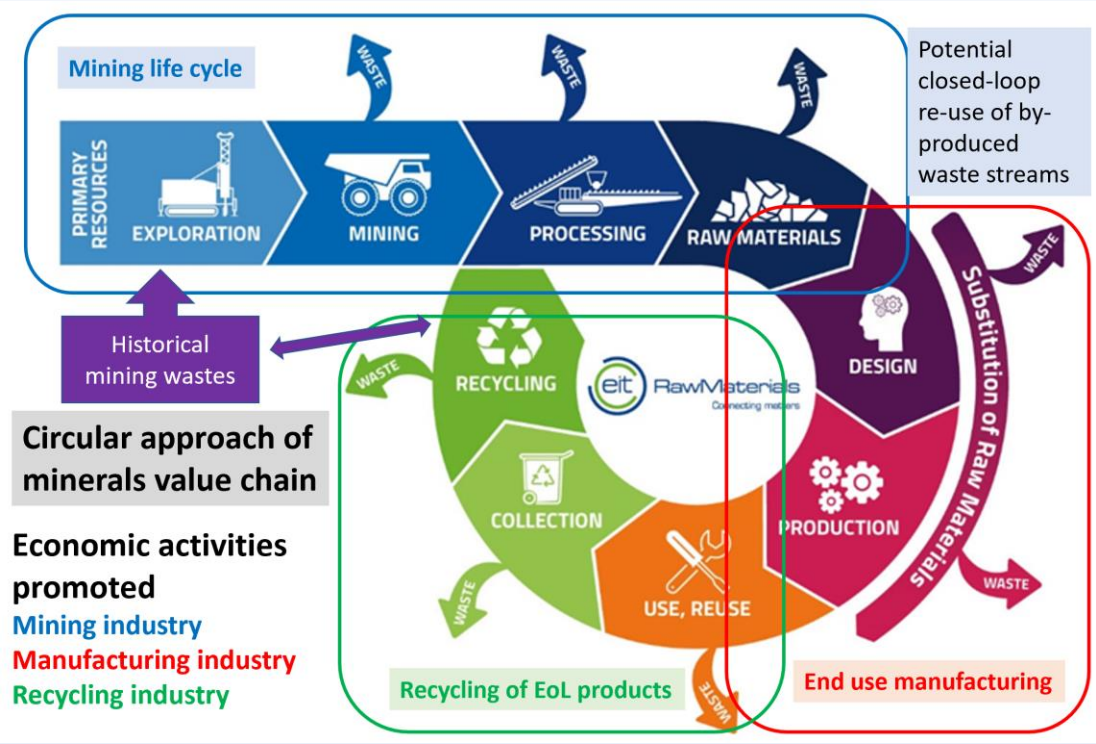
Why also extraction from secondary mineral resources?

- Rapidly growing demand (500% by 2050 according to the World Bank) for mineral raw materials (climate neutrality, energy conversion, electrification); the purpose is for a share of demand to be met through secondary resources.
- This way, reduce import dependence on critical raw materials and thereby contribute to increasing security of supply. Currently EU is 100% dependent on import suppliers in 14 out of 27 CRM, 95% on additional three CRM and 86% of REE from China. A CRMA benchmark target is to not be dependent on one single third country for more than 65% of imports for CRM by 2030.
- To achieve conversion to a circular and resource-efficient economy is needed to reach CRMA's 15% recycling target by 2030.
- Ensure the implementation of sustainable mineral value and supply chains by strengthening Europe's self-sufficiency along the entire value chain by 2030, as anticipated in the CRMA.

Minerals value chains circularity

The raw materials potential of secondary (re)sources (mineral-based and EoL) needs also to be explored!!





According to CRMA, by 2030 15% of the EU's annual consumption of each CRM should come from recycling

Exploration as part of Economic Geology

- Access to harmonized knowledge-based mineral data/information (primary and secondary mineral resources)
- Understand better the geological setting of critical mineral systems
- Apply CRM-fitting exploration technologies and methods (e.g., 3D models integrating geology, geophysics, geochemistry…)
- Consider the challenges in relation to brownfield and/or greenfield exploration targets, e.g., location of deeper-seated ore bodies, re-mining historical wastes in the case of brownfield exploration
- Resource classification based on UNFC system; degree of confidence for volume and grade estimates depend on the level of geological knowledge, e.g., drilling exploration data available??
- Beneficiation testing suggesting possible processing technology options, considering also the CRMA target that by 2030 40% of the EU's annual consumption of each strategic mineral raw material, should be refined within the Union.
- Mining design/plan considerations; open-pit and/or underground
- Pre-feasibility study

Most critical minerals are directly linked to known sulfide and oxide ore deposits

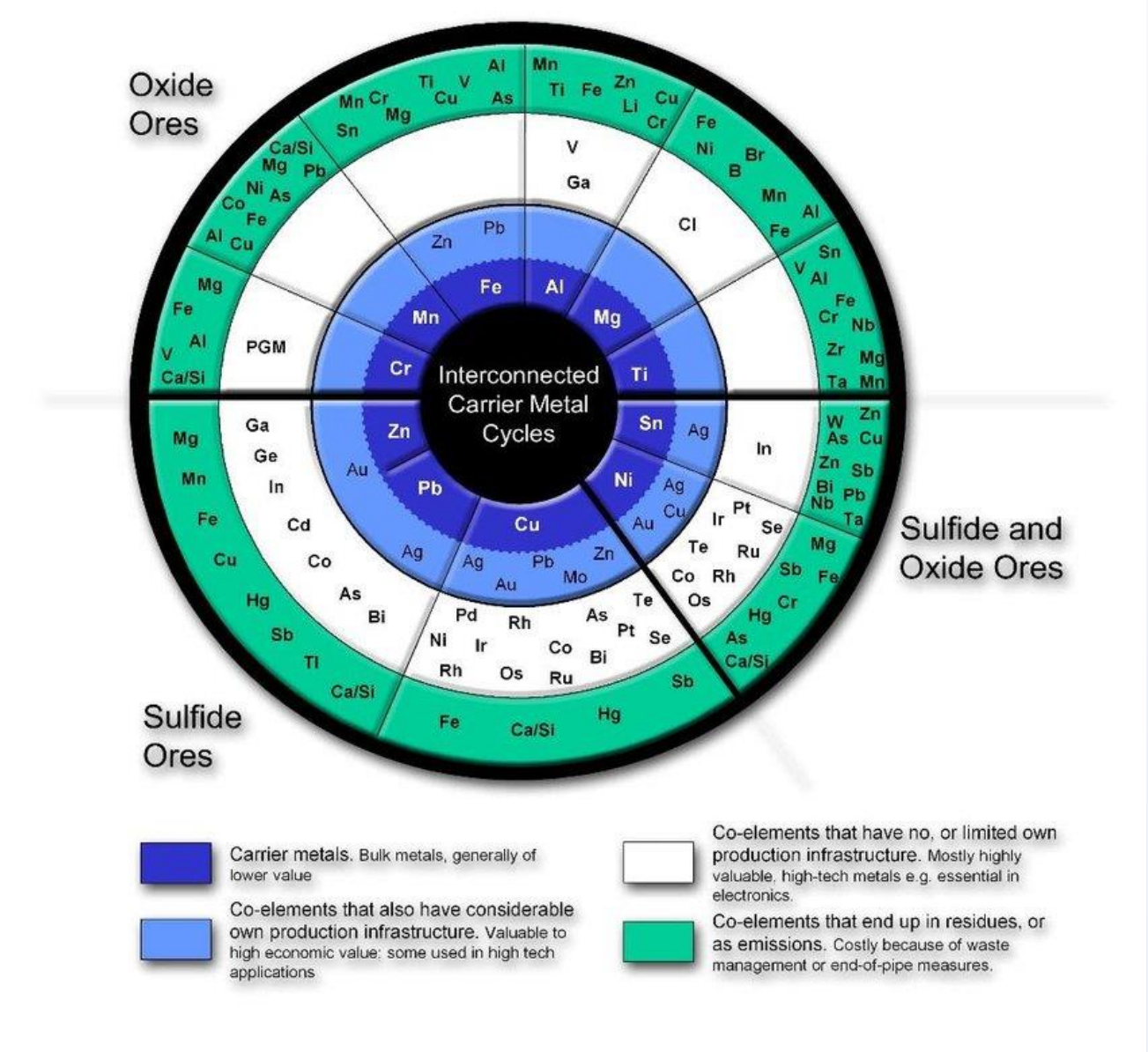
Examples on critical minerals found associated with known mineral systems,

- Co with Ni ones
- Ga, Ge, In, Sb with base metal sulfides
- PGM with Cr, Ni and Cu
- W, Nb, Ta with Sn

Exploration efforts in such cases might be a matter of,

- A feasibility study, when it comes to active mines, addressing the volume, grades recovery and rate of critical minerals (e.g., LKAB approach)
- Brownfield (deep) exploration* of historical mining fields, including mining wastes, this time focusing on critical minerals.

