



JYVÄSKYLÄN YLIOPISTO  
UNIVERSITY OF JYVÄSKYLÄ

# From Waste to Next-Generation Molecular Materials

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# Rare-Earth Elements

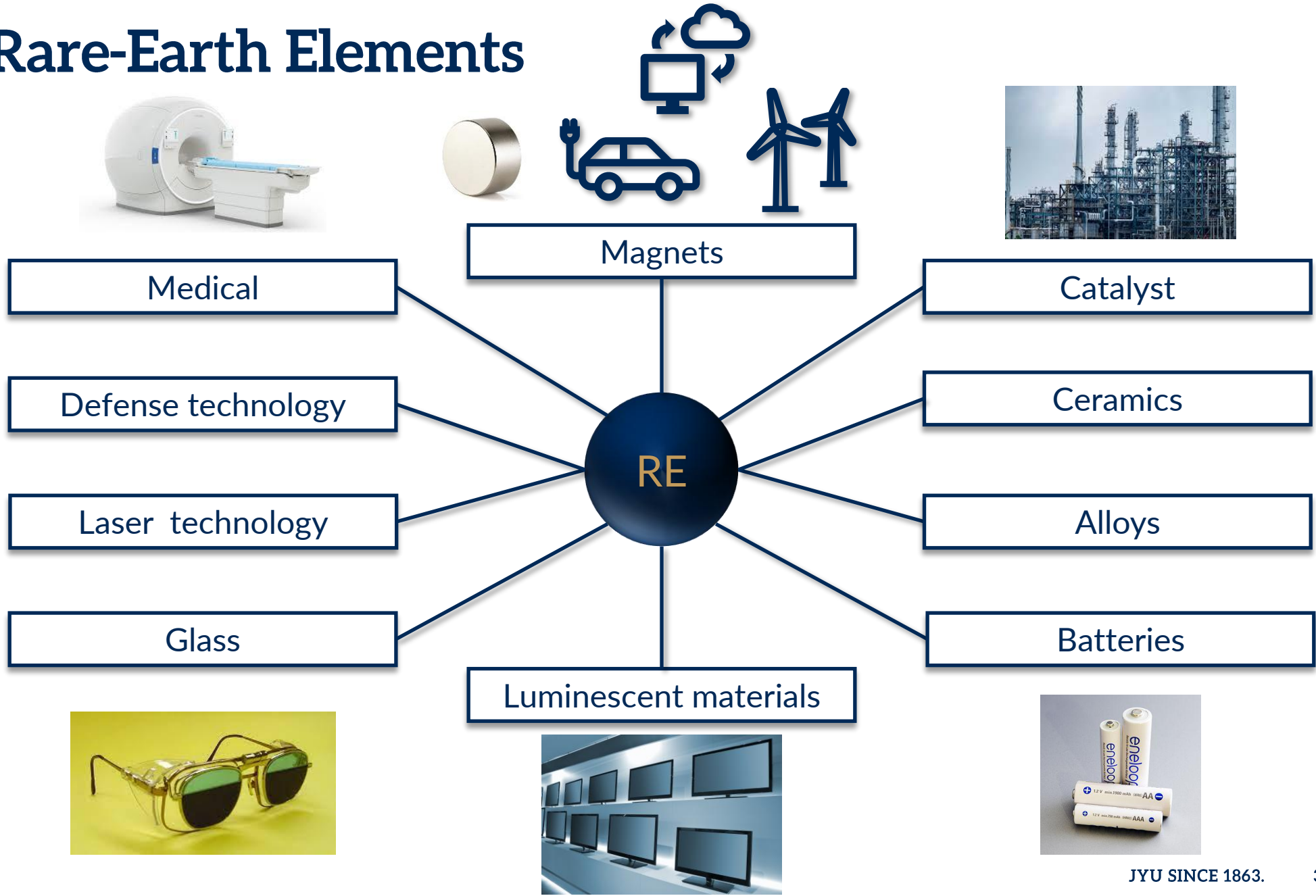
Periodic Table of the Elements

1 IA 1A H Hydrogen 1.008	2 IIA 2A Be Beryllium 9.012											13 IIIA 3A B Boron 10.811	14 IVA 4A C Carbon 12.011	15 VA 5A N Nitrogen 14.007	16 VIA 6A O Oxygen 15.999	17 VIIA 7A F Fluorine 18.998	18 VIIIA 8A He Helium 4.003	
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 Al Aluminum 26.982	6 Si Silicon 28.086	7 P Phosphorus 30.974	8 S Sulfur 32.066	9 Cl Chlorine 35.453	10 Ar Argon 39.948	
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 IIIB Sc Scandium 44.956	4 IVB 4B Ti Titanium 47.867	5 VB 5B V Vanadium 50.942	6 VIB 6B Cr Chromium 51.996	7 VIIB 7B Mn Manganese 54.938	8 VIII 8 Fe Iron 55.845		9 VIII 8 Co Cobalt 58.933	10 VIII 8 Ni Nickel 58.693	11 IB 1B Cu Copper 63.546	12 IIB 2B Zn Zinc 65.38	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798	
