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From Waste to Next-Generation Molecular Materials

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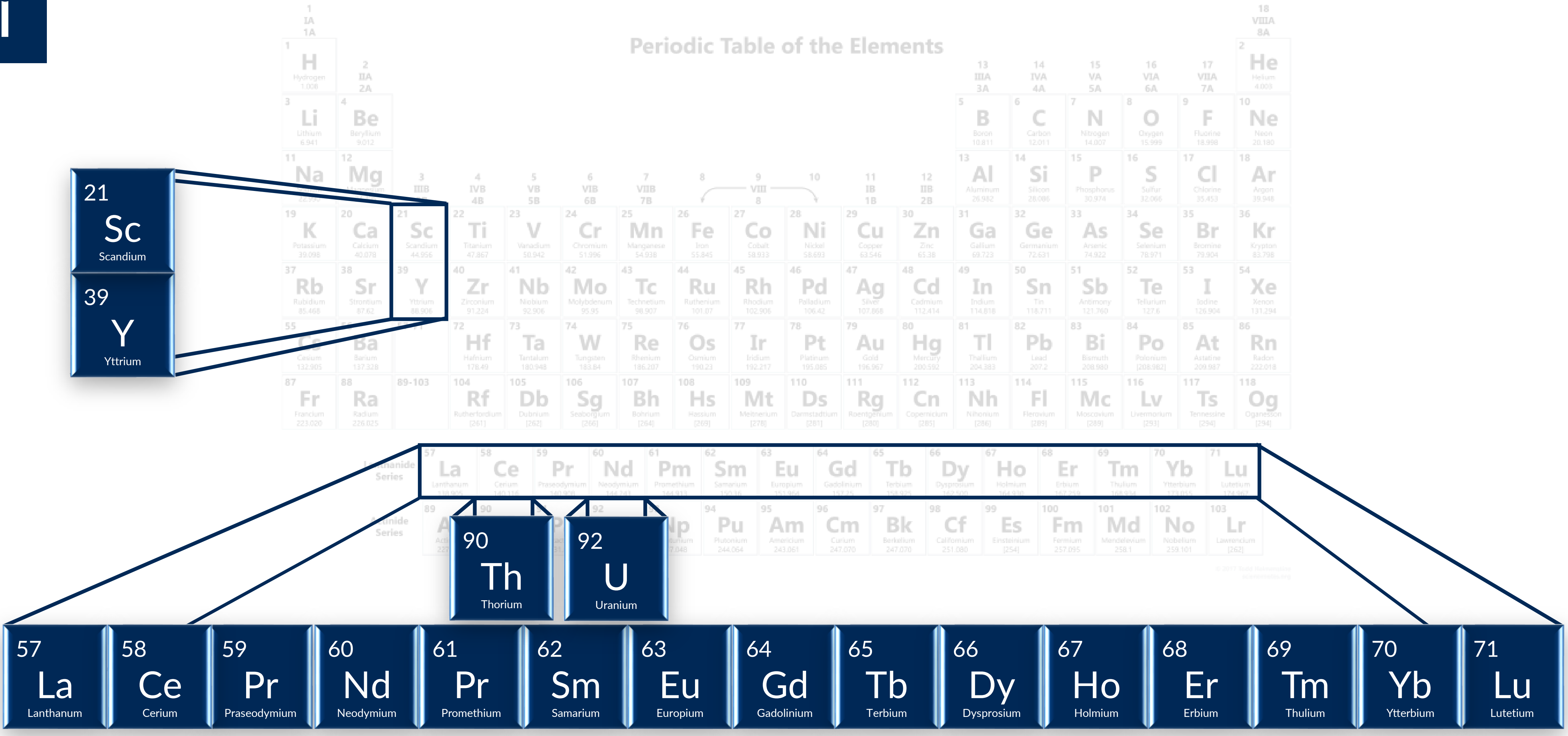
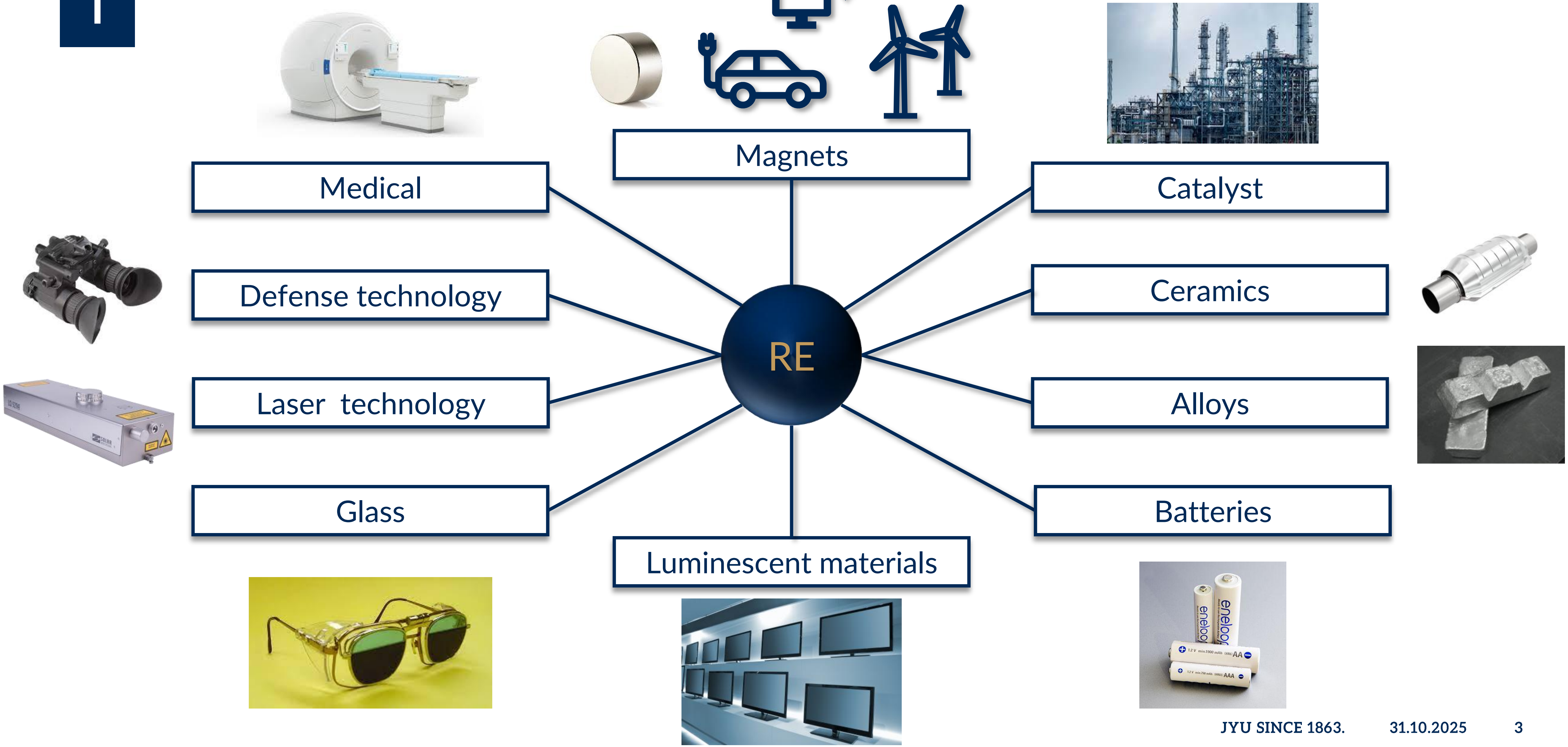
Rare-Earth Elements