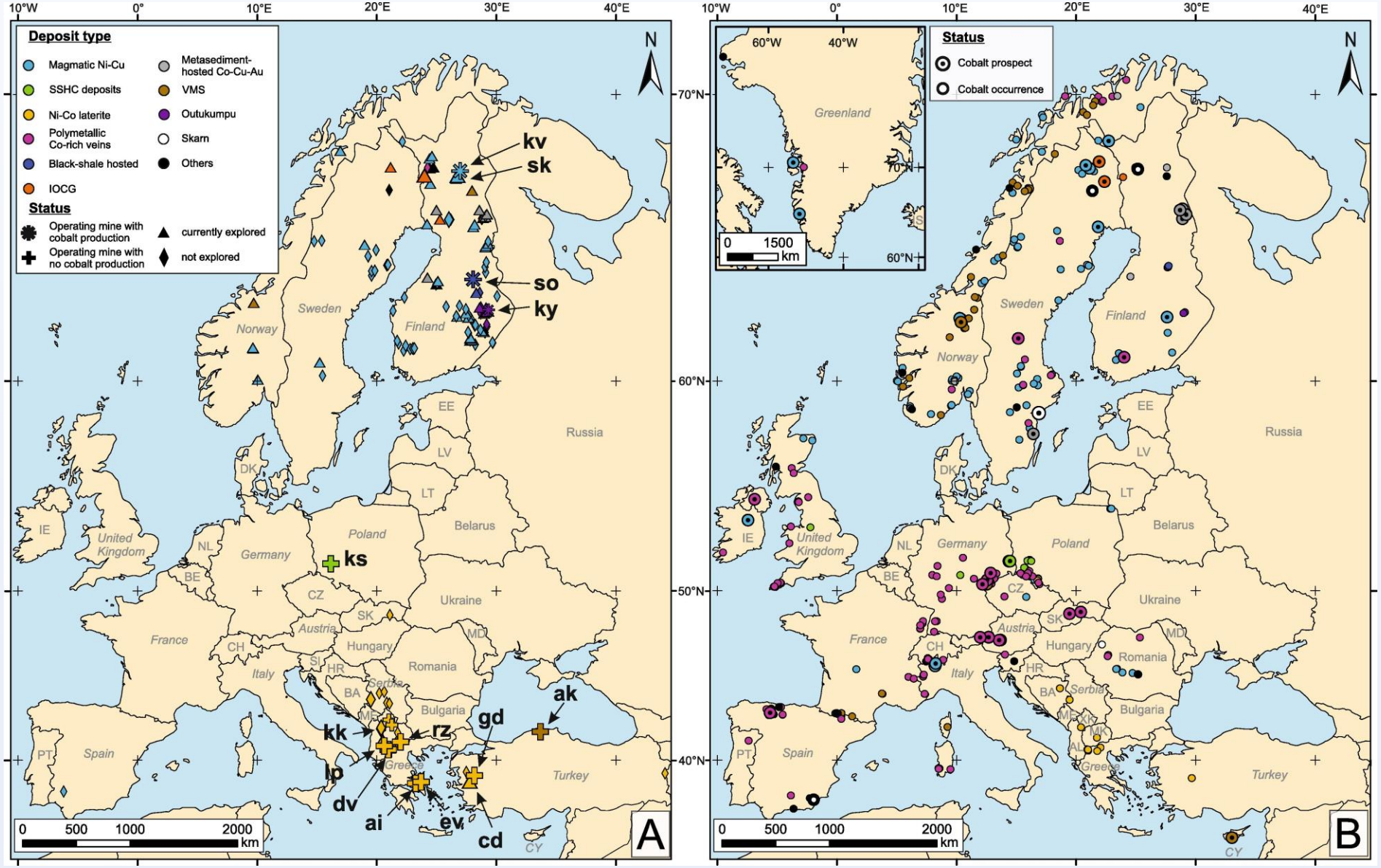
Mining wastes, a new mineral deposit target!



* Brownfield exploration; less expensive, more time-efficient, better conditions for permitting, benefits the environment, easier to be socially accepted

Mineral deposit types and exploration potential for cobalt in Europe

Source: Horn et al (2021): Cobalt resources in Europe and the potential for new discoveries. Ore Geology Reviews (in press)



Deposit types and metal associations

Number	Deposit types *(Exempel)*	Commodity Association
1	Alkaline & Peralkaline intrusions *(Norra Kärr REE-project)*	Nb, REE, P, (Ta, Zr, Sc, F, U, Fe)
2	Epithermal	Au, Ag, Sb, Hg, Te, Cu, In
3	Igneous Felsic *(Cinovec Li-project)*	Sn, W, Ta, Nb, (Mo, Li, Be, B, In, F)
4	Igneous Intermediate	Cu, Mo, Au, (Re)
5	Igneous Replacement	Fe, W, Pb, Zn, Cu, As, (Sb, Au, Ag)
6	IOCG/IOA *(Kiruna iron mine and related mining wastes)*	Fe, Cu, Au, (P, REE, U, Co)
7	Mafic intrusion	Fe, Ti, V
8	Mafic or Ultramafic *(Kevitsa Ni mine; Sakatti project)*	Ni, Cr, Cu, PGE, (Co, Bi, U, Ag)
9	Orogenic Gold	Au, (Ag, As, W, Cu, Sb, Bi)
10	Pegmatites (Keliber Li-project)	Nb, Ta, Sn, Li, Be, (U, REE)
11	Carbonate-hosted deposits	Zn, Pb, Ag, Ba
12	Sandstone- and shale-hosted deposits *(Kylylahti & Sotkamo Ni mines)*	Cu, U, Pb, (Ni, Co, Zn, V, PGE, Re)
13	Sedimentary deposits	Fe, Mn, Ba,K,Na,Sr
14	VMS	Cu, Zn, Pb, (As, Ag, Au, Te, Sn, In)
15	Residual deposits *(Greek Ni laterite and Al bauxite mines; mining wastes)*	Fe, Al, Ni, Cu, (Mn, Au, P, Co, REE, Sc)
16	Base metals veins	Pb, Zn, Cu, U, (Ba, F)

Average (max value)

Grängesberg Iron oxide-apatite ore

Waste rock

4 020 ppm P
510 ppm REE+Y (1 429)
10,3 % Fe
6 m.t.

