Mining Bacteria: A Solution for Shortage of Rare Metals

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We are surrounded by rare metals, although we cannot see them, such as semiconductors (tungsten W, molybdenum Mo, or nickel Ni) used in smartphones and personal computers, and catalysts (platinum Pt or palladium Pd) used in automobile exhaust gas treatment. It would not be an overstatement to say that it is no longer possible to maintain a modern civilized society without these rare metals.

However, it is not easy to obtain rare metals. In general, these rare metals are not abundant in the earth's crust, and the extraction and smelting of these metals require an enormous amount of electrical energy. On the other hand, with the rapid economic growth in developing countries and the expansion of the IT industry, the demand for these metals is increasing year by year, and it is expected that a stable supply will become impossible in the near future. Already, some of the rare metal producing countries are using the export restriction of rare metals as a diplomatic card, and the stable procurement of rare metals has become one of the most important issues for most of the countries all over the world.

In this situation, recycling of rare metals is expected to be a solution to the problem. If we can recover and reuse rare metals from the large amount of used electrical devices discarded as trash in cities and the scraps from industrial processes, or so-called "urban mines", we can achieve a stable and sustainable supply chain that does not depend on mining from natural deposits. For example, it is known that more than 10% of the world's known reserves of various rare metals lie in Japan's "urban mines", and there is no doubt that it is important to reuse them.

Then, how can we recover rare metals from "urban mines"? The current mainstream method is called high-energy pyrometallurgy, in which electronic devices are disassembled to pick out the parts containing rare metals, and then heated to around 1,000 °C in a high-temperature furnace to melt and reduce the metals. However, as with smelting of ores, this method requires huge energy costs and the purity of the resulting metal is low, so recycling of rare metals is still not a common practice.

To reduce the energy required, there is a method called hydrometallurgy, in which metals are dissolved as metal ions using chemicals, and then the metal ions are reduced by electricity to obtain an elementary metal. However, due to the cost of the chemicals used in the smelting process, the risk of environmental pollution, and the limitation of energy reduction because of the existence of electrochemical process, this method has not been widely adopted.

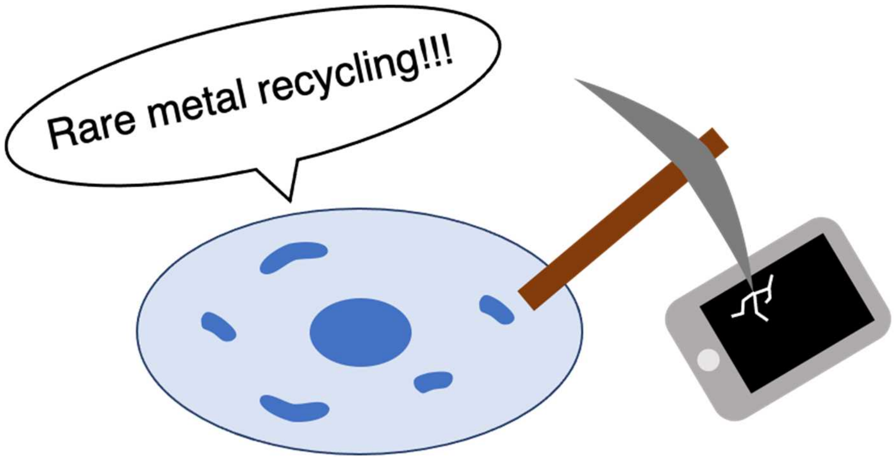
In recent years, however, a number of research results have been published that may provide a solution to these problems. That is, research on a group of microorganisms called "mining bacteria".

"Mining bacteria" is a group of bacteria that produce inorganic nanoparticles in the body by taking in metal ions from the surrounding environment[i]. For example, bacteria of the genus *Shewanella* live in anaerobic environments such as the bottom mud of oceans and lakes in the natural world, and they use energy obtained when they extract electrons from naturally available organic substances such as lactic acid and formic acid and transfer the electrons to iron ions. This process of 'transferring electrons to metal ions' is actually the exact same process used to obtain an elementary metal from metal ions in hydrometallurgy.

Surprisingly, this *Shewanella* bacteria can spontaneously (i.e., without any external electronic energy) transfer the electrons extracted from environment-friendly organic compounds not only to iron ions but also to ions of rare metals such as platinum, palladium, and rhodium to produce elementary metals.[ii] The metals produced in this way are accumulated as nano-sized particles in the bacterial cells, and these bacteria are extremely efficient at extracting up to 50-70% of the original cell mass. In other words, with the help of these "mining bacteria", it is possible to recycle rare metals with extremely low energy costs and environmental impact.

The specific procedure is as follows. Firstly, rare metals are dissolved as ions from discarded parts of electronic devices and industrial scrap. Then, add "mining bacteria" and appropriate organic compounds to the solution and wait for several tens of minutes to several hours. The "mining Bacteria" will then reduce the rare metal ions to an elementary metal, which will be incorporated into the cells as nanoparticles. After that, the bacteria in the solution are collected and the cell tissue is removed to obtain highly pure metal nanoparticles.

The recycling of rare metals by "mining bacteria" is currently in the midst of research and development for practical use. Although there are still some problems to be solved, such as how to efficiently separate bacteria that have incorporated metal nanoparticles from the solution or how to dissolve rare metals into solvent with high concentration, metal resources may soon be obtained mainly from bacteria rather than from mines in the near future.



[i] Gracioso, L. H. *et al. Sci. Adv.* **2021**, *7*, eabd9210.
[ii] Tamaoki, K. *et al. Hydrometallurgy* **2013**, *139*, 26.