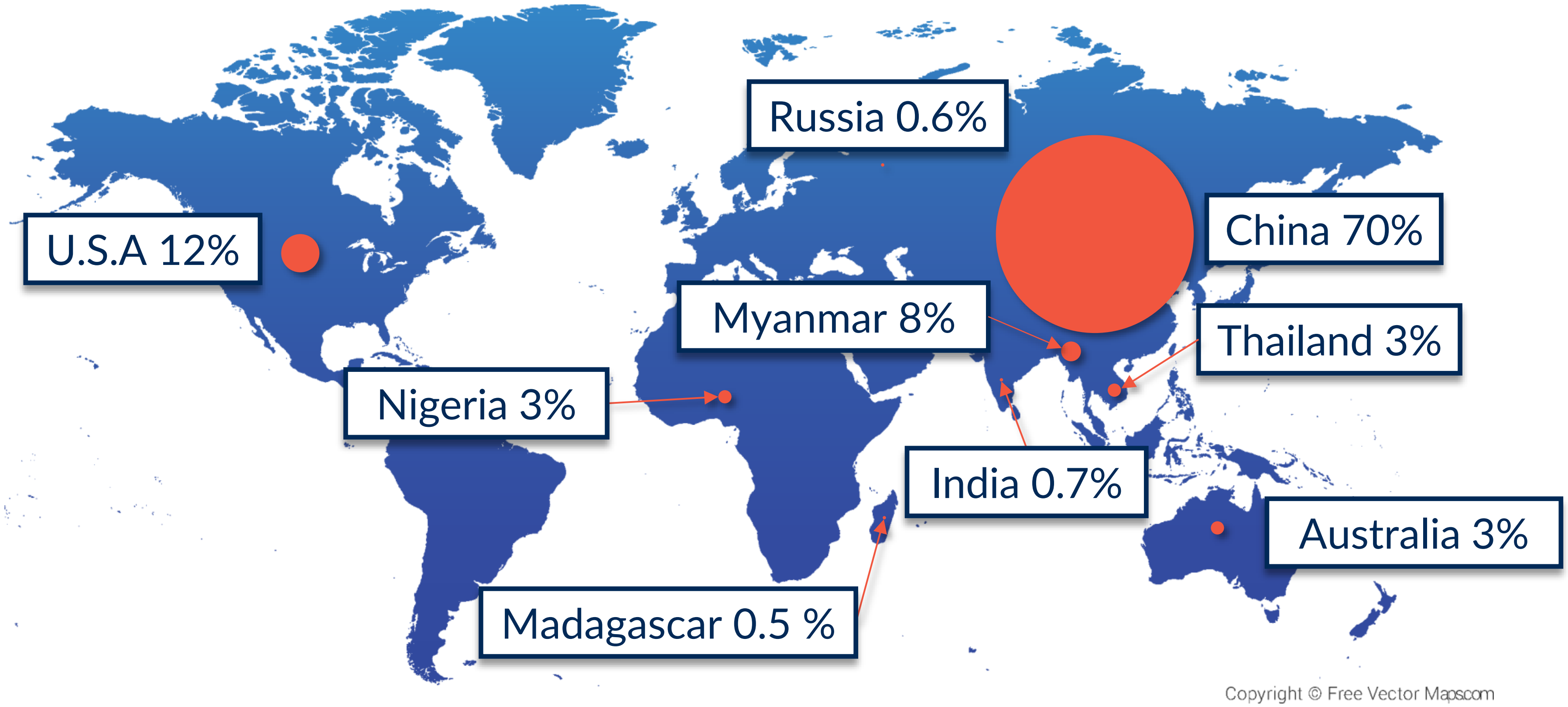


(a) https://sciencenotes.org/printable-periodic-table/ 13.03.2023

Rare-Earth Elements



Global Production of Rare-Earth Oxides in 2024 (390 000 metric tonnes in total)



(a) https://freevectormaps.com/world-maps/WRLD-EPS-02-4001?ref=atr (b) https://www.statista.com/statistics/270277/mining-of-rare-earths-by-country/ 27.3.2025. (c) Alves Dias, P.; Bobba, S.; Carrara, S.; Plazzotta, B. *The Role of Rare Earth Elements in Wind Energy and Electric Mobility: An Analysis of Future Supply/Demand Balances*; Publications Office of the European Union: Luxembourg, 2020

Methods to Reduce the Increased Demand of REEs

- **Three main methods:**
  1. Substituting critical REEs by less critical metals

  2. Investing in sustainable primary mining from old and new REE deposits

  3. Investing in urban mines and recycling technologies.

Less than 1% of the used rare-earth elements are recycled in EU, globally the recycling rate is 13%–14%.

(a) Rodriguez, N. R.; Grymonprez, B; Binnemans, K., *Ind. Eng. Chem. Res*. **2021**, *60*, 28. (b) Alves Dias, P.; Bobba, S.; Carrara, S.; Plazzotta, B., *The Role of Rare Earth Elements in Wind Energy and Electric Mobility: An Analysis of Future Supply/Demand Balances*; Publications Office of the European Union: Luxembourg, 2020). (c) RMIS - Raw materials' profiles. RMIS - Raw Materials Information System https://rmis.jrc.ec.europa.eu/rmp/ 27.3.2025.

