A Nuclear Fusion Milestone | Parasite Pushes Wolves to Take Risks

Science News

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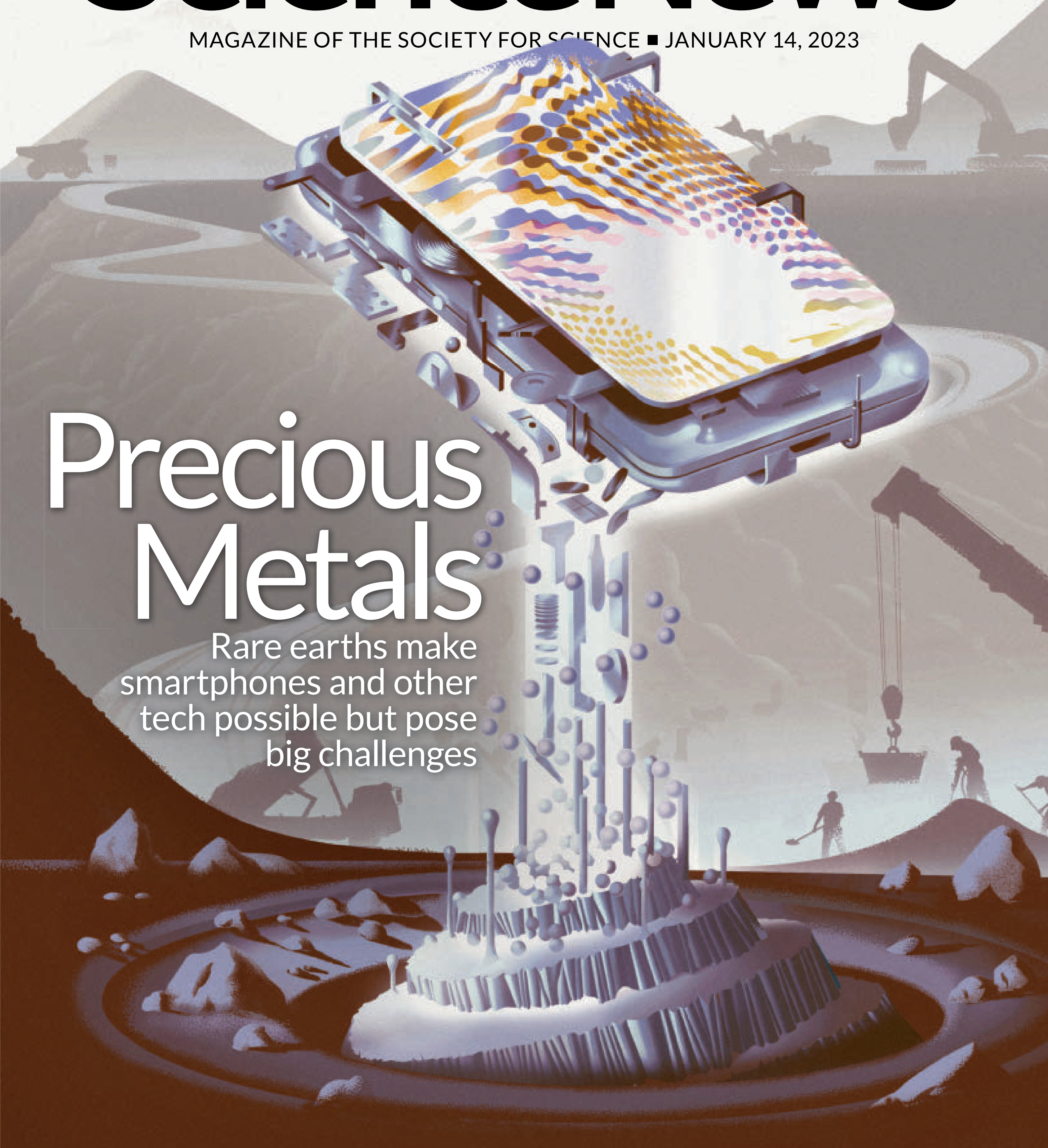

Precious Metals

Rare earths make smartphones and other tech possible but pose big challenges

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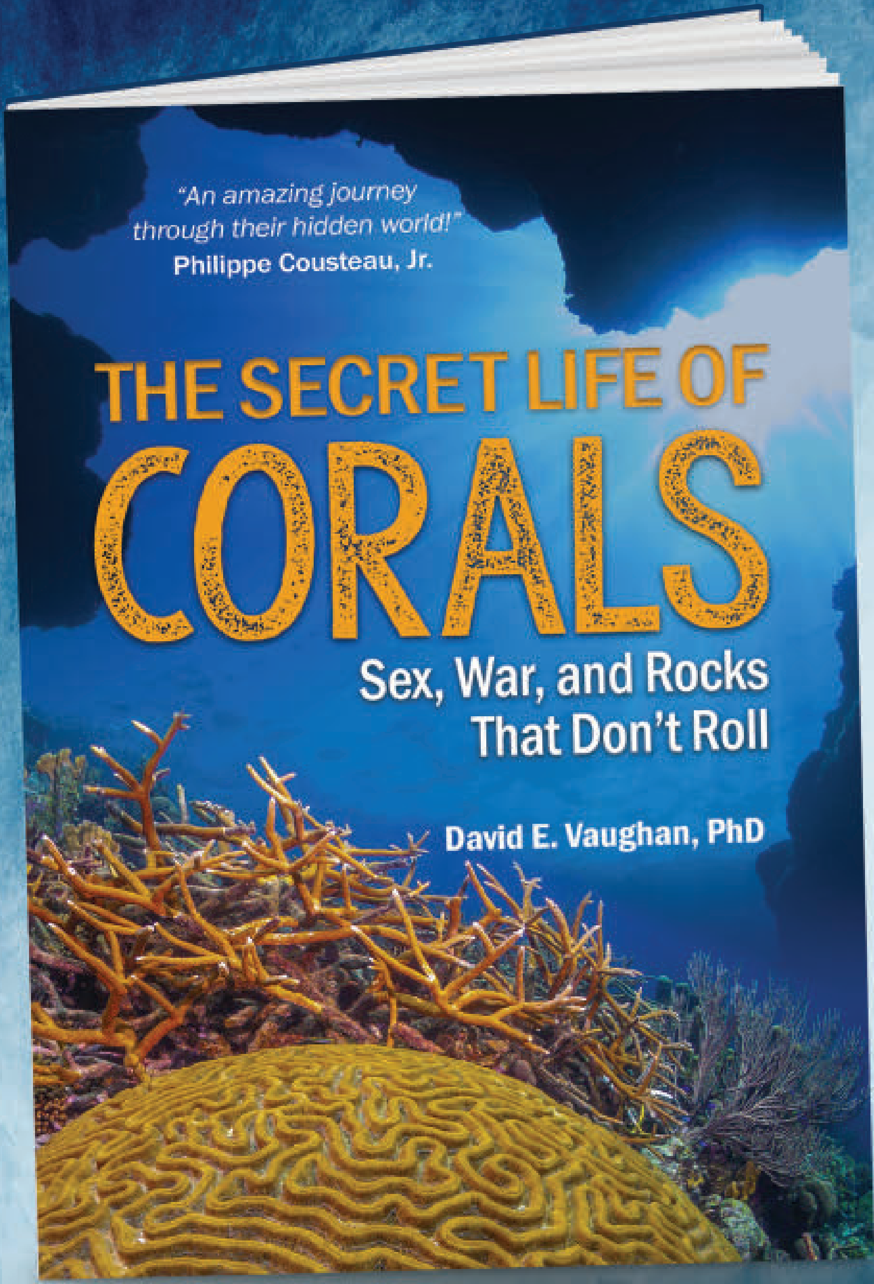
— Jeff Orlowski-Yang
Filmmaker, Director of Chasing Coral, Chasing Ice, and The Social Dilemma



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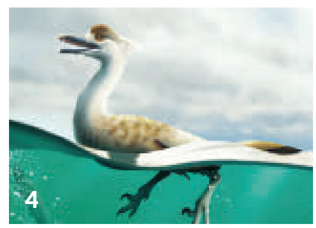
Special Report

PRECIOUS METALS

News



Departments

COVER Rare earth elements, mined in open pits, are key ingredients in smartphones and other electronics. *Sam Green*

FROM TOP: TMY350/WIKIMEDIA COMMONS (CC BY-SA 4.0); YUSIK CHOI; KOTO_FEJA/E+/GETTY IMAGES PLUS

Seeking the elements that make modern life possible

"Thank goodness for the lanthanides" is not something I say, but after reading this issue's special report on the importance of rare earth elements to society, maybe I should.

These unobtrusive metals, which include the chemical elements known as the lanthanides plus two other elements on the periodic table, are essential for making the magnets needed in electric cars and wind turbines, two key technologies for fighting climate change. The elements are ubiquitous in our homes, from smartphone and television screens to earbuds and computer hard drives.

And that's just a start.

"I became most fascinated by how the rare earths connect us to each other," staff writer Nikk Ogasa, who wrote about the chemistry of these elements (Page 24), told me. "It blows my mind that these dull-colored metals have enabled our global internet and satellite communications systems and could one day even give rise to a quantum internet."

