Researchers expand research on simplifying recycling of rare-earth metals

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Researchers at the University of Pennsylvania have pioneered a process that could enable the efficient recycling of rare-earth metals, which are found in many high-tech devices. Mining and purifying rare-earth metals is not only expensive and labor-intensive, but takes a devastating toll on the environment. The current methods for recycling them are wasteful and inefficient. The paper focused on one pairing in particular which could enable scientists to recycle rare-earths from compact fluorescent light bulbs.

In a previous study, researchers at the University of Pennsylvania pioneered a process that could enable the efficient recycling of two rare-earth metals, neodymium and dysprosium, which are found in the small, powerful magnets in many high-tech devices.

Now, in a new paper published in the *Proceedings of the National Academy of Sciences*, the researchers extend the method to the entire series of rare-earth metals. In the paper, the researchers establish a pattern, showing that it's not just selective for one or two rare earths, it can be extended to the entire series.

The paper focused on one pairing in particular, europium and yttrium, which could enable scientists to recycle rare-earth metals from compact fluorescent light bulbs.

The research was led by Eric Schelter, associate professor in the Department of Chemistry in Penn's School of Arts & Sciences, and

graduate students Justin Bogart and Zeke Cole. Connor Lippincott, an undergraduate student in the Vagelos Integrated Program in Energy Research, and Patrick Carroll, director of the X-Ray Crystallography Facility, also contributed to the study.

The incentive to develop an efficient method to recycle rare-earth metals is huge because mining and purifying them is not only expensive and labor-intensive, but takes a devastating toll on the environment.

"Everybody's heard of blood diamonds," said Schelter, "but maybe people haven't heard of blood cobalt or tantalum or lithium for that matter."

Currently, the method of separating rare-earth metals for recycling is not only expensive and energy consuming, but also takes weeks and requires massive amounts of solvents.

In this method, a series of hundreds of fluid chambers are hooked up in parallel with two fluids flowing past one another. One fluid is aqueous and acidic, and the other is organic. The dissolved metals are extracted between the immiscible solutions. This process, which must be repeated thousands of times, chemically filters the elements apart.

"They just run just tons and tons of solvents past one another in a continuous fashion," Cole said. "It uses up huge amounts of energy and there's a lot of liquid waste generated from that process.

Because of the cost of this process, rare-earths are currently only recycled at a rate of about one percent.

The new method minimizes the amount of waste generated and the amount of time and energy needed. To do this, the researchers designed a ligand to bind the ions in mixtures. The chemical compounds that form

as a result are slightly different for each type of ion. For example, in mixtures of two types of elements, one is soluble in organic solvents, while the other is not. This allows the researchers to simply filter them, separating one of the metal cations from the other.

"Our thinking was if we could take the magnets or some material that comes out of the magnets and then apply a very simple chemical method, we could purify the rare-earths out of them directly and complement existing sources in the supply chain with this new one through simple chemistry," Schelter said.

In the new paper, the separations method is extended to six early rare-earths, which were paired in different combinations with nine late rare-earths. Although in some cases the method didn't work at all, for other combinations, such as yttrium and europium, it proved effective.

This pairing is especially important because yttrium and europium are used in compact fluorescent light bulbs. The main incentive to recycle the materials used in fluorescent lightbulbs is that it keeps mercury out of landfills. Being able to get value out of the waste would add to the incentive.

"There's a synergistic set of reasons to do this because you get value when you recycle the rare-earths from the material, and you're also keeping more mercury out of the environment," Schelter said. "Those two things play off of each other."

The next steps for this research involve developing a better understanding of the system, and working to improve it as well as to make it practical. For example, a major limitation of the approach that needs to be overcome is making it work in an aerobic environment.

"We're basically just working on making the system better," Cole said.

"To make the recovered rare earths purer and to get more of them out of the separation."

They're also working on making the process greener. In both papers, the solvent used was primarily benzene, which is not only expensive but is also a carcinogenic. The researchers are investigating other, greener solvents that they could use.

Schelter believes that there will eventually be a push by companies that are socially conscious to implement ethically sourced materials and manufacturing practices. He says that the impact of this research is in taking steps to return materials to the supply chain at the end of their useful life as a consumer product.

"We shouldn't just be throwing so much material away," said Schelter. "There's still a lot of value to them. I think that as part of a sustainable approach to manufacturing and developing a 'circular' economy we should think about the impact and value of materials at every point along their lifecycle. And how we can efficiently and effectively bring them back to useful raw materials once they're at the end of their product life."

More information: Accomplishing simple, solubility-based separations of rare earth elements with complexes bearing size-sensitive molecular apertures, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1612628113

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