MINER BACTERIA

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INVISIBLE
The Codelco Chuquicamata open pit copper mine in Calama, Chile. Today 15% of copper is extracted through the use of bacteria (small photo), capable of breaking down metals.

They are capable of extracting metals in an **environmentally friendly** way. Bacteria, archaea and fungi are already used to extract copper, gold, uranium. But they could help us recover rare earths from **e-waste**. And also in **space**.

by Vito Tartamella

Bloomberg via Getty Images

Forget the huge excavators and miners with helmets and lights on their heads who venture into deep tunnels. In these mines, on the other hand, men in white coats pour liquids on high piles of rocks shredded in the open air. In those liquids, in addition to water and sulfuric acid, there are billions of miners: bacteria just over a thousandth of a millimeter long, invisible to the naked eye. In a few days, thanks to their biochemical action, they manage to isolate tons of precious minerals.

Welcome to biomining, the "third way" of mining. To isolate metals from rock formations, high-temperature furnaces (pyrometalallurgy) or very acidic solutions (hydrometallurgy) can be used: but they have very high economic costs and ecological impacts, from CO_2 emissions to those of toxic substances such as arsenic and cyanide.

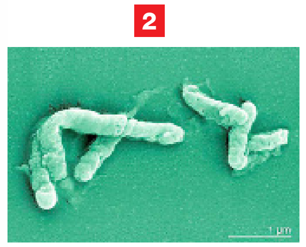
Biomination, on the other hand, uses a natural and ecological process: the metabolism of specialized microorganisms. They are bacteria, archaea and fungi, able to live in very acidic environments, up to 80 ° C temperature, capable of releasing precious elements trapped in rocks. Because instead of getting energy from sunlight, as trees do, or breaking down organic compounds like we do, these microorganisms get energy by disaggregating metals.

This technique has been used for centuries without knowing the biochemical basis, discovered only in the last 70 years. With remarkable results: today 20% of copper and 5% of gold are extracted in this way, and the process is also used for cobalt, zinc, nickel and uranium. It has in fact become the most used procedure in already exploited deposits, where excavations with traditional techniques are not economically convenient because the metals are present in very low concentrations (from 0.5% down). But it could become the most effective and environmentally friendly way of exploiting strands at high depths, pumping colonies of mining microorganisms. They will be able to recover precious metals even from hard-to-reach sources: electronic waste, but also the rocks of the Moon, Mars or asteroids.

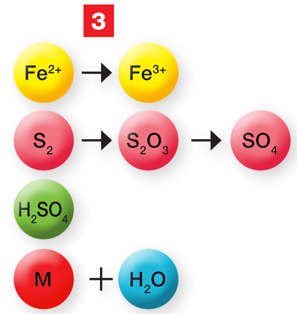
LIQUEFIED
Chile, laboratory test: bacteria "eat" a nail and a metal screw in a few days.

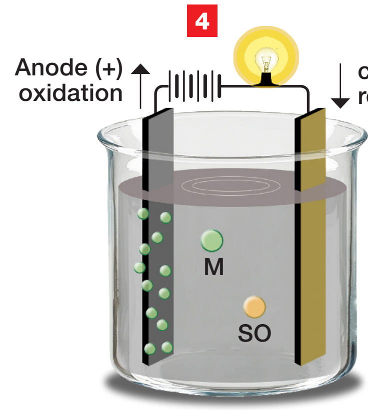
AFP/Getty Images

Metallic iron sulphides MFeS2: are metals (M) bonded to sulfur (S) and iron (Fe)



Acidithiobacillus bacteria





The metal is recovered through electrolysis: lays down in solid form in the anode