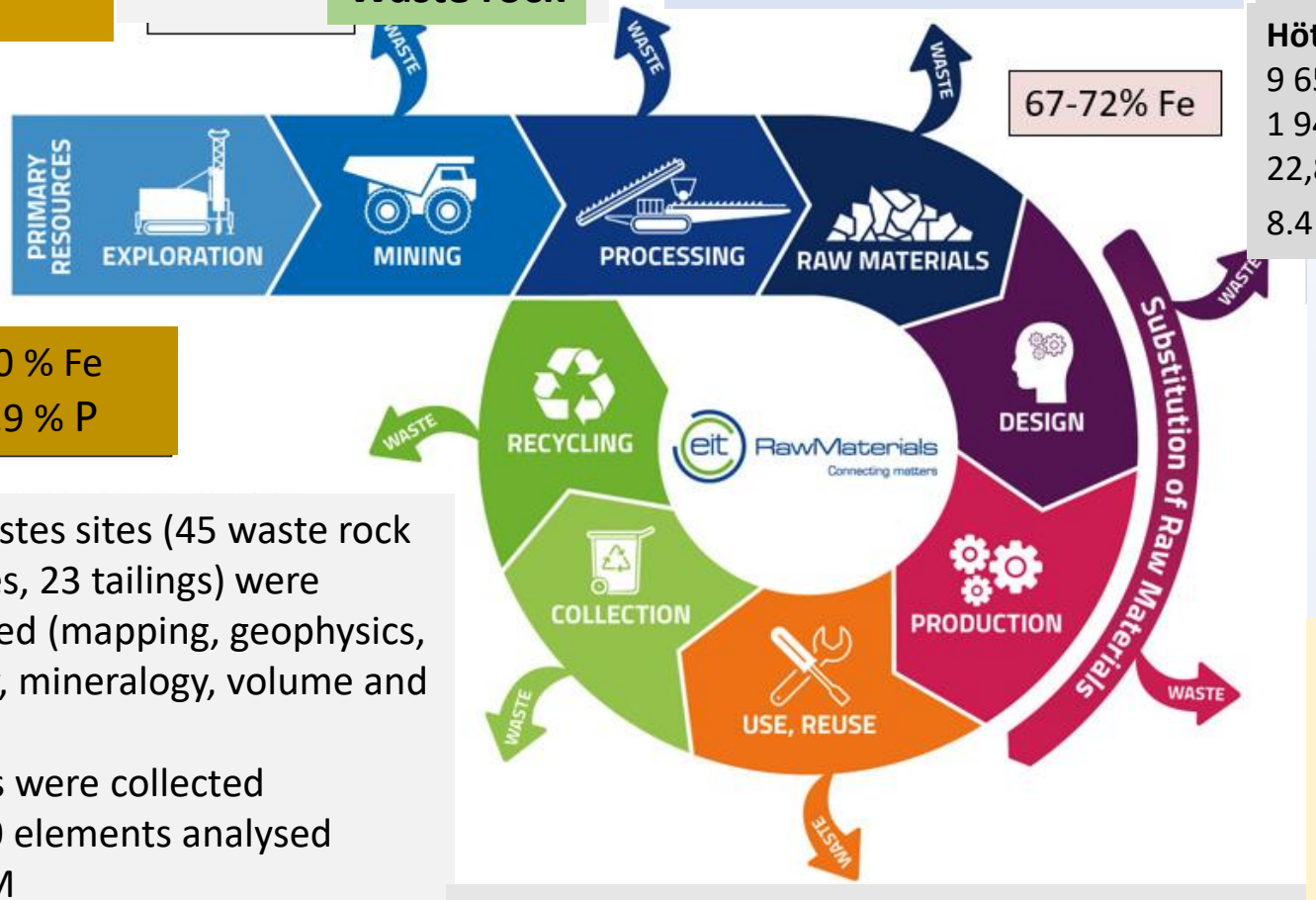
Tailings

Svandammen
9 330 ppm P
902 ppm REE+Y (1 090)
7,37% Fe
3.1 m.t.

Jan-Mats dammen
22 900 ppm P
1 850 REE+Y (3 370)
15 % Fe
2.5 m.t.

Hötjärnen
9 650 ppm P
1 940 REE+Y (2180)
22,8 % Fe
8.4 m.t.

67-72% Fe



Ore metal content

50 % Fe
0,9 % P

- 70 mining wastes sites (45 waste rock and warp piles, 23 tailings) were totally explored (mapping, geophysics, geochemistry, mineralogy, volume and grades)
- 1067 samples were collected
- More than 60 elements analysed including CRM
- 31 m.t. waste rock and warp piles
- 121 m.t. processing tailings
- UNFC classification applied

Totally potential amounts in all explored tailings:

- 240 000 tons P
- 49 000 tons REE+Y

Tailings mineralogy

Ore minerals
Fluorapatite: P, minor REE
Monazite: LREE
Xenotime: Y+REE
Magnetite: Fe, minor V
Hematite: Fe, minor V

Gangue minerals
Quartz
Feldspar
Biotite
Clinochlore
Hornblende

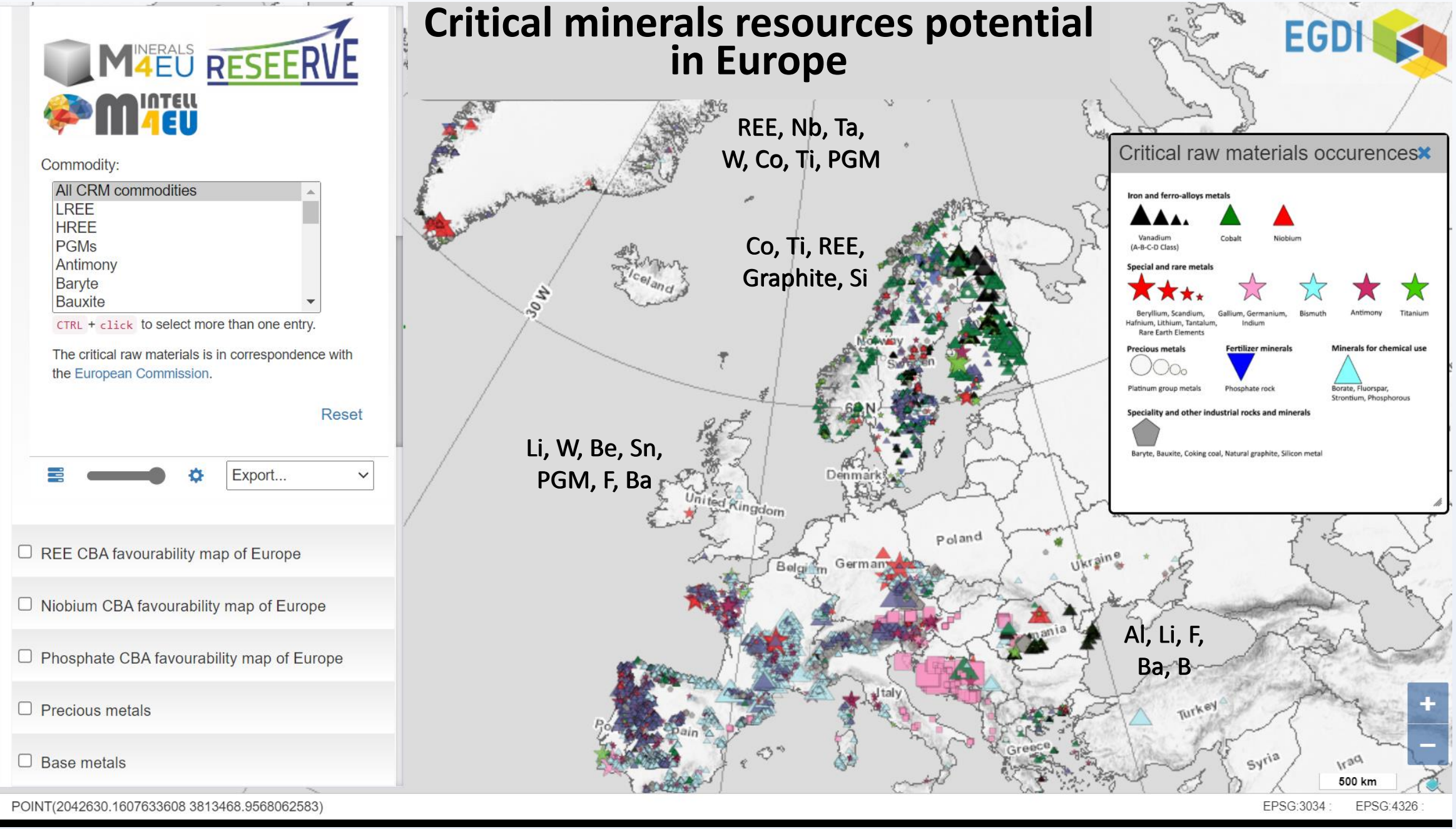
Grängesberg tailings amounts in tons

- Svandammen: 2 800 REE+Y, 29 000 P
- Jan-Mats dammen: 4 700 REE+Y, 58 000 P
- Hötjärnen: 16 000 REE+Y, 81 000 P