But to keep modern life humming, we'll need more rare earth elements. They're actually not all that rare, but they're mined at only about a dozen sites around the world. Earth and climate writer Carolyn Gramling traveled to California's Mojave Desert last summer to Mountain Pass, the sole rare earth mine in the United States (Page 14). She spent hours exploring the giant pit with officials from MP Materials, the company that owns the mine, who are hoping to make it part of the first wholly U.S.-based rare earth supply chain, from ore to magnets. Ore from the mine is currently sent to China for processing. "I felt like I needed to see it in order to describe it," Gramling told me. "It gave me a real feel for what they're trying to do there."

Mining rare earths has caused environmental pollution and harmed human health, most notably in China. More demand means more mines and further underscores the need to minimize negative impacts. MP Materials is attempting to lessen those impacts, Gramling reports. But another option for reducing harm would be to extract rare earths from the mountains of consumer products that surround us. That's also no easy task.

"When you think that we recycle so many other metals, why aren't we recycling these?" says Erin Wayman, the magazine's managing editor, who wrote about efforts to develop new ways to recycle rare earths (Page 20).

The tiny bits of rare earths in a smartphone screen or a magnet are mixed with other materials. Thus the process of extracting rare earths from consumer products isn't so simple or cost effective. "It's not like you take an aluminum can and make more aluminum," Wayman explains.

Making the process of recycling these products more economical is an infrastructure challenge, not just a technological problem. "We don't have a system where you can jut put them in a blue bin at the curb," Wayman says. It will take both new science and new recycling systems to make it happen. But people in the infant rare earth recycling industry are optimistic that it will happen, and it should, especially as we anticipate a future with more shiny screens and electric cars.
—Nancy Shute, Editor in Chief

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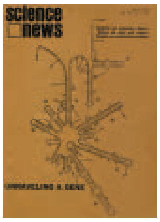


Excerpt from the January 6, 1973 issue of *Science News*

50 YEARS AGO

Biology's flower child

During the past several years, some artificial genes have been synthesized.... But no one had unraveled a real gene that dictates the production of a protein. Now researchers ... have done just that.... There is little doubt that sequencing of genes holds powerful ramifications for the advance of medical science.

UPDATE: A new era of genetics research dawned when scientists reported that they had deciphered the building blocks of a gene belonging to a virus. (The gene itself looks flowerlike when folded up.) In the decades since, scientists have rendered genetic blueprints, or genomes, for entire organisms across the tree of life. In 2001, the Human Genome Project released a rough draft of our collective genome. The master blueprint was finally completed last year (*SN: 4/23/22, p. 6*). Access to the human genome has led to powerful medical advances, including the development of targeted gene therapies and screenings for rare disorders (*SN: 3/27/21, p. 10*). In the future, people may routinely have their genomes sequenced to monitor health.

The newfound dinosaur *Natovenator polydontus* (illustrated) had a body that was similar to some modern waterfowl, researchers say.

YUSIK CHOI

INTRODUCING

Dinosaur's ducklike body hints at an aquatic lifestyle

A dinosaur unearthed in Mongolia is making a splash among paleontologists, as its sleek physique may add evidence to the idea that some dinos were suited for life in the water.

Natovenator polydontus may be the first known nonbird dinosaur to have possessed a streamlined body comparable to that of modern diving birds, researchers report December 1 in *Communications Biology*. *Natovenator* and other closely related dinosaurs may have been swimming predators, the researchers say, challenging the popular notion that dinos were landlubbers.

Natovenator was small like a duck and probably used its forelimbs when swimming, says Yuong-Nam Lee, a vertebrate paleontologist at Seoul National University in South Korea. "We think that *Natovenator* lived in shallow water and ate small fish."

This isn't the first time that researchers have suspected that a nonbird dinosaur had an aquatic lifestyle. For years, paleontologists have debated whether spinosaurs were aquatic predators (*SN: 4/23/22, p. 12*). In 2017, scientists reported that a dinosaur called *Halszkaraptor* had features analogous to those of aquatic birds and reptiles. But the team was unable to determine the dino's body shape from the fossilized remains.

In the new study, Lee and colleagues analyzed a well-preserved *Natovenator* from a fossil-rich area known as Hermiin Tsav in Mongolia, found in rocks dating to about 100 million to 66 million years ago. The jaw, teeth, neck and limbs are akin to those of *Halszkaraptor*, the scientists report, suggesting the two had comparable lives.

What's more, the orientation of *Natovenator*'s ribs indicates that it had a streamlined body like that of modern waterfowl, with a compressed and flattened rib cage akin to aquatic reptiles, Lee's team says.

The close resemblance between *Natovenator* and a duck or cormorant is almost certainly an example of convergent evolution, says Thomas Holtz Jr., a vertebrate paleontologist at the University of Maryland in College Park who was not involved in the study. "Similar body plans evolve because of similar lifestyles."

It is unclear just how strong a swimmer *Natovenator* may have been. The dinosaur's forelimbs appear short, and its hind limbs seem to lack attributes of kick-propelled swimmers like loons, Holtz says. But semiaquatic mammals like minks and some other successful modern swimming predators have skeletons that aren't highly specialized for life in the water either, he says. "*Natovenator* might be intermediate in swimming ability, between something like a mink and a loon." — *Nikk Ogasa*

THE NAME GAME

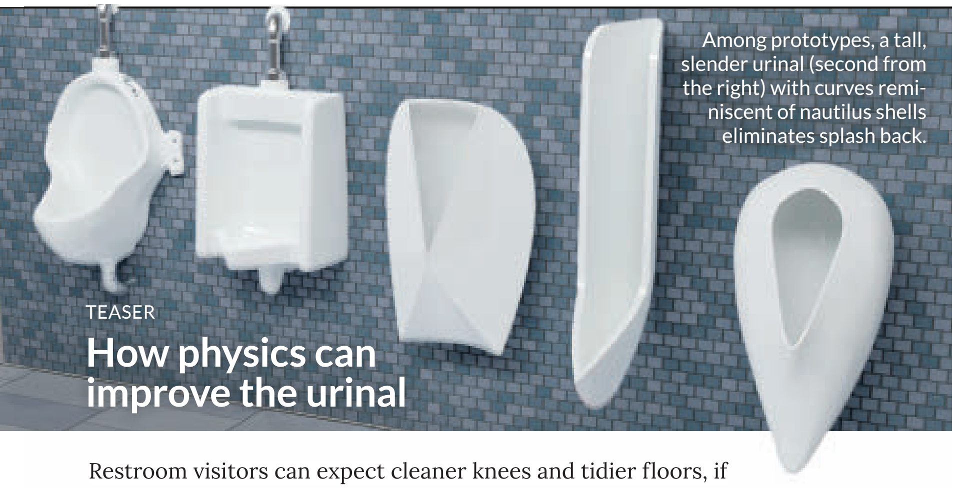
The metric system gains new prefixes

Meet the metric system's newest prefixes: ronna-, quetta-, ronto- and quecto-. Adopted November 18 at the 27th General Conference on Weights and Measures in Versailles, France, ronna- and quetta- describe very large numbers while ronto- and quecto- describe very small ones. For example, Earth's mass can be expressed as six ronnagrams while an electron's mass is about one rontogram.

Numerically, ronna- is 10^{27} (that's a digit followed by 27 zeros) and quetta- is 10^{30} (30 zeros). Their analogs ronto- and quecto- refer to 10^{-27} and 10^{-30}, the way milli- refers to 10^{-3}, or 0.001.

"The quantity of data in the world is increasing exponentially. And we expect that to continue to increase and probably accelerate because of quantum computing," says Richard Brown, head of metrology at the National Physical Laboratory in Teddington, England. It was clear that new official prefixes were needed because people were coming up with their own, such as bronto- after *Brontosaurus*, Brown says. The official prefix names are loosely based on the Greek and Latin names for nine and 10.

"The use of a suitable prefix makes things more understandable," Brown says. And even if there isn't an immediate use for the new additions, "they will gain traction over time." —*Deborah Balthazar*



Among prototypes, a tall, slender urinal (second from the right) with curves reminiscent of nautilus shells eliminates splash back.

TEASER

How physics can improve the urinal

Restroom visitors can expect cleaner knees and tidier floors, if they happen to use a new urinal inspired by curves in nature.

The key to making a splashless urinal is ensuring that a person's pee stream hits the porcelain at a shallow angle no matter where the stream is aimed, scientists reported November 22 at the American Physical Society's Division of Fluid Dynamics meeting in Indianapolis.

"For a small enough angle, there is no splash," says mechanical engineer Zhao Pan of the University of Waterloo in Canada. Pan and colleagues call the angle where splashing ceases the critical angle.

The team's design—a tall, narrow urinal with a curving inner surface—employs the same geometric formula as a nautilus shell. In tests, spraying dyed fluids into conventional urinals resulted in splash that would have ended up on a person's legs and feet and on the floor. When the researchers repeated the tests using the new urinal and inspected the surrounding surfaces, "I couldn't find even a single droplet," says Waterloo mechanical engineering student Kaveeshan Thurairajah. The smooth flow across the surface prevents droplets from flying out.