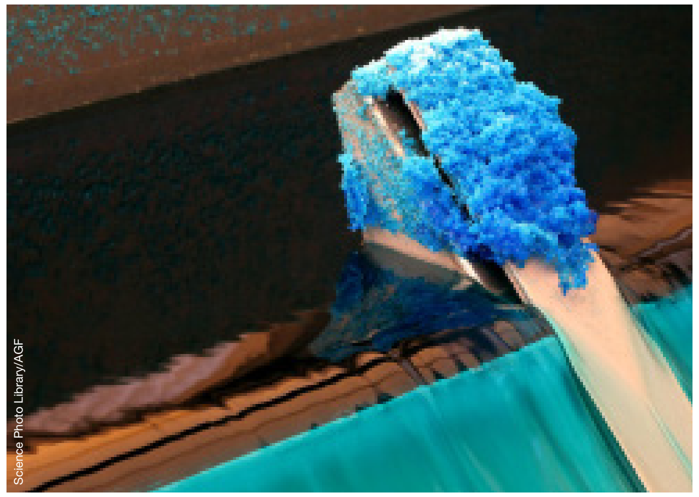
HOW BIOEXTRACTION WORKS

The bioextraction process starts from minerals (**1**) that contain iron (Fe) and sulfur (S), bound to a metal (M) that you want to extract: copper, nickel, cobalt, gold etc. On these minerals is poured an aqueous solution that contains acidophilic bacteria (**2**) of the genus Acidithiobacillus: these microorganisms obtain energy by oxidizing iron and sulfur, that is, associating them with oxygen.
The result of the action of bacteria (**3**) is that sulfur binds to oxygen, passing from disulfide (S_2) to thiosulfate (S_2O_3) and sulfuric acid (H_2SO4), which increases the acidity of the solution. The iron of the ore, insoluble, is transformed into soluble ferrous iron (Fe^{2}+) and then into ferric iron (Fe^{3}+), which acts as an oxidizing compound, in a continuous cycle. And so the metal (M) separates from the mineral, dissolving in water. Then it will be enough to subject to electrolysis (**4**)) the liquid thus obtained: with the passage of an electric current the solid metal particles are deposited on the anode to be recovered.

SYSTEMS IN COMPARISON	**Pirometallurgy (recovery at high temperatures > 2,000 °C)**	**Hydrometallurgy** (fusion through acids)	**Bioleaching** (recovery through the use of bacteria, archaea, fungi)
Energy	High expenditure	Low expenditure	Low expenditure
ecological impact	High emissions of CO_2, particulate matter and toxic gases	Leachates of acidic waters and harmful substances	Low impact, acidic water leachates

These bacteria derive **energy** by breaking down metals. Used for centuries, they were only discovered in **1951**: they live in acidic environments

HZDR/Frank Bierstedt



Science Photo Library/AGF

STUDIES
Bacterial treatment of copper extracted from concentrated solutions of copper sulphide minerals. In the other photo, a scientist from the Helmholtz Institute in Freiberg (Germany) studies bacteria in a bioreactor.

PLINY THE ELDER AND THE RIO TINTO

Latin writer Pliny the Elder in the treatise *Naturalis Historia* explained how to obtain metals by slowly running water in the mines during the winter, and then evaporating it in the summer. A process used mainly in the deposits along the Rio Tinto, in Spain: a very acidic and reddish river, due to the presence of iron dissolved in water. Already at the end of the 1800s in those mines were amassed heaps of low-quality minerals, 10 meters high, on which water was flowed for several months, and then recovered the copper so "leached", that is, separated from the other elements.

It wasn't until 1951 that Kenneth Temple, a researcher at the University of West Virginia, examined the iron-rich waters leaking from the coal mines of the Eastern United States. Discovering that the agent responsible for the oxidation processes was a bacterium, named *Acidithiobacillus ferrooxidans.* It was not an absolute surprise: already in 1922 bacteria capable of growing in sulfur and thriving in sulfuric acid had been discovered. Since then, several similar microorganisms have been found, capable of living in geothermal sites, rich in geysers and hot pools, both on land and in the oceans: bacteria (*Leptospirillum ferrooxidans, Sphingomonas desiccabilis*), archaea (*Sulfolobus metallicus, Pyrococcus furiosus, Acidianus sulfidivorans*) and fungi (*Aspergillus niger, Penicillum simplicissimum*). For decades, however, these microorganisms have remained in the shadow of those responsible for diseases: only in 1980 was the DNA of ferrooxidans isolated, and only since the 2000s has understanding of their chemical metabolism deepened.