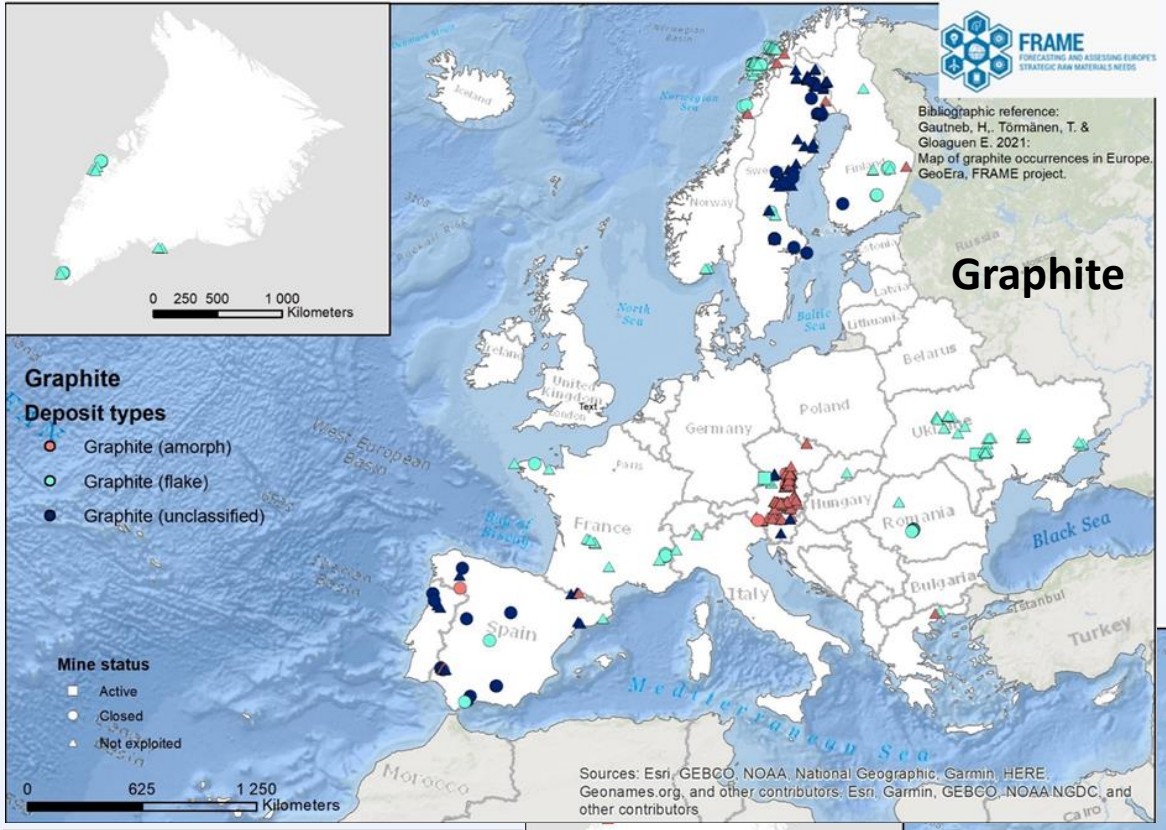
Mining wastes, a new mineral deposit target!

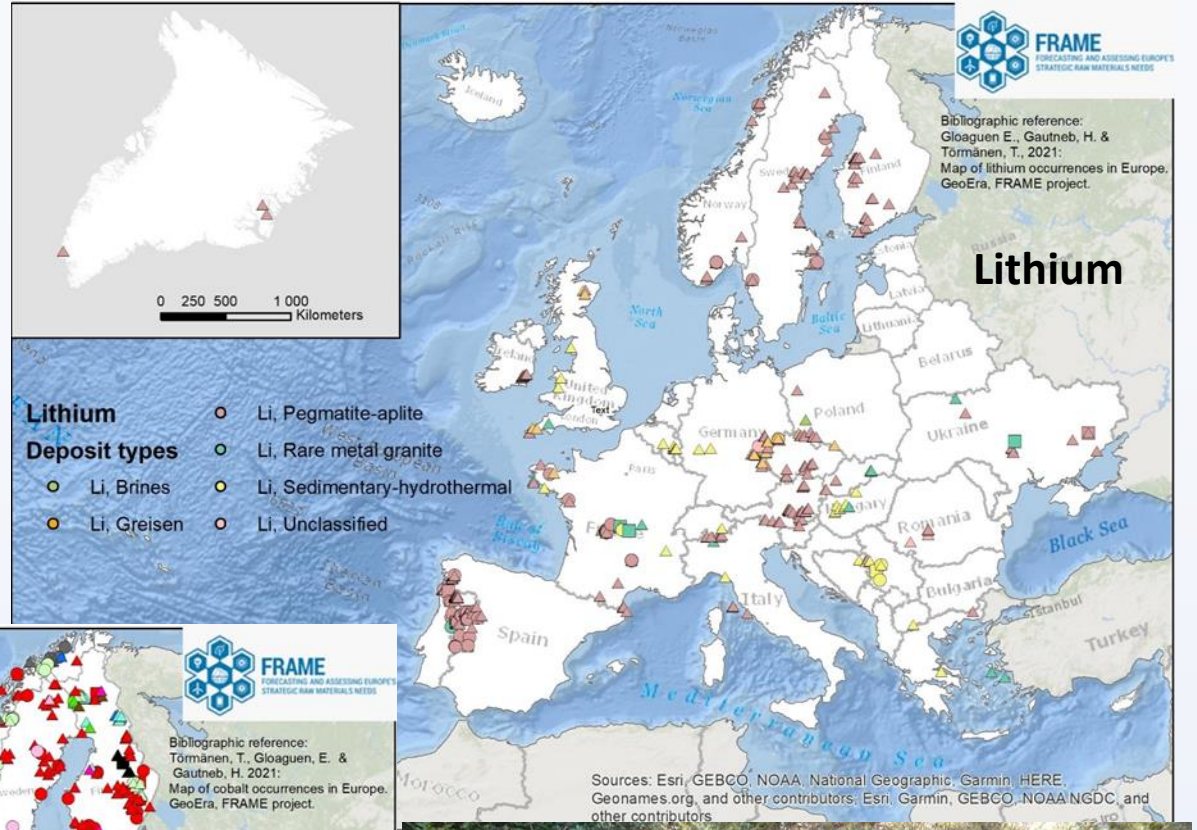
Green Minerals

Critical minerals resources potential in Europe

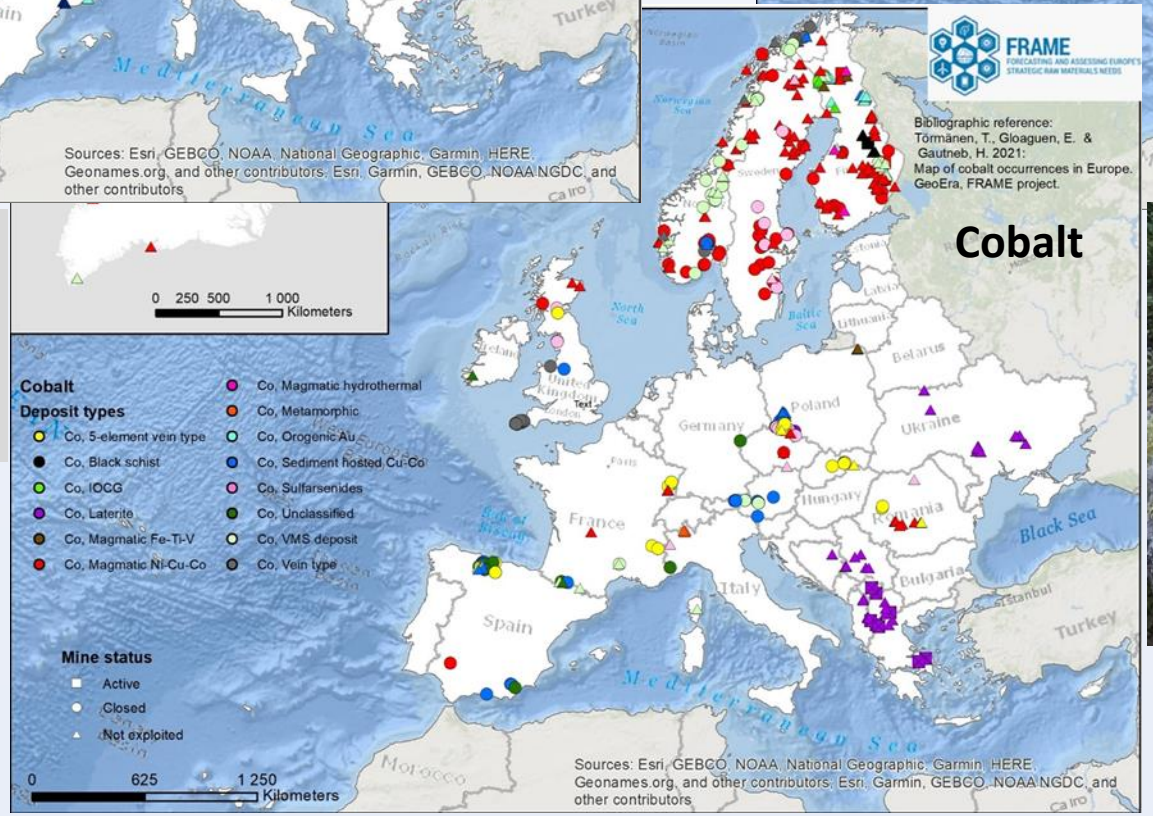


EGDI is EuroGeoSurveys' European Geological Data Infrastructure





Potential battery mineral resources in the EU



Greenfield Li, Graphite and mineral exploration!!