It's unclear whether people using the new urinal will find a way to make a mess. To tell how well it works in future real-world tests, Pan says, "just look at the floor." —*James R. Riordon*

FROM TOP: EDUARDO GONZALEZ DIAZ/EYEEM/GETTY IMAGES; MIA SHI AND Z. PAN/UNIV. OF WATERLOO

FOR DAILY USE

Dry pet food may be 'greener' than wet food

Pet owners may have a new reason to reach for the kibble. Dry cat and dog food tends to be better for the environment than wet food, researchers in Brazil report November 17 in *Scientific Reports*.

Nearly 90 percent of calories in wet chow come from animal sources, an analysis of more than 900 pet food products shows. That's roughly double the share of calories from animal ingredients in dry food. The team also factored in the cost of different pet food ingredients across several environmental measures. Those findings suggest that making wet food uses more land and water and emits more greenhouse gases than making dry food does.

Scientists already knew that meat-heavy human diets drive greenhouse gas emissions. But when it comes to environmental sustainability, "we shouldn't ignore pet food," says economist Peter Alexander of the University of Edinburgh.

Just how much various pet foods impact the environment isn't clear, Alexander says. Commercial feline and canine fares aren't typically made from prime cuts of meat. Instead, the foods often include the gristle and bits people aren't likely to eat.

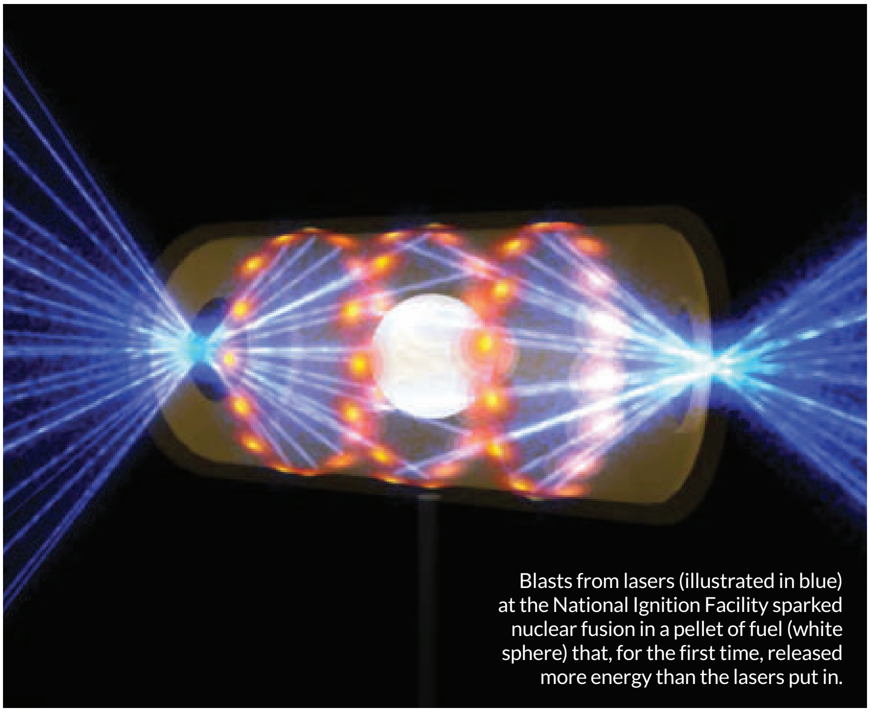
How to calculate the carbon cost of these leftovers is an ongoing debate, says environmental scientist Gregory Okin of UCLA. Some argue that the by-products are basically carbon neutral since they come from animals raised for human consumption. But animal ingredients in pet food might not be just scraps; including even a small amount of meat meant for people adds up. Still, knowing there's a difference between moist and crunchy morsels could help eco-minded pet owners, Okin says. —*Meghan Rosen*

News

PHYSICS

Nuclear fusion passes key milestone

‘Breakthrough’ raises hope for a plentiful clean energy source



Blasts from lasers (illustrated in blue) at the National Ignition Facility sparked nuclear fusion in a pellet of fuel (white sphere) that, for the first time, released more energy than the lasers put in.

LAWRENCE LIVERMORE NATIONAL LABORATORY

BY JAMES R. RIORDON

Scientists have finally managed to bottle the sun.

At 1:03 a.m. PST on December 5, researchers with the National Ignition Facility, or NIF, in Livermore, Calif., ignited controlled nuclear fusion that, for the first time, resulted in the net production of energy. A 3-million-joule burst emerged from a peppercorn-sized capsule of fuel when it was heated with a 2-million-joule laser pulse. Details of the long-awaited achievement, which mimics how the sun makes energy, were revealed in a news conference December 13 by U.S. Department of Energy officials.

“This is a monumental breakthrough,” says physicist Gilbert Collins of the University of Rochester in New York, who is a former NIF collaborator but was not involved with the research leading to the latest advance. “Since I started in this field, fusion was always 50 years away.... With this achievement, the landscape has changed.”

Fusion potentially provides a clean energy source. The fission reactors now used to generate nuclear energy rely on heavy atoms, like uranium, to release energy when they break down into lighter atoms, including some that are radioactive. While it’s comparatively easy to generate energy with fission, it’s an environmental nightmare to deal with the leftover radioactive debris that can remain hazardous for hundreds of millennia.

Controlled nuclear fusion, on the other hand, doesn’t produce such long-lived radioactive waste, but it’s much harder to achieve technically in the first place. In nuclear fusion, light atoms fuse together to create heavier ones. In the sun, that typically occurs when a proton, the nucleus of a hydrogen atom, combines with other protons to form helium.

Getting atoms to fuse requires a combination of high pressure and temperature to squeeze the atoms tightly together. Intense gravity does much of the work in the sun.

At NIF, 192 lasers directed into a can housing a small capsule filled with deuterium and tritium, heavy types of hydrogen, provided a blast of energy that did the trick instead. About 4 percent of that fuel was fused in the process. The new result far surpassed the 1.3 million joules of energy produced by an earlier NIF experiment that nearly reached the break-even point for nuclear fusion (*SN: 9/11/21, p. 11*).

“These recent results [at] NIF are the first time in a laboratory anywhere on Earth [that] we were able to demonstrate more energy coming out of a fusion reaction than was put in,” NIF physicist Tammy Ma said at the news conference. She predicted that pilot projects for power plants based on the fusion approach will be built in the “coming decades.”

But this latest fusion burst still didn’t produce enough energy to run the laser power supplies and other systems of the NIF experiment. It took about 300 million joules of energy from the electrical grid to get a hundredth of that energy back in fusion.

> “Now it’s up to the scientists and engineers to see if we can turn these physics principles into useful energy.”
>
> RICCARDO BETTI

“The net energy gain is with respect to the energy in the light that was shined on the target, not with respect to the energy that went into making that light,” says physicist Riccardo Betti of the University of Rochester, who was also not involved with the research. “Now it’s up to the scientists and engineers to see if we can turn these physics principles into useful energy.”

Despite that, it’s a potential turning point in the technology comparable to the invention of the transistor or the Wright brothers’ first flight, Collins says. “We now have a laboratory system that we can use as a compass for how to make progress very rapidly.” ■

PALEONTOLOGY

Mammoth die-off timeline debated

DNA skews estimates of the beasts' demise, scientists claim

BY BAS DEN HOND

Some ancient DNA may be leading paleontologists astray in attempts to date when woolly mammoths went extinct.

In 2021, an analysis of plant and animal DNA from Arctic sediment samples, spanning about the last 50,000 years, suggested that mammoths survived in northern Siberia until about 3,900 years ago (SN: 1/15/22, *p.* 22). That's much later than when fossil evidence suggests the last of the animals died out, in continental Eurasia. The youngest known mammoth fossil in the region dates to about 10,700 years ago.

The 2021 finding was one of several in recent years that used ancient environmental DNA, or eDNA, found in sediment and other material to suggest new insights into animal extinctions. eDNA from woolly rhinos in Eurasia and horses in Alaska have also indicated that these animals survived thousands of years longer in some areas than was generally thought.

But thousands of years is also how long the animals' large bones can linger on the ground in the frigid north, slowly weathering and shedding tiny bits of DNA, two researchers write in the Dec. 1 *Nature*.

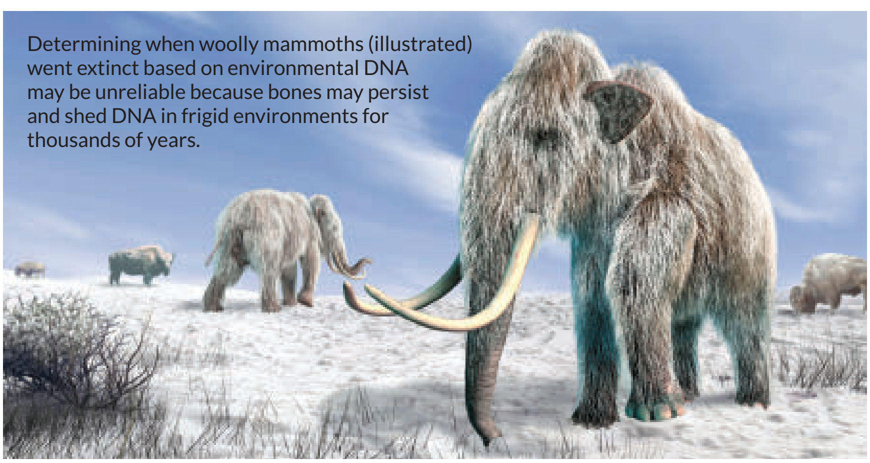
That means the youngest ancient DNA in sediment samples may have come from such bones, not shed by living mammoths and other megafauna. Studies that rely on this genetic evidence could skew estimates of when these animals went extinct by thousands of years toward the present, say paleontologists Joshua Miller of the University of Cincinnati and Carl Simpson of the University of Colorado Boulder.