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.294	
55 Cs Cesium 132.905	56 Ba Barium 137.328	89-103 Lanthanide Series		72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.227	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Actinide Series		104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]
		Lanthanide Series		57 La Lanthanum [139]	58 Ce Cerium [140]	59 Pr Praseodymium [141]	60 Nd Neodymium [144]	61 Pm Promethium [145]	62 Sm Samarium [150]	63 Eu Europium [152]	64 Gd Gadolinium [157]	65 Tb Terbium [159]	66 Dy Dysprosium [163]	67 Ho Holmium [165]	68 Er Erbium [167]	69 Tm Thulium [169]	70 Yb Ytterbium [173]	71 Lu Lutetium [175]
		Actinide Series		89 Ac Actinium [227]	90 Th Thorium [232]	91 Pa Protactinium [231]	92 U Uranium [238]	93 Np Neptunium [237]	94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [251]	99 Es Einsteinium [254]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [259]	103 Lr Lawrencium [262]

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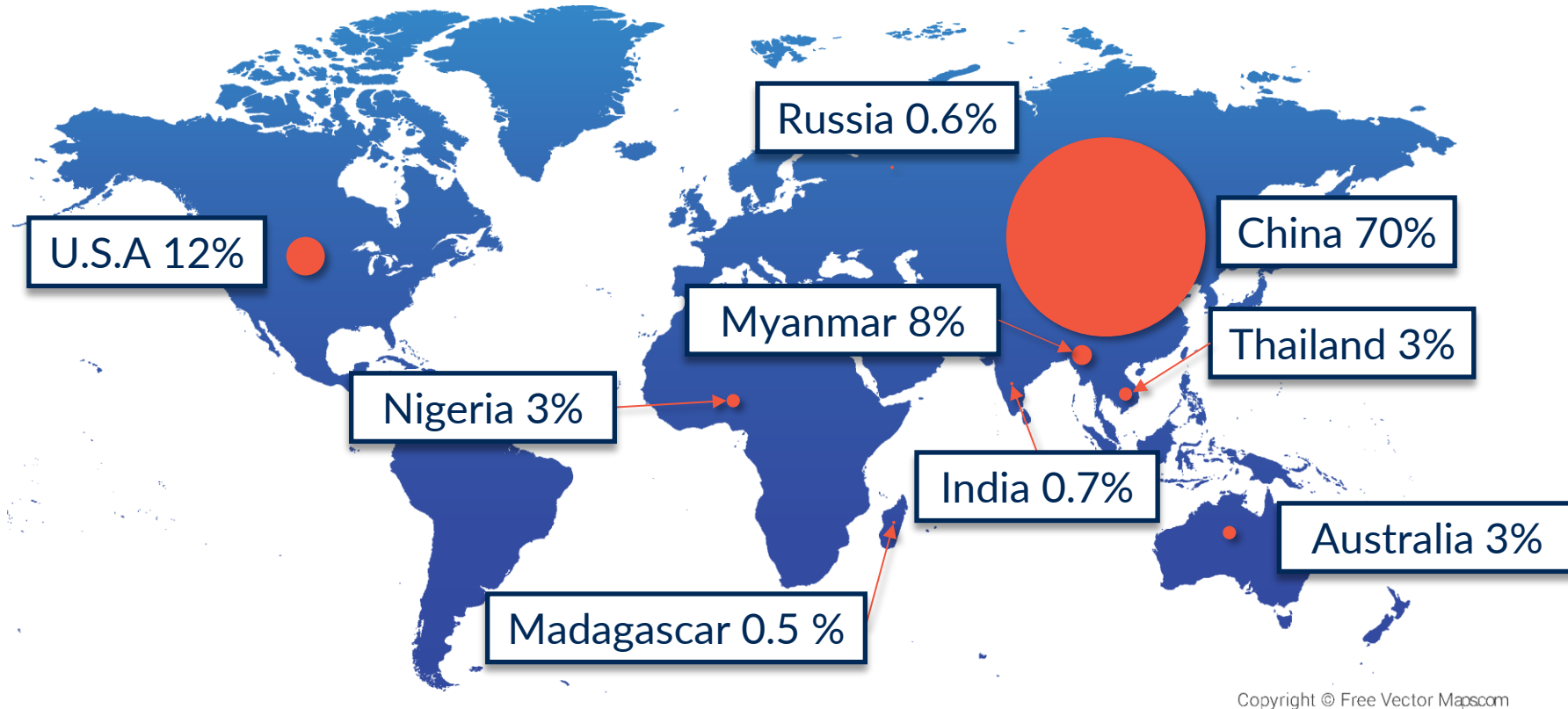