Waste and Side Streams for Rare-Earth Elements

Mining wastewaters

- REEs content depends highly on the raffinate
- Might also contain thorium and uranium

Permanent Magnets

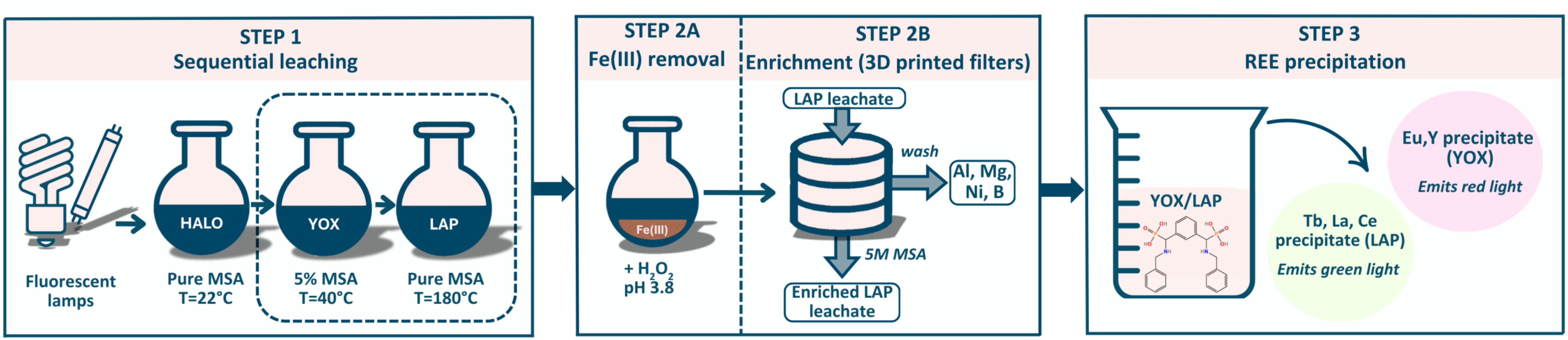
- Good source for Nd, Pr, Dy, Tb and Gd.
- Composition of typical NdFeB magnet - REEs: Nd (28–35%); Pr, Tb, Dy, and Gd: (0–10%); B (1–2%); Ni (0–15%); Co, and Al (0–1%); Fe (≤68%)

Lamp Phosphor Waste

- Lamp phosphor waste powder: the red phosphor $Y_2O_3:Eu^{3+}$ (YOX) (10−20 wt %), the green phosphors $LaPO_4:Ce^{3+},Tb^{3+}$ (LAP) and (Ce,Tb) $MgAl_{11}O_{19}$ (CAT) (6−7 wt %), and the blue phosphor $BaMgAl_{10}O_{17}Eu^{2+}$ (BAM) (5 wt %).

(a) Virtanen, E. J.; Kukkonen, E.; Yliharju, J.; Tuomisto, M.; Frimodig, J.; Kinnunen, K.; Lahtinen, E.; Hänninen, M. M.; Väisänen, A.; Haukka, M.; Moilanen O., *Sep. Purif. Technol*, **2025**, *353*, 128599. (b) Virtanen, E. J.; Yliharju, J.; Kukkonen, E.; Christiansen, T.; Tuomisto, M.; Miettinen, A.; Väisänen, A.; Moilanen, J. O., **2025**, *ChemRxiv*, 10.26434/chemrxiv-2025-mf608 (c) Niskanen, J.; Lahtinen, M.; Perämäki, S., *Cleaner Engineering and Technology*, **2022**, *10*, 100544. (d) Dudarko, O.; Kobylinska, N.; Kessle, V.; Seisenbaeva, G., *Hydrometallurgy*, **2022**, 210, 105855. (e) Rodriguez, N. R.; Grymonprez, B; Binnemans, K., *Ind. Eng. Chem. Res*. **2021**, *60*, 28.