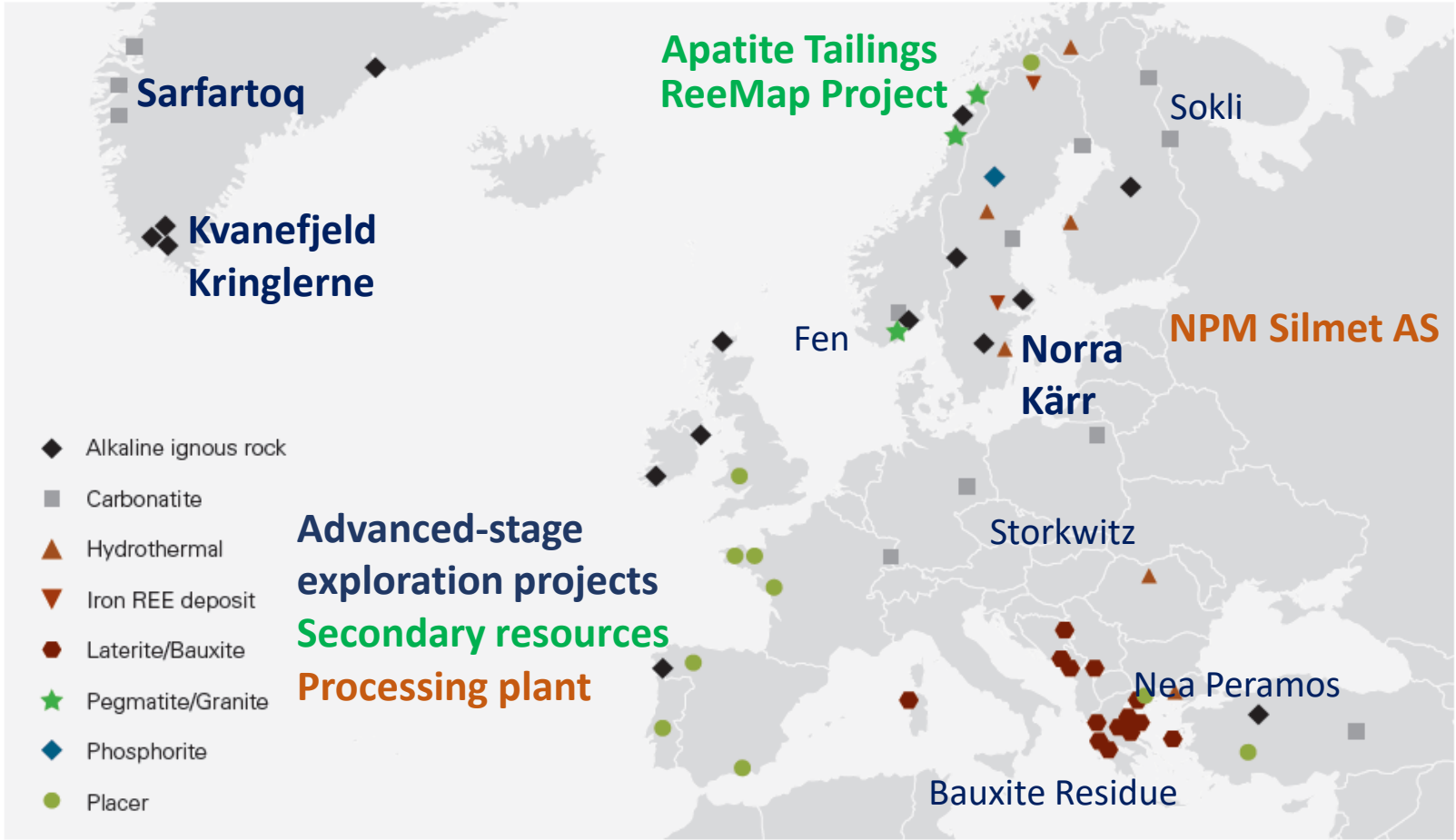
Spodumene pegmatite, Bergby, Sweden

REE mineral deposit types and projects in EU and Greenland (hybrid exploration targets)

- 156 mineralisations in Europe
- 36 advanced projections in the world, only 7 in Europe

