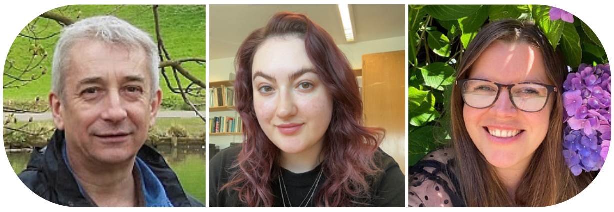
Extraction and recycling of important E-metals



Andy Markwick, Elena Bulmer and **Phoebe Smith-Barnes** explain how the processes of reclamation and extraction of important E-metals are rapidly changing

E-metals are metals that are used in electronic-based technologies, for example in the manufacture of computer components, batteries, electric motors and smart phones. They are often rarer in abundance or costly to extract or recycle. Examples include nickel, gold, silver, copper and the rare earth elements.

The world is awakening to an immediate need to dramatically reduce the use of fossil fuels, particularly for energy production (90%), which results in CO_2 emissions, and to an increase in the use of E-metals for world transportation and communication. However, it is important to recognise that 10% of fossil fuels also have a wide range of other important uses, for example in the manufacture of medicines and building materials (Wollensack, Budzinski and Backmann, 2022). Countries are investing in alternative energy supplies, such as nuclear, wind, wave, hydroelectric and solar, and, as Macdonald (2023) argues, there is great potential in hydrogen fuel cells. A very significant challenge, however, is finding ways to store the energy produced, for example in batteries. Figure 1 shows the high reliance of renewable energy on the production of metals.

One transportation solution that is gaining momentum is the production of electrified cars, vans and lorries. However, with a move towards electrified transportation comes a much-increased demand for raw materials such as metals like Li, Ni, Au, Ag, Sn, Cu, Cd, Mn, Mg and rare earth elements (lanthanides: lanthanum, La, to lutetium, Lu). Figure 2 shows a projection of demand for minerals (metals) by 2050. As a percentage of use in 2017, some of the rarer or more difficult-to-extract minerals (e.g. cobalt and lithium) will need to increase by over 450%.

The standard methods for metal extraction from ores (minerals – often oxides and carbonates) require energy-intensive processes such as smelting (melting of ore) and /or leaching (dissolving out or dissolution) at high temperatures (pyrometallurgy).

For many years, science curricula across a range of countries have introduced students to these extremely important extraction processes, often from an historical perspective. These pyrometallurgy processes have a significant associated CO_2 footprint

	Wind	Solar photovoltaic	Concentrated solar power	Hydro	Geothermal	Energy Storage	Nuclear	Coal	Gas	Carbon capture and storage
Aluminum	■	■				■	■	■	■	
Chromium	■			■	■	■	■	■	■	■
Cobalt						■		■	■	■
Copper	■	■	■	■	■	■	■	■	■	■
Graphite						■				
Indium		■					■			
Iron	■					■				
Lead	■	■		■		■	■			
Lithium						■				
Manganese	■			■	■	■		■	■	■
Molybdenum	■	■		■	■		■	■	■	■
Neodymium	■									
Nickel	■	■		■	■	■	■	■	■	■
Silver		■	■				■			
Titanium				■	■		■	■	■	
Vanadium						■	■	■		
Zinc	■	■		■		■	■			
Total	10	8	2	8	6	11	11	9	8	6

Figure 1 The metals (mineral sources) required for transitioning towards different low-carbon technologies
https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

lithium	(965%)	
cobalt		
indium	(241%)	
vanadium		Predicted relative
nickel		demand for metals
silver	(60%)	in 2050
neodymium		
aluminium		
copper		
manganese	(4%)	

Figure 2 A prediction of the relative demand for metals for 2050 compared to 2017

and often release toxic gases into the environment, such as chlorine, nitrogen oxides, sulfur dioxide, hydrogen sulfide and arsenic. Hydrometallurgy via cyanidation, concentrated acid, alkali or H_2O_2 is widely used in the extraction of metals such as gold, lithium, aluminium and silver and as a consequence too often produces soluble cyanides and heavy metal contaminants that enter watercourses, leading to very significant environmental damage (Thompson *et al*., 2020). Although such practices provide livelihoods for many, too often they impact negatively on the lives of people who are in poverty.