Lamp Phosphor Waste



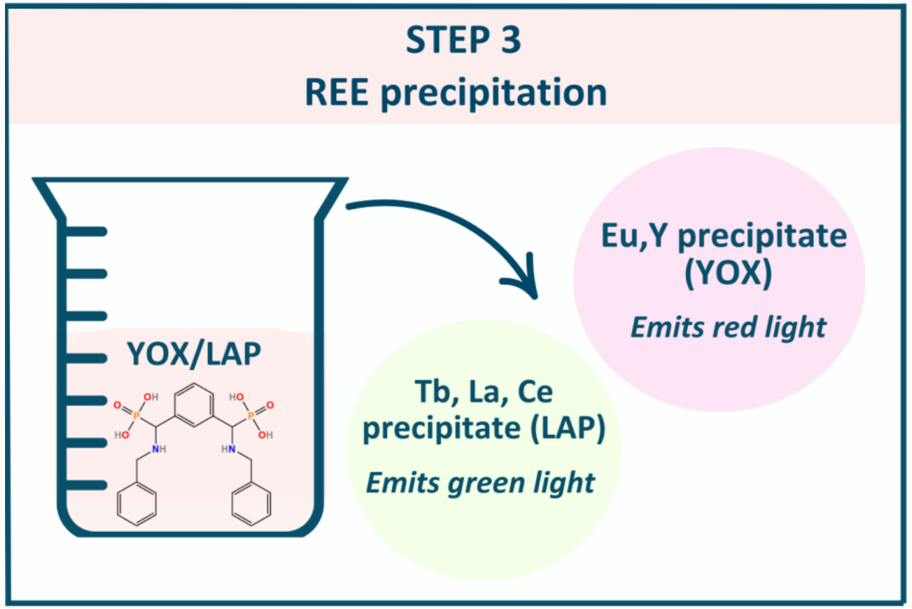
(a) Krista Oikarinen, K.; Kukkonen, E.; Tuomisto, M.; Yliharju, J.; Miettinen, A.; Lastusaari, M.; Väisänen, A.; Moilanen J. O. *unpublished result*.

From Recycling to Upcycling

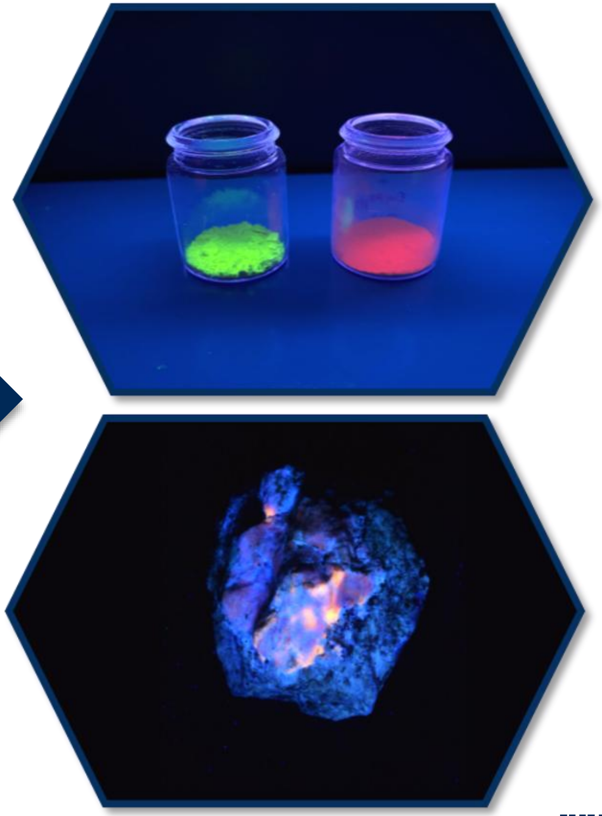
Upcycling

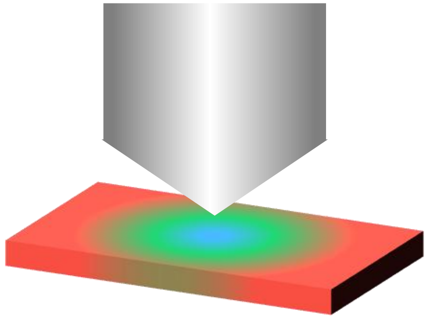
"Is the process of transforming by-products, waste materials, useless, or unwanted products into new materials or products perceived to be of greater quality."

New photonic materials based on α-aminobis(phosphonates), aluminates, hackamanites, etc.

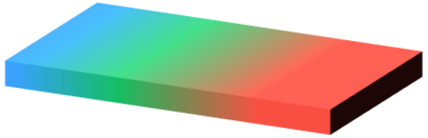


Upcycling





Pressure Sensor



Optical Thermometer

(a) https://en.wikipedia.org/wiki/Upcycling

THANK YOU!