In the meantime, however, many mining companies have begun to exploit mining bacteria: in New Mexico, Arizona, Chile and Australia to obtain copper, in Uganda for cobalt, in Finland for nickel, in Canada and Russia for uranium. It is enough to pour sulfuric acid, water and strains of these bacteria on piles of crushed rocks and collect the leachate on a polyethylene coating. This liquid is subjected to electrolysis (the passage of an electric current) and the metal settles on an electrode, ready to be recovered (*see diagram above*). An effective procedure without environmental impact: the metabolism of bacteria does not produce CO_2, on the contrary, it consumes it. The only flaw is time: bioextraction takes 6 to 12 months to extract copper from a pile.

USEFUL IN EXPLOITED FIELDS

Since 1986, another one has been added to this process in heaps: bioreactors. The rocks are placed in huge 1,300 m³ containers (the equivalent of over 50 tankers) where microbes are able to extract metals quickly and already in solid form. The containers are constantly shaken to keep the concentrate in suspension and to circulate oxygen and CO_2: an expensive and faster process (3-5 days), and for this reason used especially for precious metals such as gold in South America, Africa, Australia and China.

"Bioextraction is the only realistic method of extracting ▸

Ton Koene/Mondadori Portfolio

THOSE DEPOSITS IN THE HOUSE DRAWERS

In Italy, in 2020, 478,817 tons of electronic waste (WEEE) were collected, equal to about a third (36.8%) of the estimated total waste. Most are household appliances (washing machines and dishwashers, 34.4%), followed by refrigerators and air conditioners (26.5%), small appliances (21.4%) and screened devices (17%, WEEE Coordination Center data). The European Union has set itself the goal of recovering at least 65% of the weight of WEEE, but only Croatia and Bulgaria have succeeded (source Eurostat). It's a shame, because WEEE has concentrations of metals well above those of economically viable mines, as the table on the side shows. If you want to know the treasure that is hidden in the electronic devices that you no longer use at home, you can calculate it with the Ewaste calculator, a European Union project that also indicates the nearest WEEE collection center: bit.ly/3lyJ7XA.

metal	**concentration in soil** (per tonne)	**concentration in electronic waste** (per tonne)
gold	1 g	**20-300 g** (printed circuits)
palladium	1 g	**10-200 g** (printed circuits)
cobalt	100 g-6 kg	**120-200 kg** (lithium-ion batteries)
neodymium	1 kg	**250 kg** (magnets)
indium	10 g	**200-400 g** (Lcd screens)
copper	5 kg	**50-150 kg** (electronic waste)

SOURCE: Francesca Pagnanelli, Università La Sapienza di Roma - "Economia circolare verso le nanotecnologie: i prodotti da batterie a fine vita", 2020

NEGLECTED
E-waste in the Netherlands: today they are still recycled too little.

Today we only recycle **36.8%** of electronic waste. Bacteria could help to recover many **precious metals**

metals from low-quality minerals, which are becoming increasingly common," says Barrie Johnson, a professor of environmental biotechnology at Bangor University (UK). "Much of the near-surface and metal-rich deposits have been exploited. Bacteria can extract metals from unattainable deposits, at a depth of one km underground." Today, traditional mines have to dig and crush huge amounts of rocks: a process that alone consumes 5% of all the energy produced in the world, not counting the environmental impact.

"You could pump microbes underground to extract the metal; then it would be enough to suck the leachate on the surface to recover the metal. With much less money and environmental impact. The technology of fracking (extracting oil by pumping a high-pressure fluid underground) has made this operation feasible, but it has yet to be tested in practice. This will probably be how we extract most metals within a century," Johnson continues.

The European Union, which imports 80% of metals, has funded the BioMore project ,88.5 million euros) to identify the 15 European mines that could benefit from bioextraction. For Italy, those of Sarrabus-Gerrei, in Southern Sardinia, where antimony and tungsten can be extracted, are indicated.