When, and why, mammoths and some other Ice Age creatures vanished is a lingering mystery. Dating when these animals went extinct could help reveal what drove them to their demise—humans, a warming climate, some combination of the two or something else entirely.

But getting a good sense of when a species disappeared from its range, or from the planet, is not straightforward. For long-gone animals, fossils can help, but it would be a huge coincidence if the youngest fossil ever found of an extinct species was also the last individual to live.

Where fossils falter, DNA has started picking up the slack. Over the last two decades, eDNA has become a go-to technique to find out what organisms are living, or used to live, in a certain place (SN: 2/26/22, *p.* 4). Paleontologists generally focus on a variant of eDNA that gloms onto minerals and other material and gets buried over time. That "sedimentary ancient DNA," or sedaDNA, is what Yucheng Wang, an evolutionary geneticist at the University of Cambridge, and colleagues analyzed in the 2021 study.

"The DNA can come from a living animal, but it can also come from poop, from bones," Miller says. "In our case, we're focusing on bones."



Determining when woolly mammoths (illustrated) went extinct based on environmental DNA may be unreliable because bones may persist and shed DNA in frigid environments for thousands of years.

SCIENCE PHOTO LIBRARY-LEONELLO CALVETTI/GETTY IMAGES

In warmer climates, a bone lasts long enough to spread DNA for only a few decades at most, which usually is not important for getting a general date of extinction, Miller says. "But up in these cold settings, you would expect a much, much larger, even millennial-scale gap."

Miller and Simpson based their estimates of how long mammoth bones can shed DNA into the environment on radiocarbon dating of large animal bones found in cold climates today. Caribou antlers as old as 2,000 years have been found on the ground on islands in Norway and Canada, and 5,000-year-old remains of elephant seals have been found in the open near Antarctica's coastline.

Wang and colleagues disagree that the mammoth eDNA in their sample could be partly from old bones weathering down. The youngest mammoth eDNA they found shows low genetic diversity, the team notes in a reply in the same issue of *Nature*. That's precisely what's expected if the DNA actually came from a declining population at the end of mammoths' time on Earth, instead of from a thriving population earlier on.

"I think Miller and Simpson bring up a valid point for further testing and analysis," says evolutionary geneticist Hendrik Poinar, a pioneer of eDNA research who wasn't involved in either study.

"But I don't think that their analysis is nearly sufficient to combat the multiple avenues of evidence which suggest late persisting megafauna," says Poinar, of McMaster University in Hamilton, Canada. He points out that Wang and colleagues also examined eDNA from plants and concluded that woolly mammoths in northern Siberia could have survived for longer thanks to the steppe-tundra, the animals' natural habitat, holding on there.

Miller finds the nearly 7,000-year time span between the youngest known mammoth fossil in northern Siberia and the youngest mammoth eDNA reported by Wang's team suspicious. That work indicates "there should be dozens, or hundreds of [relatively recent] dead mammoths somewhere," he says. "People have been looking for them.... And you just don't find anything." ■

ANTHROPOLOGY

Homo naledi may have lit fires

South African caves hold remnants of small fireplaces

BY BRUCE BOWER

An ancient hominid called *Homo naledi*, represented here by a child's partial skull, possibly used fire between 335,000 and 236,000 years ago, cave finds suggest.

The ancient hominid *Homo naledi* may have lit controlled fires in the pitch-dark chambers of an underground cave system, new discoveries hint.

Researchers have found remnants of small fireplaces and sooty wall and ceiling smudges in passages and chambers throughout South Africa's Rising Star cave complex, paleoanthropologist Lee Berger announced in a December 1 lecture hosted by the Carnegie Institution for Science in Washington, D.C.

"Signs of fire use are everywhere in this cave system," said Berger, of the University of the Witwatersrand, Johannesburg.

H. naledi presumably lit the blazes in the caves since no remains of any other hominids have turned up there, Berger and colleagues say. But the team has yet to date the fire remnants. And researchers outside Berger's group have yet to evaluate the finds.

H. naledi fossils date to between 335,000 and 236,000 years ago (SN: 6/10/17, p. 6), about when *Homo sapiens* originated. Many researchers suspect that regular use of fire by hominids for light, warmth and cooking began roughly 400,000 years ago (SN: 5/5/12, p. 18).

Such behavior has not been attributed to *H. naledi* before, largely because of its small brain. Berger contends it's now clear that a brain roughly one-third the size of human brains today still enabled *H. naledi* to achieve control of fire.

Last August, he examined two underground chambers where *H. naledi* fossils had been found. He said he noticed ceiling surfaces that displayed blackened, burned areas and were also dotted by what appeared to be soot particles.

Meanwhile, expedition codirector and Witwatersrand paleoanthropologist Keneiloe Molopyane led excavations of a nearby cave chamber. There, the team uncovered two small fireplaces containing charred bits of wood and burned bones of antelopes and other animals. Remains of a fireplace and nearby burned animal bones were then discovered in a more remote cave chamber where *H. naledi* fossils have been found, Berger said.

Still, the main challenge for investigators will be to date the burned wood and bones and other fire remains from the Rising Star chambers and demonstrate that the material comes from the same sediment layers as *H. naledi* fossils, says paleoanthropologist W. Andrew Barr of George Washington University in Washington, D.C., who wasn't involved in the work. "That's an absolutely critical first step before it will be possible to speculate about who may have made fires for what reason," Barr says.

Bone, wood and charcoal from the South African site should also be examined to determine whether darkened areas resulted from burning or mineral staining, says archaeologist Sarah Hlubik of Harvard University. A careful analysis of the layout of remains in the Rising Star chambers, she adds, will indicate whether Berger's group discovered small fireplaces or only material that washed into the cave system. ■

HEALTH & MEDICINE

Air pollution mucks up lung defenses

Particulate buildup impairs respiratory immunity as people age

BY AIMEE CUNNINGHAM

The lungs' immune defenses can wane with age, leaving older adults more susceptible to lung damage and severe bouts of respiratory infections. One reason why this might happen: Inhaled particulate matter from pollution gunks up the works over time, weakening the lungs' immune system, researchers report November 21 in *Nature Medicine*.

Air pollution is a major cause of disease and early death worldwide and disproportionately impacts poor and marginalized communities (SN: 8/29/20, p. 7). Particulate matter — a type of pollution emitted from vehicle exhaust, power plants, wildfires and other sources — has been tied to respiratory, cardiovascular and neurological diseases (SN: 9/30/17, p. 18).

Columbia University scientists analyzed lung immune tissue from 84 organ donors ranging in age from 11 to 93 years old. The donors were nonsmokers or had no history of heavy smoking. With age, the lungs' lymph nodes — which filter foreign substances and contain immune cells — became loaded with particulate matter, turning them a deep onyx.

When lymph nodes build up that much material, "they can't do their job," says cell biologist Elizabeth Kovacs of the University of Colorado Anschutz Medical Campus in Aurora.

The lymph nodes are home to an array of immune cells, including macrophages. These cellular Pac-Mans gobble up pathogens and debris, including particulate matter. Macrophages in pollutant-filled lymph nodes made fewer proteins that recruit other immune cells and showed signs of having a diminished capacity for gobbling.

The findings indicate that older people have accumulated so much debris, "they may not be able to accumulate more," Kovacs says, impairing their ability to deal with inhaled material.

Pollution is a threat to the health of the world's population, the team writes. And that threat includes an impact on respiratory immunity with age. ■

WIKUS DE WET/AFP VIA GETTY IMAGES

Gambling Debt Reveals Stunning Turquoise Jewelry

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Old Pete was a retired stuntman bursting with stories. There was the time he stared down a grizzly bear. There was the time he won a competition and got to kiss a Hollywood starlet as the prize. And there was the time he got into a fistfight with the Duke. Many stories. Some were probably even true. I know two things for sure: that he had an excellent collection of turquoise and that he owed me for a poker game he lost. The last time I saw him, he opened a drawer and pulled out a collection of beautiful Navajo turquoise jewelry to repay his debt. Pete's jewelry inspired our Tucson Sun Turquoise Collection.

This jewelry set features turquoise that's been gently enhanced to bring out its finest shades in a Southwestern motif. Finished with oxidized silver, this jewelry set captures the beauty and mystery of the Arizona desert. The rarest and most valuable turquoise is found right here in the American Southwest, but the future of the blue beauty is unclear. I recently spoke with turquoise traders who explained that less than 5% of turquoise mined worldwide can be set into jewelry. Once thriving, many Southwest mines have closed.