As a consequence, the processes of reclamation and extraction of important E-metals are rapidly changing, and a quick curriculum response is required to provide students with up-to-date information about future technologies, such as deep eutectic solvents (DES), developed at the University of Leicester (Abbott *et al*., 2015, Jenkin *et al*., 2016). These new technologies are critical for global transformation towards carbon-neutral economies and so investment in adapting our current outdated science curriculum for our students seems a sensible way forward. The UK's current GCSE (ages 14–16) and A-level (ages 16–18) curriculums provide a sound conceptual foundation for understanding DES technologies, for example intermolecular bonding, redox, dissolution processes and thermodynamics. It is extremely likely that any future career pathways relating to E-metals and their applications will require students to have a good knowledge of these developing technologies. It is important to recognise that the exploitation of people, particularly children, in the increasing need to extract E-metals will inevitably become worse (McKie, 2021). These conflicting arguments can be utilised extremely well in science to enhance students' argumentation skills.

This increased need for metals for cleaner energy, transportation and communication (e.g. lithium-ion batteries, computer, and smartphone components, etc.) not only requires greater extraction rates from metallic ores (Jenkin *et al*., 2016) but also the ability to recover metals (E-waste) that have been or would normally end up in landfill sites and heavy metal pollution of the environment. Without an effective strategy to recover and recycle these materials, it has been estimated that, by 2030, 747 000 000 tons of E-waste will be added to landfill sites (Ahirwar and Tripathi, 2021).

E-waste contains a rich source of metals such as gold, palladium, nickel, copper and silver, and primary resources of these metals are becoming rare. It is therefore imperative that alternative metal-extraction processes are discovered that address the problems and have the following characteristics:

- Non-toxic (biodegradable and environmentally in-active).
- Low-cost (chemicals and energy consumption).
- Synthesised easily – simple production stages, effective use of resources/time, low temperature.
- Process is circular – chemicals used in the process can be reclaimed and reused at low cost.
- Leachates are low viscosity and so can easily mix and flow, making dissolution and extraction faster (in this context, leachates are solutions formed from dissolving E-metals in the DES liquid).
- Leachates are anhydrous to reduce the impact of hydration/hydroxide formation reactions to the metal surface (this impedes further reaction).

Solvents such as the deep eutectic solvents have been shown to have these characteristics (Jenkin *et al*., 2016). They can dissolve pure metals from E-waste (e.g. computer components, batteries, etc.) and ores such as cuprite (copper iron sulfide) and limonite (nickel-rich iron oxide). In general, the process requires a mixture of two chemicals that when mixed form a solution that has a much lower melting point than either of the original components. This is called a eutectic composition. The solution that is made acts as an extremely good solvent for the metal ions, either from precursor pure metals or metal ores. To enable extraction, an oxidising agent (acting a little like a catalyst) is added to oxidise the metal, forming a cation, which can more easily be dissolved in the DES. Recovery of the metal is then achieved either by electrolysis (deposition of metal at a cathode) or by displacement reactions with a less-reactive metal. Research is now underway to find the best ways to recover the metals from the DES.

These processes being developed at Leicester University and in other universities across the world have great potential for increasing the availability and obtainability of critical metals for the growing technology markets. However, even with breakthroughs such as these, the continued and, indeed, increased use of resources is unsustainable, and some have argued that we must redefine global neoliberal-based economics into a forward-thinking circular economy, that thoughtfully considers how, from extraction of materials to their end of life, we plan in the potential to recycle waste, that is, '*we see waste as a resource, so it makes the products we use today into the resources we use tomorrow with materials that flow in continuous cycles while regenerating our natural systems*' (McLean, 2022: 7).

For a more detailed explanation of the processes involved in the DES chemistry and process see the linked article in *SSR in Depth* (Markwick, Bulmer and Smith-Barnes, 2023).

References

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Useful weblinks

To explore some of the global issues we are facing, and the new technologies being created:

Association for Science (ASE): www.ase.org.uk/resources/school-science-review/issue-354/climate-change-evidence-and-causes

Institute of Physics: www.iop.org/search?keyword=Climate%20change

National Association for Environmental Education https://naee.org.uk

The Geological Society: www.geolsoc.org.uk

The Royal Society: https://royalsociety.org/topics-policy/projects/climate-change-evidence-causes/basics-of-climate-change

OECD: www.oecd.org/greengrowth

Royal Society of Chemistry: https://edu.rsc.org/searchresults?parametrics=&qkeyword=climate+change

UNESCO: www.unesco.org/en/climate-change/education

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