RARE (AND WASTED) EARTHS

In the meantime, however, other more immediate applications are already on the horizon. Especially with regard to the extraction of rare earths, the group of 17 chemical elements capable of high performance in the optical, magnetic and electronic fields. They are used in batteries and computer screens, in the magnets of electric motors and wind turbines and in lasers. But they are in the hands of the few countries that host the largest deposits: China, which holds 58% of the world market, followed at a long distance by the USA (16%) and Burma (12.5%).

To free themselves from this monopoly, several countries are trying to extract rare earths from sources that everyone owns: electronic waste (WEEE). They have a high concentration of precious metals (gold and silver), metals of industrial interest (copper, cobalt, palladium) and, in fact, rare earths such as neodymium (*see table above*), all present at concentrations far higher than those of mines.

Today, most of these precious elements are thrown into unsorted waste: Europe has set itself the goal of recycling at least 65% of WEEE, but only Croatia and Bulgaria have reached (and exceeded) the goal. Italy, which has recycled 36.8%, is among the states that recycle the least, along with Slovenia, Romania and Malta.

"Laws privilege quantity at the expense of quality," comments Francesca Beolchini, professor of theory of the development of chemical processes at the Polytechnic University of Marche. "Once the goal of recovering 65% of the mass of electronic waste has been reached, the rest can be thrown away. Plastic, steel and aluminium are recovered in electronic waste; electronic boards, on the other hand, are sold to exporters who send them to the only two European melting furnaces, in Germany and Belgium, which are thus able to recover the materials of which they are made, but at the price of harmful emissions and high energy consumption. The glass of the monitors, on the other hand, is shredded, but it is a pity because it contains rare metals such as yttrium, indium, gallium and gold. It's an approach we can't afford anymore."

Esa

AT WORK IN ORBIT
Astronaut Luca Parmitano prepares bioreactors to test the extraction capabilities of bacteria in zero gravity on the International Space Station. On the right, heaps of minerals in the Sotkamo mine in Finland: 8 meters high and 1,200 meters long, they are sprayed with acids and bacteria by bioextraction.

Terrafame

An effective way to recover these metals could be through bioextraction: "The Laboratory of Environmental Technologies of the University of Ancona is patenting a method of extracting copper from electronic boards using ferrooxidant bacteria. We have yet to test the method on large volumes, but we are confident of doing it in a short time: it is a sustainable process, with low environmental impact and low energy consumption. In the meantime, we are also studying a biological method to extract gold, silver and palladium from electronic boards."

In this field, research is taking its first steps all over the world. Recently Cornell University has tried a new way: modify the DNA of oxidizing bacteria to improve their performance. "Today," writes Alexa Smith in a study published in *Nature Communications,* "the bacterium Gluconobacter oxydans manages to recover 56% of the rare earths contained in waste. It is enough to silence a single gene to improve bioleaching by 18%».

SPACE MINERS

The prospect of creating genetically modified bacteria, however, does not convince everyone: "There is always the risk that modified bacteria will disperse into the environment, with consequences that are difficult to predict," comments Johnson. "The world of ferrooxidant bacteria is yet to be discovered: many species are still unknown, and we do not know their metabolism and their genetic heritage in depth. It is a promising field of research, not only for the mining industry, but also to understand how life has evolved on Earth or other planets, given that these bacteria are capable of living in hostile environments."

Speaking of hostile environments, these microorganisms have been tested in space: in 2019, bacteria Sphingomonas desiccabilis were sent to the International Space Station, to extract rare earths from basalt rocks collected in Iceland, with a chemical composition similar to that of lunar and Martian rocks. Researchers at the University of Edinburgh wanted to test whether the bacteria could act even in weightlessness. The experiment, told in the journal *Nature*, has succeeded: in the coming years, instead of drills and excavators, tiny teams of bacteria can be sent to extract precious metals to the Moon, Mars or asteroids. F