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NEWS

ASTRONOMY

Why some black holes blaze bright

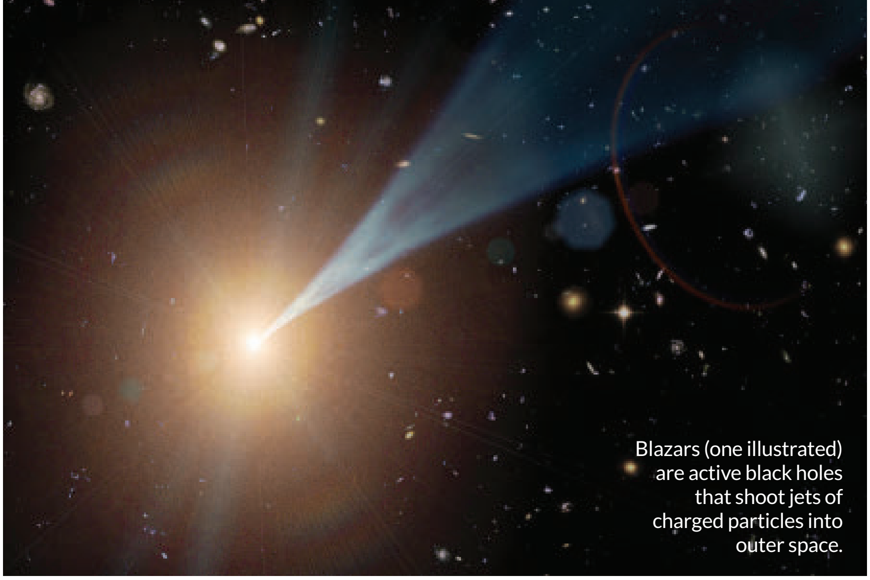
Shock waves help accelerate jets of escaping particles

BY LISA GROSSMAN

For the first time, astronomers have observed how certain supermassive black holes launch jets of high-energy particles into space — and the process is shocking.

Shock waves propagating along the jet of one such blazar contort magnetic fields that accelerate escaping particles to nearly the speed of light, astronomers report in the Nov. 24 *Nature*. Studying such extreme acceleration can help probe fundamental physics questions that can't be studied any other way.

A blazar is an active black hole at the center of a galaxy that shoots a jet of high-energy particles toward Earth, making it appear as a bright spot from millions or even billions of light-years away (SN: 9/5/15, p. 4). Astronomers knew that these jets' extreme speeds and tight collimated beams had something to do with the shape of magnetic fields around black holes, but the details were fuzzy.



Blazars (one illustrated) are active black holes that shoot jets of charged particles into outer space.

Enter the Imaging X-Ray Polarimetry Explorer, or IXPE, an orbiting telescope launched in December 2021. It measures X-ray polarization, or how X-ray light is oriented as it travels through space. While previous observations of polarized radio waves and optical light probed parts of blazar jets days to years after they'd been accelerated, polarized X-rays can see into a blazar's active core.

"In X-rays, you're really looking at the heart of the particle acceleration … the region where everything happens," says astrophysicist Yannis Liodakis of the University of Turku in Finland.

In March 2022, IXPE observed an especially bright blazar called Markarian 501 that's about 450 million light-years from Earth.

Liodakis and colleagues had two ideas for how magnetic fields might accelerate Markarian 501's jet. One option is magnetic reconnection, where magnetic field lines break, reform and connect with other nearby lines. The same process accelerates

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HEALTH & MEDICINE

8 cups of water a day idea debunked

How much water people need to stay hydrated isn't universal

BY ALLISON GASPARINI

Are you drinking enough water?

The question seems like it should have a straightforward answer — a specific amount of water needed daily to combat dehydration. But the rate and way in which the human body takes in and excretes water is not universal.

By studying more than 5,000 people that ranged in age from 8 days to 96 years in 23 countries, researchers have found that the turnover of water in a person's body varies widely depending on the individual's physical and environmental factors. The findings, published in the Nov. 25 *Science*, suggest that the idea that a person should ideally consume eight 8-ounce glasses of water a day is not a one-size-fits-all solution to dehydration.

Even within the groups studied, "individual variabilities could be huge," says biomedical engineer Kong Chen, codirector of the Metabolic Clinical Research Unit at the U.S. National Institutes of Health's Clinical Center in Bethesda, Md.

Yosuke Yamada, a physiologist at the National Institutes of Biomedical Innovation, Health and Nutrition in Kyoto, Japan, and colleagues used a stable isotope of hydrogen known as deuterium to track the movement of water through people's bodies. Drinking water accounts for only half of the total water intake by humans, with the rest coming from food. Simply measuring the amount of water that a person drinks in a day is not enough to accurately gauge water turnover, or the amount of water used by the body daily.

Men ages 20 to 30 and women ages 20 to 55 had the highest water turnover, the team found. These numbers varied significantly depending on humidity, altitude, latitude and physiological factors, such as whether a person was athletic. For both men and women, the low end of water turnover averaged around 1 to 1.5 liters per day and the high end averaged around 6 liters per day.

But the findings are not a road map for how much water individuals in certain populations should drink daily, Chen says. Instead, the data raise more questions about the effects of particular environments on an individual's water turnover.

People who live in countries that score low on the human development index, or HDI, have a higher water turnover rate, Yamada says. Even when the team adjusted for climate, body size, sex and other factors, people living in low-HDI countries — which, for this study, included

JPL-CALTECH/NASA

plasma on the sun (SN: 12/7/19, p. 14). If that was the blazar's acceleration engine, the polarization of light should be the same along the jet in all wavelengths.

Another option is a shock wave shooting particles down the jet. At the site of the shock, the magnetic fields suddenly switch from turbulent to ordered. That switch could send particles zooming away, like water through the nozzle of a hose. As the particles leave the shock site, turbulence should take over again. If a shock was responsible for the acceleration, short-wavelength X-rays should be more polarized than longer-wavelength optical and radio light, as measured by other telescopes.

That's exactly what the team saw. "We got a clear result," Liodakis says, that favors the shock wave explanation.

More work is needed to figure out what produced the shock, says astrophysicist James Webb of Florida International University in Miami. But "this is a step in the right direction," he says. "It's like opening a new window and looking at the object freshly, and we now see things we hadn't seen before. It's very exciting." ■

Ghana, Kenya, Nigeria and Tanzania — still had higher water turnover rates than those in high-HDI countries, including Belgium, Japan and the United States. The disparity may be due to the frequent use of indoor climate control in the high-HDI countries, the team suggests.

The water turnover rate could also represent a significant marker of an individual's metabolic health. Ten percent of a person's total body water is lost daily to the metabolic processes in cells. For people with less access to safe drinking water, this loss can also be a "huge issue," Yamada says.

More than 2 billion people in the world don't have access to safe drinking water and that number is projected to grow, according to a 2018 United Nations report (SN: 8/18/18 & 9/1/18, p. 14). Hopefully experts will be able to use the findings to figure out how to help people stay hydrated in the face of water shortages, Yamada says. ■

NEUROSCIENCE

Synapses stick around in mice's brains

'Silent' connections may explain how adults make new memories

BY CLAUDIA LÓPEZ LLOREDA

Learning lots of new information as a baby requires a pool of ready-to-go, immature connections between nerve cells to form memories quickly. Called "silent" synapses, these connections are inactive until summoned to help create memories, and were thought to be present mainly in the developing brain and die off with time. But a new study reveals that there are many silent synapses in the adult mouse brain, researchers report in the Dec. 8 *Nature*.

Neuroscientists have long puzzled over how the adult human brain can have stable, long-term memories, while at the same time maintaining a certain flexibility to be able to form new memories, a concept known as plasticity. Silent synapses may be part of the answer, says Jesper Sjöström, a neuroscientist at McGill University in Montreal who was not involved in the work.

"The silent synapses are ready to hook up," he says, possibly making it easier to store new memories as an adult by using these connections instead of having to override or destabilize mature synapses already connected to memories. "That means that there's much more room for plasticity in the mature brain than we previously thought."

In a previous study, neuroscientist Mark Harnett of MIT and colleagues had spotted many long, rod-shaped structures called filopodia in adult mouse brains. That surprised Harnett because the protrusions are mostly found on nerve cells in the developing brain.

"Here they were in adult animals, and we could see them crystal clearly," Harnett says. So the team decided to examine the filopodia to see what role they play, and if they were possibly silent synapses.

The researchers used a technique to expand the brains of adult mice combined with high-resolution microscopy. Since nerve cell connections and the molecules called receptors that allow for communication between connected cells are so small, these methods revealed synapses that past research missed.

The team looked for the typical signs of a silent synapse: the presence of a type of receptor called NMDA and the absence of another known as AMPA. Both of these receptors respond to the chemical messenger glutamate, but both typically need to be present for a synapse to be active.

Of the more than 2,000 synapses that the team looked at, about 30 percent were filopodia and, of those, nearly all had characteristics suggesting that they could be silent synapses.