# Rare-Earth Elements





# 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%.



# 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 ( $\leq 68\%$ )

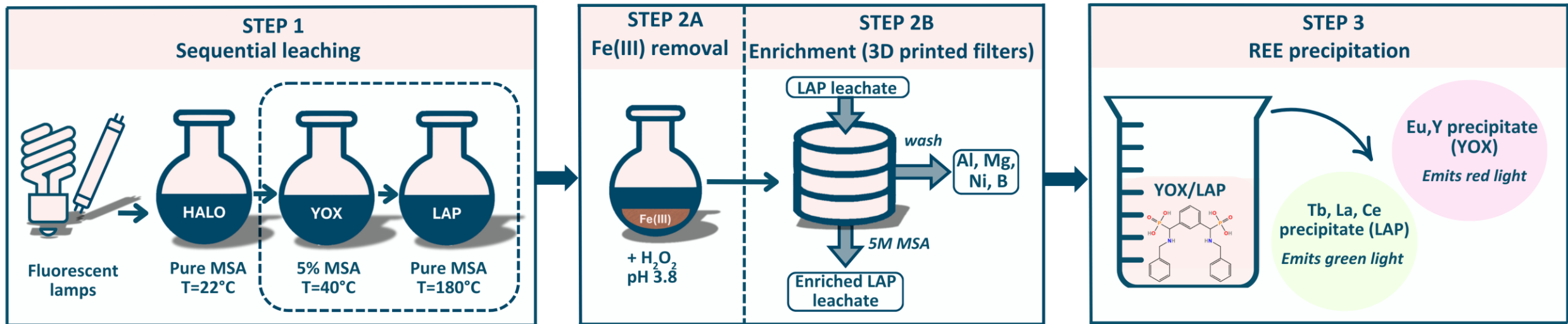
## Lamp Phosphor Waste



- 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 %).