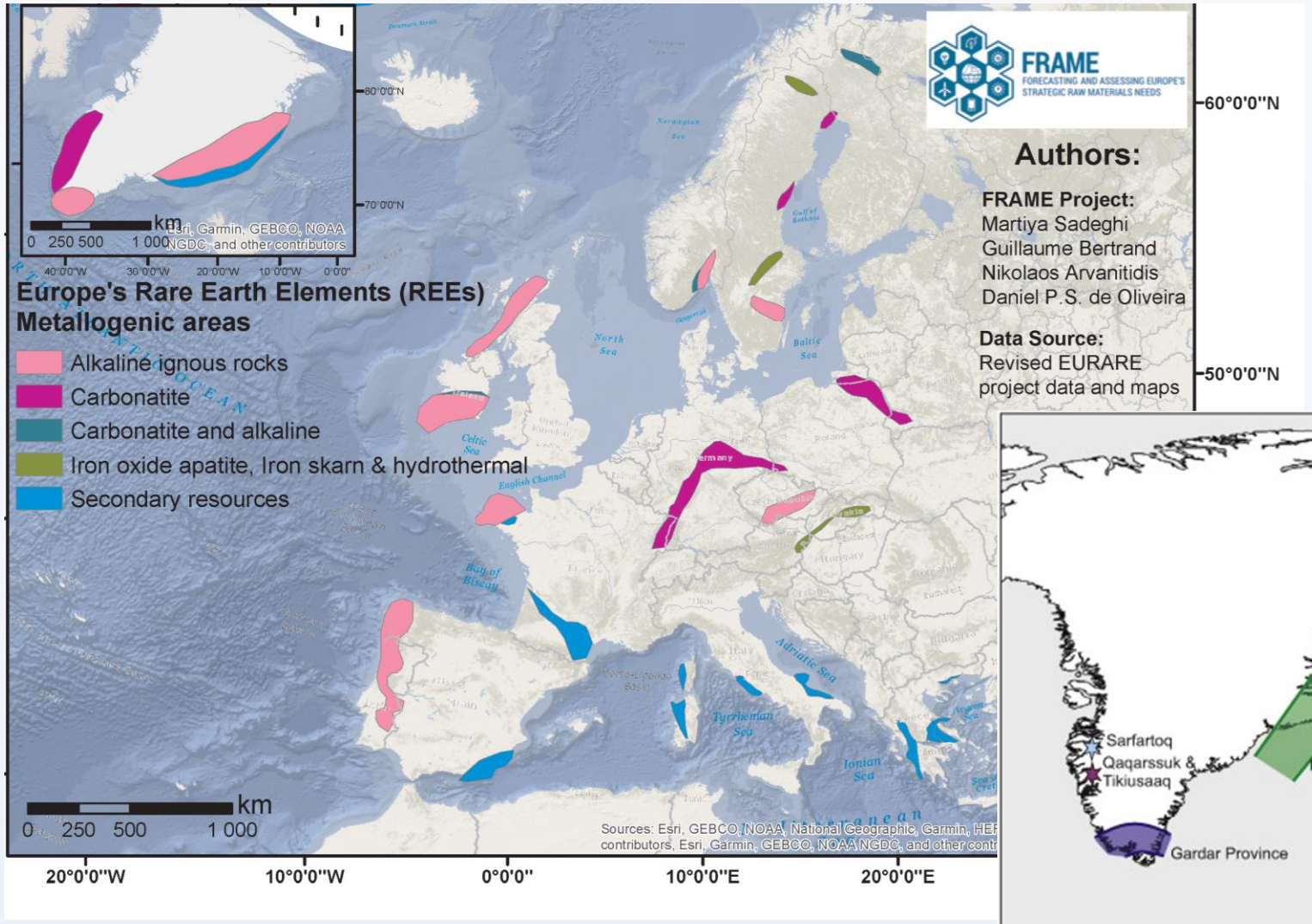
Eudialyte/Silicate mineral

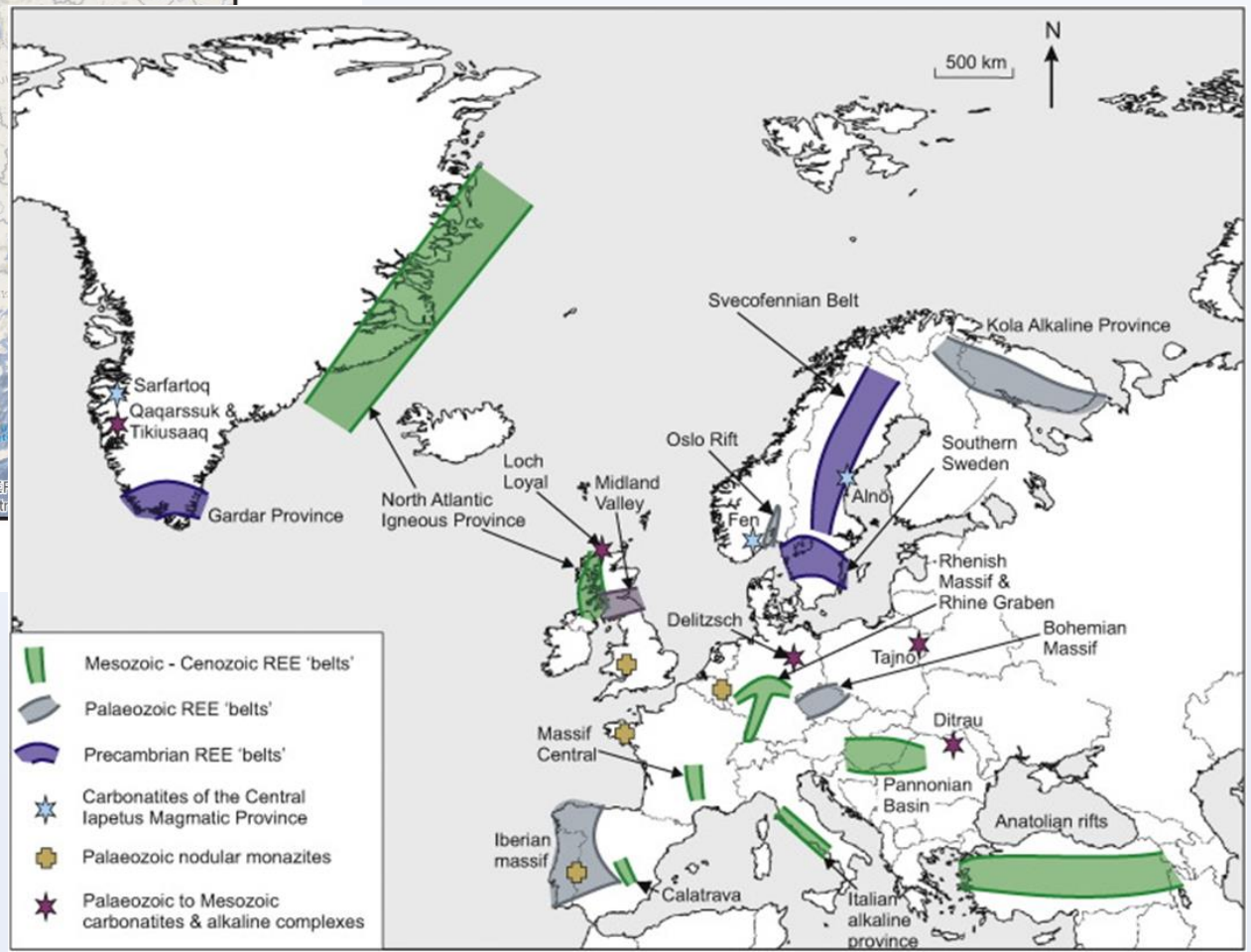
Kakortokite / Nepheline syenite



The exploitable reserves of rare earths in the Kvanefjeld, Kringlerne and Norra Kärr deposits can alone supply Europe's needs for decades to come
Source: EURARE; ERECON; FRAME

REE mineral belts of high exploration potential referring to geological time and deposit types





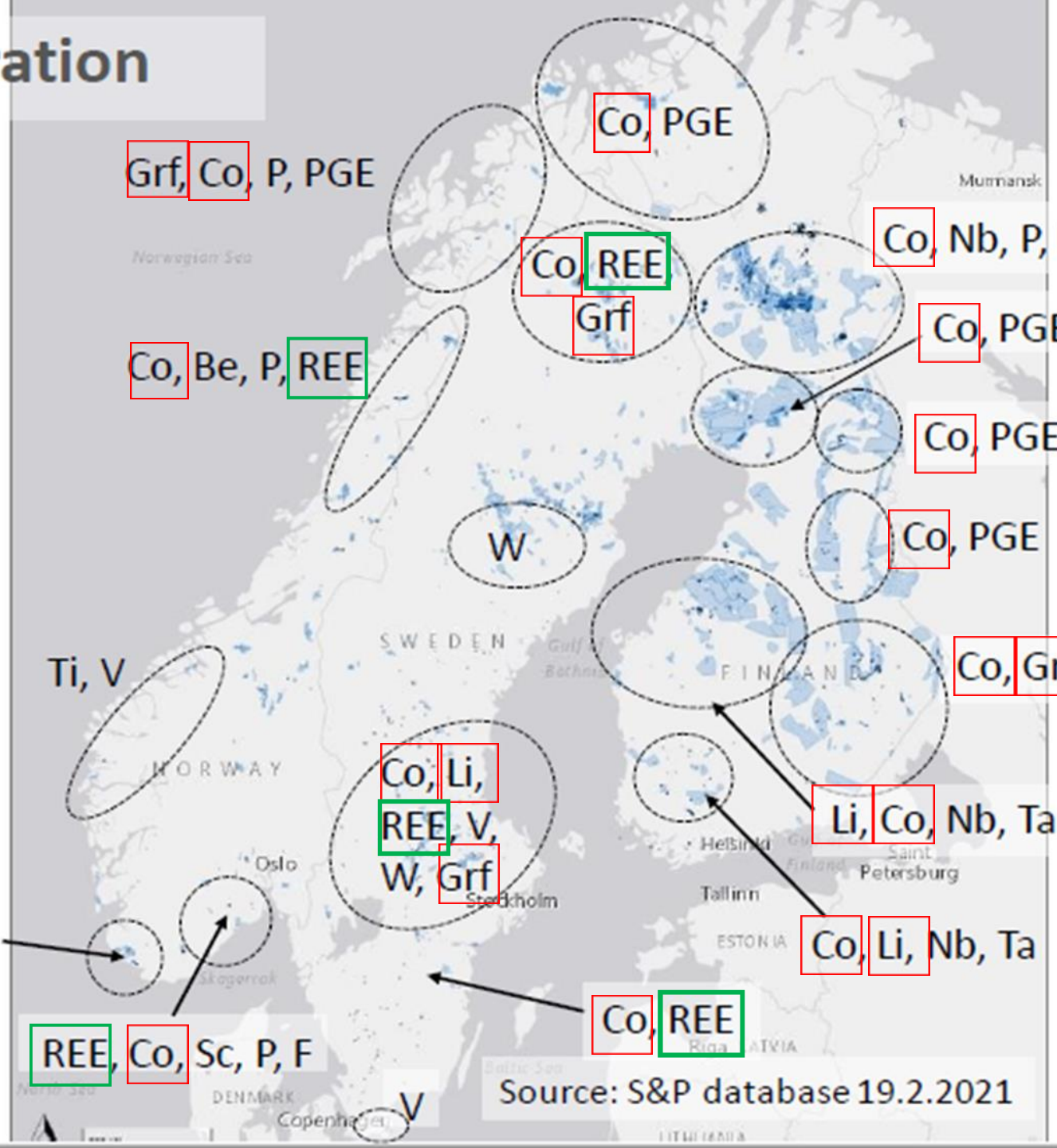
K.M. Goodenough et.al. (2016):Europe's rare earth element resource potential: An overview of REE metallogenetic provinces and their geodynamic setting. Ore Geology Reviews Volume 72, Part 1.