To test whether the connections were truly silent, the researchers turned to glutamate. Artificially adding the chemical messenger was not enough to activate the synapses, the team found, suggesting the connections were actually silent ones.

Adding an electrical current in addition to glutamate turned these connections from immature into mature synapses. That's also what happens in the developing brain when a new memory is formed from a silent synapse.

It's unclear whether silent synapses are also prevalent in the adult human brain, though Harnett and other scientists like Sjöström think it's likely. Harnett's team is now using the same techniques on human brains to find out. ■

A nerve cell (illustrated) branches out to create connections called synapses. Inactive, or silent, synapses in adult mice may be important for forming new memories, scientists say.

KOTO_FEJA/E+/GETTY IMAGES PLUS

ANIMALS

Parasite makes gray wolves take risks

Toxoplasma gondii infections dramatically impact social behavior

BY JAKE BUEHLER

A parasite might be driving some wolves to lead or go solo.

Wolves in Yellowstone National Park infected with *Toxoplasma gondii* make more daring decisions than their uninfected counterparts, researchers report November 24 in *Communications Biology*. The wolves' enhanced risk-taking means they are more likely to leave their pack, or become leaders of their own.

"Those are two decisions that can really benefit wolves, or could cause wolves to die," says field biologist Connor Meyer of the University of Montana in Missoula. The findings reveal a parasite's potent ability to influence a wolf's social fate.

With wildlife, disease is usually considered in the context of killing a host, Meyer says. "We have evidence now that just being infected with a certain parasite — *Toxoplasma* — can have pretty major implications for wolf behavior."

Single-celled *T. gondii* has a track record of altering animal behavior. Its most important hosts are cats, which provide a breeding ground for the parasite in the small intestine. Parasite offspring hitch a ride to the outside world on feline feces, which other animals ingest. The parasite then alters the behavior of its new host by tweaking certain hormones, making the host bolder or more aggressive. Infected mice, for example, can fatally lose their fear of cats. When cats eat the mice, the parasite cycle continues (*SN Online*: 1/14/20).

In Yellowstone National Park, many gray wolves (*Canis lupus*) are also infected with *T. gondii*, recent research has shown. So Meyer and colleagues wondered if those wolves show signs of any parasite mind-bending.

Gray wolves were reintroduced to Yellowstone in 1995. Ongoing study of the park's packs meant that the researchers had access to about 26 years' worth of blood samples, behavioral observations and movement data for 229 wolves.

The team screened the blood samples for the presence of antibodies against *T. gondii* parasites, which would reveal an infection. Researchers also noted which wolves left their pack or became a pack leader. Both are high-stakes moves for a wolf, Meyer says. For instance, wolves that challenge pack leaders risk injury, and wolves that strike out in search of a new pack risk starvation.

Infected wolves were 11 times as likely as noninfected wolves to disperse from their pack, the team found, and about 46 times as likely to eventually become leaders. The findings fit with *T. gondii*'s apparent ability to boost boldness across a wide range of warm-blooded life.

Gray wolves in Yellowstone National Park take more risks when infected with *Toxoplasma gondii* parasites, research suggests.

RUSSELL BURDEN/PHOTODISC/GETTY IMAGES PLUS

The study fills a crucial gap in the *Toxoplasma* pool of knowledge, says neurobiologist Ajai Vyas of Nanyang Technological University in Singapore.

"Most of the earlier work has been done in the lab," Vyas says. But that approach has limitations, especially for re-creating how animals experience the effects of the parasite in their natural environment. Such research has "become almost like studying whale swimming behavior in backyard pools; [it] does not work very well," he says.

Wolves' enhanced boldness may even form a feedback loop, Meyer and colleagues propose. The team found that wolves' infection rates were highest when the animals' ranges overlapped with Yellowstone's densest aggregations of cougars (*Puma concolor*), which also carry the parasite. Infected wolf leaders may be more likely to bring pack members into riskier situations, including approaching cougar territories, making additional infections more likely. But it's unclear whether the parasite is encouraging this overlap by modifying behavior.

The feedback loop idea is "very fascinating," says epidemiologist Greg Milne of the Royal Veterinary College in London. Still, more work is needed to confirm it, Milne says. Such research may involve determining if infected wolves are more likely to migrate into an area with more cougars.

"People are just starting to really appreciate that personality differences in animals are a major consideration in behavior," says study coauthor Kira Cassidy, a wildlife biologist at the Yellowstone Wolf Project in Bozeman, Mont. "Now we add a parasite impacting behavior to the list."

Next, Meyer, Cassidy and colleagues are interested in examining the long-term consequences of *T. gondii* infection, and whether infected wolves make better leaders or dispersers than uninfected wolves.

It's also not known how infection impacts survival and reproduction rates, Cassidy says. "Infection may very well be detrimental in some ways and advantageous in others." ■

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Mountain Pass (shown), in southeastern California, remains the United States' only mine for rare earth elements, the building blocks of magnets used in smartphones, wind turbines and electric vehicles.

From Mine to Magnet

The green economy needs more rare earths, and the United States hopes to expand its production

By Carolyn Gramling

TMY350/WIKIMEDIA COMMONS (CC BY-SA 4.0)

In spring 1949, three prospectors armed with Geiger counters set out to hunt for treasure in the arid mountains of southern Nevada and southeastern California.

In the previous century, those mountains yielded gold, silver, copper and cobalt. But the men were looking for a different kind of treasure: uranium. The world was emerging from World War II and careening into the Cold War. The United States needed uranium to build its nuclear weapons arsenal. Mining homegrown sources became a matter of national security.

After weeks of searching, the trio hit what they thought was pay dirt. Their instruments detected intense radioactivity in brownish-red veins of ore exposed in a rocky outcrop within California's Clark Mountain Range. But instead of uranium, the brownish-red stuff turned out to be bastnaesite, a mineral bearing fluorine, carbon and 17 curious elements known collectively as rare earths. Traces of radioactive thorium, also in the ore, had set the Geiger counters pinging.

As disappointing as that must have been, the bastnaesite still held value, and the prospectors sold their claim to the Molybdenum Corporation of America, later called Molycorp. The company was interested in mining the rare earths. During the mid-20th century, rare earth elements were becoming useful in a variety of ways: Cerium, for example, was the basis for a glass-polishing powder and europium lent luminescence to recently invented color television screens and fluorescent lamps.

For the next few decades, the site, later dubbed Mountain Pass mine, was the world's top source for rare earth elements, until two pressures became too much. By the late 1980s, China was intensively mining its own rare earths — and selling them at lower prices. And a series of toxic waste spills at Mountain Pass brought production at the struggling mine to a halt in 2002.

But that wasn't the end of the story. The green-tech revolution of the 21st century brought new attention to Mountain Pass, which later reopened and remains the only U.S. mine for rare earths.

Rare earths are now integral to the manufacture of many carbon-neutral technologies — plus a whole host of tools that move the modern world. These elements are the building blocks of small, superefficient permanent magnets that keep smartphones buzzing, wind turbines spinning, electric vehicles zooming and more (see Page 24).

Mining U.S. sources of rare earth elements, President Joe Biden's administration stated in February 2021, is a matter of national security.

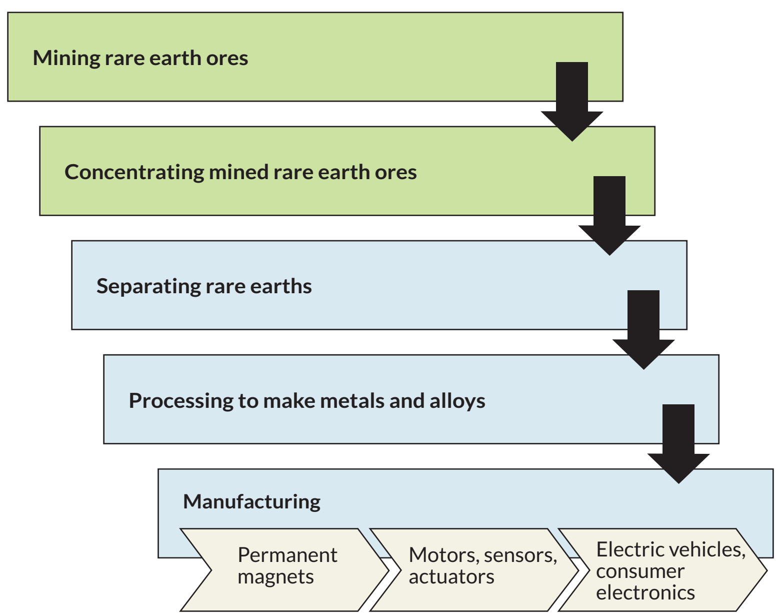
Rare earths are not actually rare on Earth, but they tend to be scattered throughout the crust at low concentrations. And the ore alone is worth relatively little without the complex, often environmentally hazardous processing involved in converting the ore into a usable form, says Julie Klinger, a geographer at the University of Delaware in Newark. As a result, the rare earth mining industry is wrestling with a legacy of environmental problems.