# Lamp Phosphor Waste



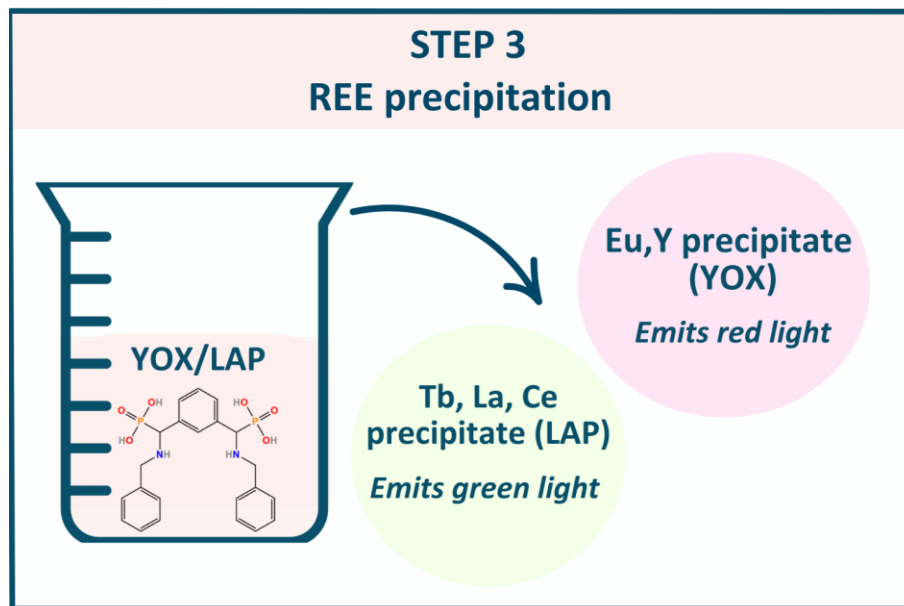


# From Recycling to Upcycling

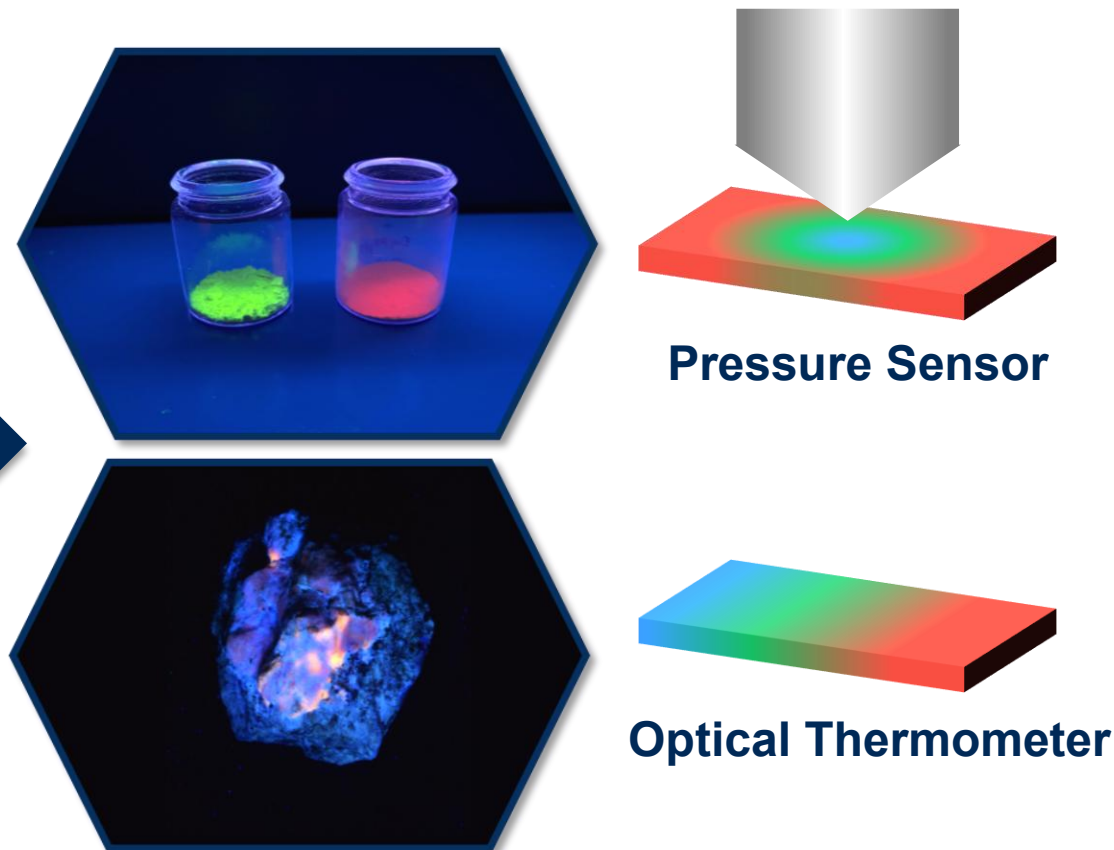
## Upcycling

“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  $\alpha$ -aminobis(phosphonates), aluminates, hackamanites, etc.



**Upcycling**





**THANK YOU!**