Green Minerals

Current Exploration Interests

Only commodities from the EU critical raw material list are indicated

Note that high-purity quartz is not included in the map



Battery minerals

Magnet minerals

Critical mineral exploration potential in Finland, Norway and Sweden

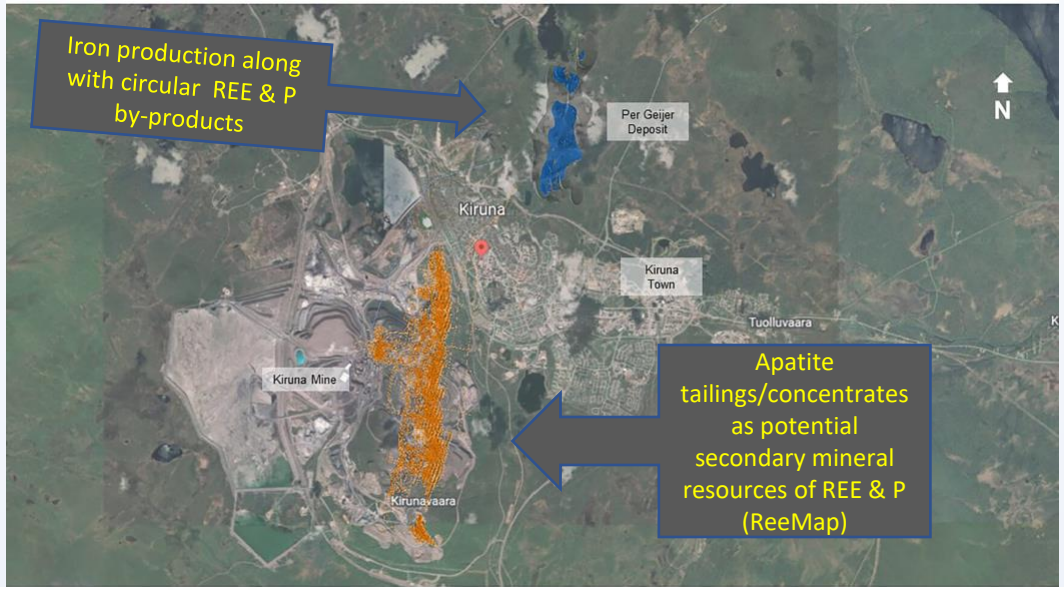
GEOLOGICAL SURVEY OF NORWAY - NGU -

SGU Geological Survey of Sweden

GTK

LKAB reports exploitable REE mineral resources

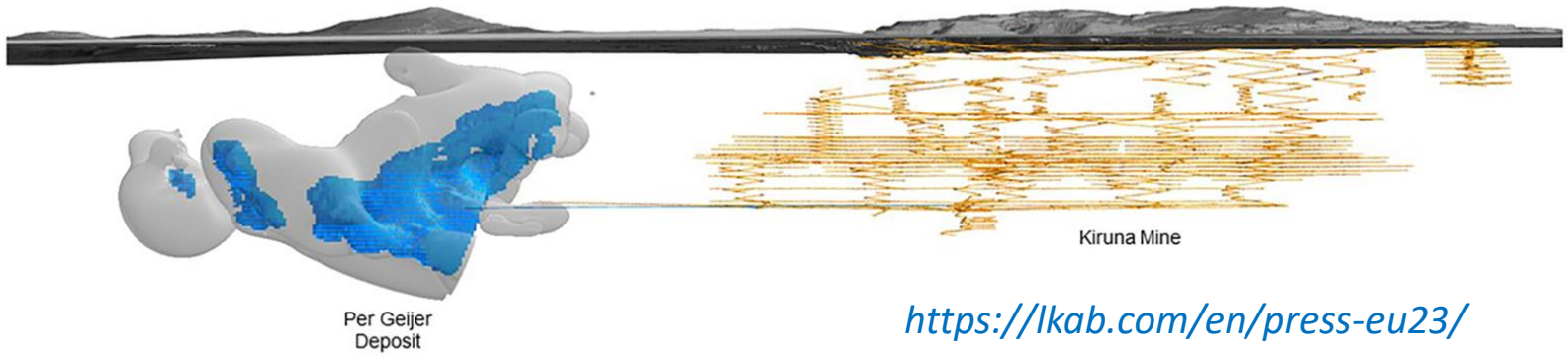
Currently producing 80 percent of Europe's iron ore



- PERC estimation of 500 million tons with high iron content and up to seven times the grade of phosphorus as the orebodies that LKAB mines in Kiruna today
- more than one million tons of rare earth metals in the form of Rare Earth Oxides
- LKAB is already planning a circular industrial park in Luleå with new technology for the extraction and processing of phosphorus, rare earth elements and fluorine based on today's existing mining production (ReeMAP project).

Per Geijer Deposit

The plan is to be able to apply for an exploitation concession in 2023.



https://lkab.com/en/press-eu23/

Circular/resource efficient approach!

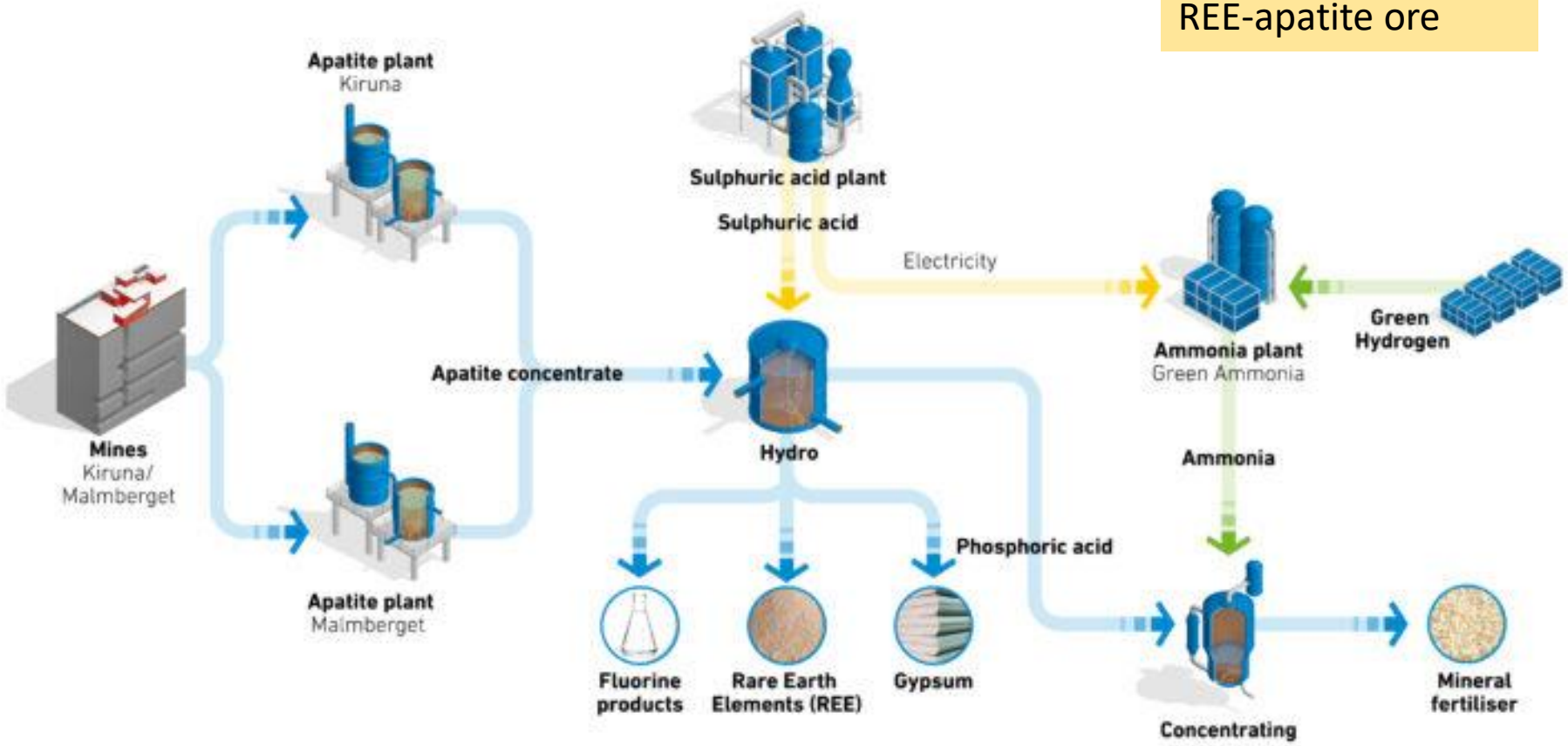
The REE in Per Geijer occur together with phosphorus in the mineral apatite, may be produced as by-products, creating completely different opportunities for possible competitive mining.