Rare earths are mined by digging vast open pits in the ground, which can contaminate the environment and disrupt ecosystems. When poorly regulated, mining can produce wastewater ponds filled with acids, heavy metals and radioactive material that might leak into groundwater. Processing the raw ore into a form useful to make magnets and other tech is a lengthy effort that takes large amounts of water and potentially toxic chemicals, and produces voluminous waste.

"We need rare earth elements…to help us with the transition to a climate-safe future," says Michele Bustamante, a sustainability researcher at the Natural Resources Defense Council in Washington, D.C. Yet "everything that we do when we're mining is impactful environmentally," Bustamante says.

But there are ways to reduce mining's footprint, says Thomas Lograsso, a metallurgist at the Ames National Laboratory in Iowa and the director of the Critical Materials Institute, a Department of Energy research center. Researchers are investigating everything from reducing the amount of waste produced during the ore processing to improving the efficiency of rare earth element separation, which

Many steps
The United States mines and concentrates rare earths. But the intention is to begin handling the later processing steps needed to make magnets, which currently happens overseas.
SOURCE: U.S. DEPARTMENT OF ENERGY



can also cut down on the amount of toxic waste. Scientists are also testing alternatives to mining, such as recycling rare earths from old electronics or recovering them from coal waste (see Page 22).

Much of this research is in partnership with the mining industry, whose buy-in is key, Lograsso says. Mining companies have to be willing to invest in making changes. “We want to make sure that the science and innovations that we do are driven by industry needs, so that we’re not here developing solutions that nobody really wants,” he says.

Klinger says she’s cautiously optimistic that the rare earth mining industry can become less polluting and more sustainable, if such solutions are widely adopted. “A lot of gains come from the low-hanging fruit,” she says. Even basic hardware upgrades to improve insulation can reduce the fuel required to reach the high temperatures needed for some processing. “You do what you [can].”

Environmental wastelands

Between the jagged peaks of California’s Clark range and the Nevada border sits a broad, flat, shimmering valley known as the Ivanpah Dry Lake. Some 8,000 years ago, the valley held water year-round. Today, like many such playas in the Mojave Desert, the lake is ephemeral, winking into appearance only after an intense rain and flash flooding. It’s a beautiful, stark place, home to endangered desert tortoises and rare desert plants like Mojave milkweed.

From about 1984 to 1998, the Ivanpah Dry Lake was also a holding pen for wastewater piped in from Mountain Pass. The wastewater was a byproduct of chemical processing to concentrate the rare earth elements in the mined rock, making it more marketable to companies that could then extract those elements to make specific products. Via a buried pipeline, the mine sent wastewater to evaporation ponds about 23 kilometers away, in and around the dry lake bed.

The pipeline repeatedly ruptured over the years. At least 60 separate spills dumped an estimated 2,000 metric tons of wastewater containing radioactive thorium into the valley. Federal officials feared that local residents and visitors to the nearby Mojave National Preserve might be at risk of exposure to that thorium, which could lead to increased risk of lung, pancreatic and other cancers. Unocal Corporation, which had acquired Molycorp in 1977, was ordered to clean up the spill in 1997, and the company paid over $1.4 million in fines and settlements. Chemical processing of the raw ore ground to a halt. Mining operations stopped shortly afterward.

Half a world away, another environmental disaster was unfolding. The vast majority — between 80 and 90 percent — of rare earth elements on the market since the 1990s have come from China. One site alone, the massive Bayan Obo mine in Inner Mongolia, accounted for 45 percent of rare earth production in 2019.

Bayan Obo spans some 4,800 hectares, about half the size of Florida’s Walt Disney World resort. It is also one of the most heavily polluted places

Desirable resources A small number of countries currently mine for rare earth elements (yellow circles show locations). But rare earth resources have been identified in many other locations, including Vietnam, Turkey and Greenland. SOURCE: E. DEADY/GLOBAL RARE EARTH ELEMENT (REE) MINES, DEPOSITS AND OCCURRENCES/BRITISH GEOLOGICAL SURVEY 2021

Rare earth mining locations
1. Mountain Pass, Calif. (U.S.)
2. Araxá (Brazil)
3. Lovozero (Russia)
4. Khibiny (Russia)
5. Bayan Obo (China)
6. Weishan (China)
7. Maoniuping (China)
8. Longnan (China)
9. Northern Myanmar
10. Thai Peninsula (Thailand)
11. Chavara (India)
12. Karonge (Burundi)
13. Mandena (Madagascar)
14. Mount Weld (Australia)

IULIIA KONOVALIUK/ISTOCK/GETTY IMAGES PLUS, ADAPTED BY E. OTWELL on Earth. Clearing the land to dig for ore meant removing vegetation in an area already prone to desertification, allowing the Gobi Desert to creep southward.

In 2010, officials in the nearby city of Baotou noted that radioactive, arsenic- and fluorine-containing mine waste, or tailings, was being dumped on farmland and into local water supplies, as well as into the nearby Yellow River. The air was polluted by fumes and toxic dust that reduced visibility. Residents complained of nausea, dizziness, migraines and arthritis. Some had skin lesions and discolored teeth, signs of prolonged exposure to arsenic; others exhibited signs of brittle bones, indications of skeletal fluorosis, Klinger says.

The country's rare earth industry was causing "severe damage to the ecological environment," China's State Council wrote in 2010. The release of heavy metals and other pollutants during mining led to "the destruction of vegetation and pollution of surface water, groundwater and farmland." The "excessive rare earth mining," the council wrote, led to landslides and clogged rivers.

Faced with these mounting environmental disasters, as well as fears that it was depleting its rare earth resources too rapidly, China slashed its export of the elements in 2010 by 40 percent. The new limits sent prices soaring and kicked off concern around the globe that China had too tight of a stranglehold on these must-have elements. That, in turn, sparked investment in rare earth mining elsewhere.

In 2010, there were few other places mining rare earths, with only minimal production from India, Brazil and Malaysia. A new mine in remote Western Australia came online in 2011, owned by mining company Lynas. The company dug into fossilized lava preserved within an ancient volcano called Mount Weld.

Mount Weld didn't have anywhere near the same sort of environmental impact seen in China: Its location was too remote and the mine was just a fraction of the size of Bayan Obo, according to Saleem Ali, an environmental planner at the University of Delaware. The United States, meanwhile, was eager to once again have its own source of rare earths—and Mountain Pass was still the best prospect.

Resurrecting a mine

After the Ivanpah Dry Lake mess, the Mountain Pass mine changed hands again. Chevron purchased it in 2005, but did not resume operations. Then, in 2008, a newly formed company called Molycorp Minerals purchased the mine with ambitious plans to create a complete rare earth supply chain in the United States.

The Bayan Obo mine (shown) in China's Inner Mongolia region was responsible for nearly half of the world's rare earth production in 2019. Mining there has taken a heavy toll on the local residents and the environment.

WU CHANGQING/VCG VIA GETTY IMAGES

The goal was not just mining and processing ore, but also separating out the desirable elements and even manufacturing them into magnets. Currently, the separations and magnet manufacturing are done overseas, mostly in China. The company also proposed a plan to avoid spilling wastewater into nearby fragile habitats. Molycorp resumed mining, and introduced a "dry tailings" process—a method to squeeze 85 percent of the water out of its mine waste, forming a thick paste. The company would then store the immobilized, pasty residue in lined pits on its own land and recycle the water back into the facility.

Unfortunately, Molycorp "was an epic debacle" from a business perspective, says Matt Sloustcher, senior vice president of communications and policy at MP Materials, current owner of Mountain Pass mine. Mismanagement ultimately led Molycorp to file for Chapter 11 bankruptcy in 2015. MP Materials bought the mine in 2017 and resumed mining later that year. By 2022, Mountain Pass mine was producing 15 percent of the world's rare earths.

MP Materials, too, has an ambitious agenda with plans to create a complete supply chain. And the company is determined not to repeat the mistakes of its predecessors. "We have a world-class…unbelievable deposit, an untapped potential," says Michael Rosenthal, MP Materials' chief operating officer. "We want to support a robust and diverse U.S. supply chain, be the magnetics champion in the U.S."

Painful separation

On a hot morning in August, Sloustcher stands at the edge of the Mountain Pass mine, a giant hole in the ground, 800 meters across and up to 183 meters deep, big enough to be visible from space. It's an impressive sight, and a good vantage point from which to describe a vision for the future. He points out the various buildings: where the ore is crushed and ground, where the ground rocks are chemically treated to slough off as much non–rare earth material as possible, and where the water is squeezed from that waste and the waste is placed into lined ponds.

The end result is a highly concentrated rare earth oxide ore — still nowhere near the magnet-making stage. But the company has a three-stage plan "to restore the full rare earth supply to the United States," from "mine to magnet," Rosenthal says. Stage 1, begun in 2017, was to restart mining, crushing and concentrating the ore. Stage 2 will culminate in the chemical separation of the rare earth elements. And stage 3 will be magnet production, he says.

Since coming online in 2017, MP Materials has shipped its concentrated ore to China for the next steps, including the arduous, hazardous process of separating the elements from one another. But in November, the company announced to investors that it had begun the preliminary steps for stage 2, a "major milestone" on the way to realizing its mine-to-magnet ambitions.