LKAB ReeMAP project

From a primary iron ore to a secondary REE-apatite ore

From apatite-rich mining waste / processing tailing / concentrate
to secondary extraction / recovery and production,

- first of
  - REE
  - gypsum
  - fluorine
- and thereafter
  - phosphorus fertilizer



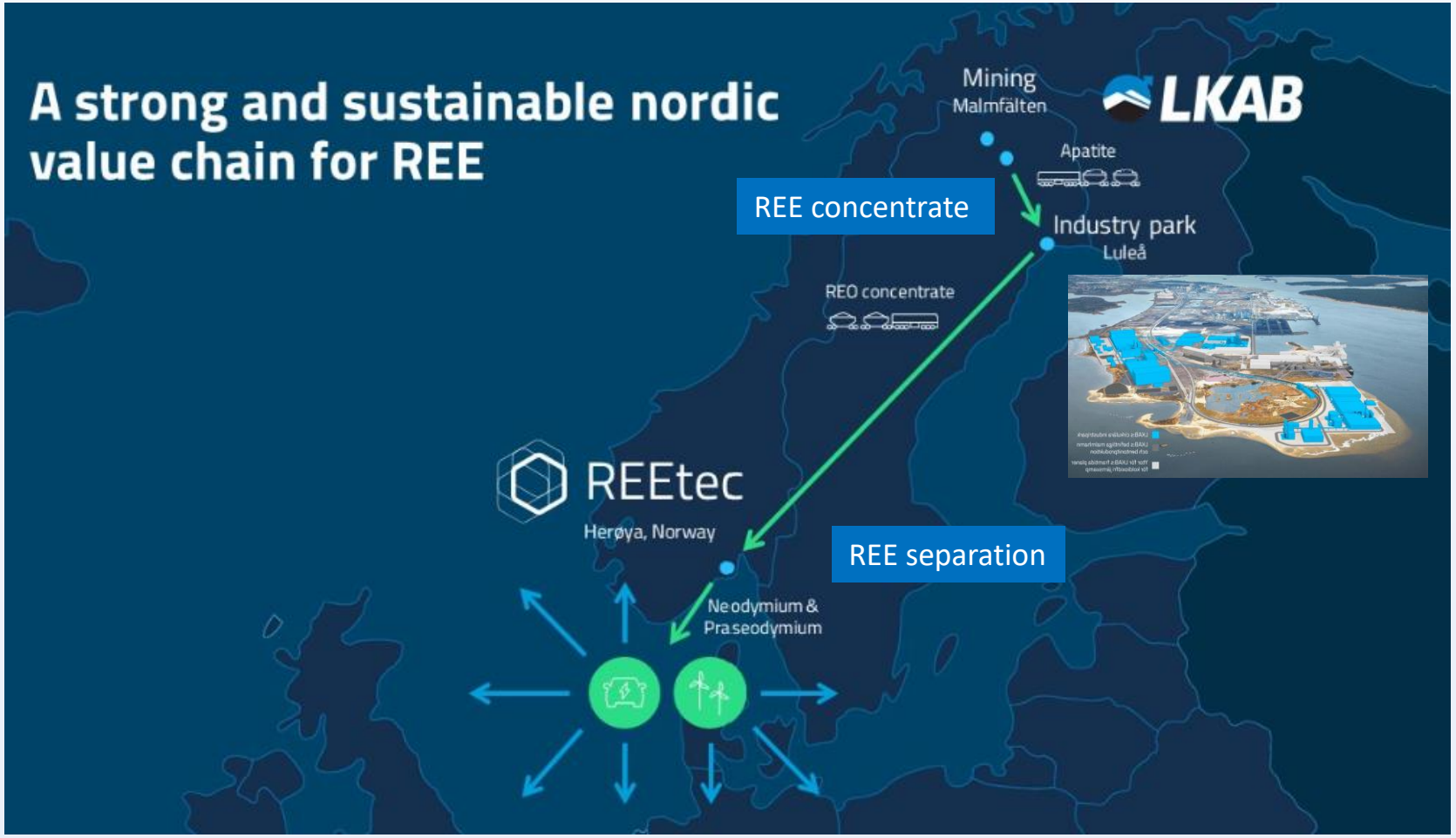
Kiruna iron ore has been mined for more than 130 years

A production start is planned for 2027!

https://ree-map.com/

LKAB collaboration with Norwegian REEtec

To meet the need for increasing Europe's processing capacity LKAB has entered collaboration with Norwegian REEtec, having developed an innovative and sustainable technology for separation of REE.
Extraction and processing of phosphorus, REE and fluorine are already part of LKAB's ReeMAP project.
https://lkab.com/en/press/lkab-becomes-largest-owner-in-reetec-as-builds-a-strong-nordic-industry-for-rare-earth-elements/



EU's economic geology sets the spot for exploitable resources of CMRM

Europe's opportunity to become self-sufficient, resilient and sustainable in critical and strategic minerals supply from its own resources, is strongly favoured by its geological setting and metallogenetic evolution.

- Predictive mapping, along with updated geological knowledge and improved mineral intelligence, results in areas of high regional-scale exploration potential to enable targeting prospective mineral resources of REE, lithium, cobalt and REE in Europe. Sweden, Norway and Finland have undertaken joint efforts providing a common approach and assessment on raising the exploration and resource potential of battery and magnet minerals in the Fennoscandian mineral belt.
- MS should promote national and/or transboundary CMRM exploration, focusing on brownfield areas with the twofold target of exploring for deeper-seated orebodies and historical mining wastes!
- Recycling alone is not yet sufficient to meet EU's and the world's current growth in demand for mineral raw materials. However, constitutes a potential exploration target, considering also the CRMA target that by 2030 15% of the EU's annual consumption of each CRM should come from recycling.
- The fast-growing demand of mineral raw materials has also raised the need for policy update and innovation. For example, it will take at least 10-15 years before LKAB can begin mining and deliver REE products to the market. The Swedish government announced that it will be easier to open a mine!
- The CRMA aims at reducing the permitting time drastically as MS should ensure that the permit granting process related to such projects does not exceed pre-set time limit. The question is how MS will respond to this?
- Strategic projects addressing CRM will be identified and financed by the EC together with a European Critical Raw Materials Board that is yet to be established. It has been drafted that "private investment alone is not sufficient" and that the effective roll-out of projects along the CRM value chains may require public support (so called State aid)

Questions; Comments; Discussion

ProMine

Nano-particle products from new mineral resources from Europe

ProSUM – Prospecting Secondary raw materials in the Urban Mine and mining waste.

Minerals Intelligence Network for Europe

European Geological Data Infrastructure

Euro Geo Source Oil – Gas – Minerals

EU Raw Materials Statistics

Application of web GIS technologies for the sustainable supply of Europe with Energy and Mineral Resources

Development of a sustainable exploitation scheme for Europe's REE ore deposits

570 million euro from "Horizon 2020" on 91 mineral projects with 1767 participants that delivered added R&I value, which, when exploited, may promote more efficient exploration of both primary and secondary mineral resources