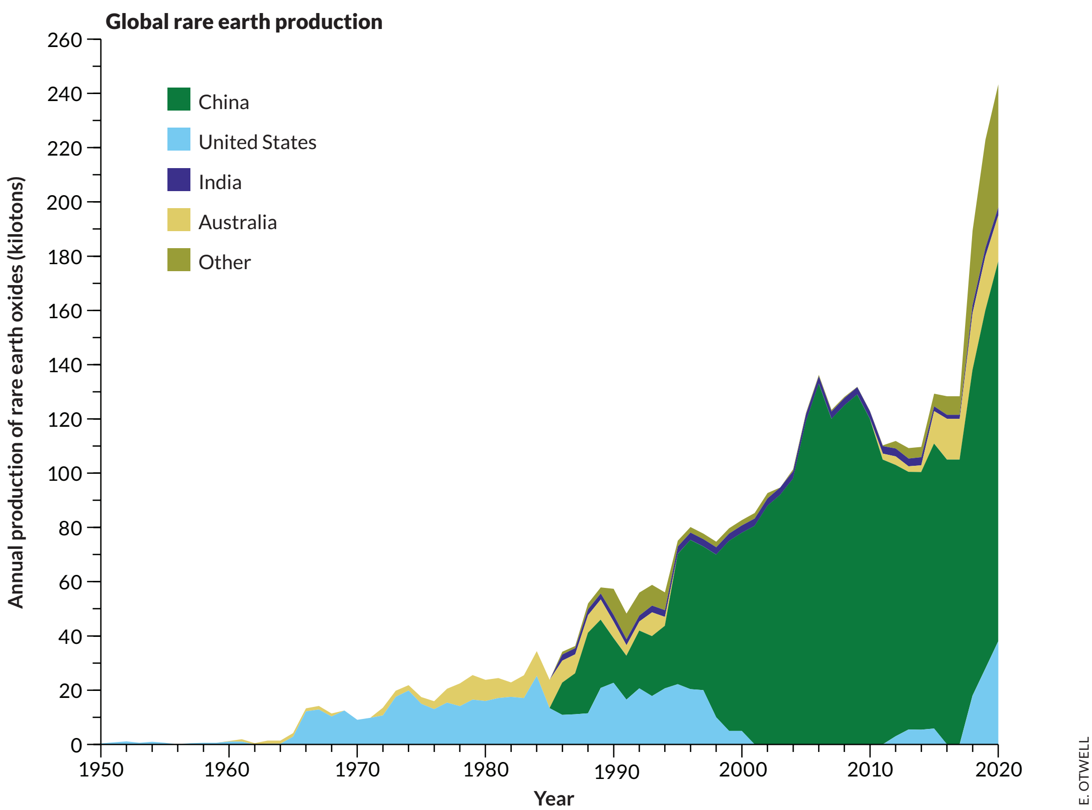
With investments from the U.S. Department of Defense, the company is building two separations facilities. One plant will pull out lighter rare earth elements — those with smaller atomic numbers, including neodymium and praseodymium, both of which are key ingredients in the permanent magnets that power electric vehicles and many consumer electronics. MP Materials has additional grant money from the DOD to design and build a second processing plant to split apart the heavier rare earth elements such as dysprosium, also an ingredient in magnets, and yttrium, used to make superconductors and lasers.

Like stage 2, stage 3 is already under way. In 2022, the company broke ground in Fort Worth, Texas, for a facility to produce neodymium magnets. And it inked a deal with General Motors to supply those magnets for electric vehicle motors.

But separating the elements comes with its own set of environmental concerns.

The process is difficult and leads to lots of waste. Rare earth elements are extremely similar chemically, which means they tend to stick together. Forcing them apart requires multiple sequential steps and a variety of powerful solvents to separate them one by one. Caustic sodium hydroxide causes cerium to drop out of the mix, for example. Other steps involve solutions containing organic molecules called ligands, which have a powerful thirst for metal atoms. The ligands can selectively bind to particular rare earth elements and pull them out of the mix.

Shifting sources
In the mid-20th century, the U.S. Mountain Pass mine was the world's top source for rare earth oxides. China began to dominate global production in the 1990s. In the last decade, the return of Mountain Pass along with the opening of Australia's Mount Weld and production in Myanmar, Brazil and other locations have begun to shift that balance. SOURCE: S.M. JOWITT/ *MRS BULLETIN* 2022



But one of the biggest issues plaguing this extraction process is its inefficiency, says Santa Jansone-Popova, an organic chemist at Oak Ridge National Laboratory in Tennessee. The scavenging of these metals is slow and imperfect, and companies have to go through a lot of extraction steps to get a sufficiently marketable amount of the elements. With the current chemical methods, “you need many, many, many stages in order to achieve the desired separation,” Jansone-Popova says. That makes the whole process “more complex, more expensive, and [it] produces more waste.”

Under the aegis of the DOE’s Critical Materials Institute, Jansone-Popova and her colleagues have been hunting for a way to make the process more efficient, eliminating many of those steps. In 2022, the researchers identified a ligand that they say is much more efficient at snagging certain rare earths than the ligands now used in the industry. Industry partners are on board to try out the new process this year, she says.

In addition to concerns about heavy metals and other toxic materials in the waste, there are lingering worries about the potential impacts of radioactivity on human health. The trouble is that there is still only limited epidemiological evidence of the impact of rare earth mining on human and environmental health, according to Ali, and much of that evidence is related to the toxicity of heavy metals such as arsenic. It’s also not clear, he says, how much of the concerns over radioactive waste are scientifically supported, due to the low concentration of radioactive elements in mined rare earths.

Such concerns get international attention, however. In 2019, protests erupted in Malaysia over what activists called “a mountain of toxic waste,” about 1.5 million metric tons, produced by a rare earth separation facility near the Malaysian city of Kuantan. The facility is owned by Lynas, which ships its rare earth ore from Australia’s Mount Weld to the site. To dissolve the rare earths, the ore is cooked with sulfuric acid and then diluted with water. The residue that’s left behind can contain traces of radioactive thorium.

Lynas had no permanent storage for the waste, piling it up in hills near Kuantan instead. But the alarm over the potential radioactivity in those hills may be exaggerated, experts say. Lynas reports that workers at the site are exposed to less than 1.05 millisieverts per year, far below the radiation exposure threshold for workers of 20 millisieverts set by the International Atomic Energy Agency.

“There’s a lot of misinformation about byproducts such as thorium.... The thorium from rare earth processing is actually very low-level radiation,” Ali says. “As someone who has been a committed environmentalist, I feel right now that there’s not much science-based decision making on these things.”

GOH SENG CHONG/BLOOMBERG VIA GETTY IMAGES

Australian company Lynas built a plant near Kuantan, Malaysia, (shown in 2012) to separate and process the rare earth oxide ore mined at Mount Weld in Western Australia. Local protests erupted in 2019 over how the company disposes of its thorium-laced waste.

Given the concerns over new mining, environmental think tanks like the World Resources Institute have been calling for more recycling of existing rare earth materials to reduce the need for new mining and processing.

“The path to the future has to do with getting the most out of what we take out of the ground,” says Bustamante, of the NRDC. “Ultimately the biggest lever for change is not in the mining itself, but in the manufacturing, and what we do with those materials at the end of life.”

That means using mined resources as efficiently as possible, but also recycling rare earths out of already existing materials. Getting more out of these materials can reduce the overall environmental impacts of the mining itself, she adds.

That is a worthwhile goal, but recycling isn’t a silver bullet, Ali says. For one thing, there aren’t enough spent rare earth–laden batteries and other materials available at the moment for recycling. “Some mining will be necessary, [because] right now we don’t have the stock.” And that supply problem, he adds, will only grow as demand increases. ■

Explore more

- Julie Michelle Klinger. *Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes.* Cornell University Press, 2017.

Recycling RARE EARTH Elements

As demand grows, pulling the metals out of discarded stuff is worth a try

By Erin Wayman

JORG GREUEL/PHOTODISC/GETTY IMAGES PLUS

For most of the jobs rare earth elements do, there are no good substitutes. So to help meet future demand and diversify who controls the supply — and perhaps even make rare earth recovery "greener" — researchers are looking for alternatives to conventional mining.

Proposals include everything from extracting the metals from coal waste (see Page 22) to really out-there ideas like mining the moon. But the approach most likely to make an immediate dent is recycling.

"Recycling is going to play a very important and central role," says Ikenna Nlebedim, a materials scientist at Ames National Laboratory in Iowa and the Department of Energy's Critical Materials Institute. "That's not to say we're going to recycle our way out of the critical materials challenge." Still, in the rare earth magnets market, for instance, by about 10 years from now, recycling could satisfy as much as a quarter of the demand for rare earths, based on some estimates. "That's huge," he says.

But before the rare earths in an old laptop can be recycled as regularly as the aluminum in an empty soda can, there are technological, economic and logistical obstacles to overcome.

Extraction challenge

Recycling seems like an obvious way to get more rare earths. It's standard practice in the United States and Europe to recycle from 15 to 70 percent of other metals, such as iron, copper, aluminum, nickel and tin. Yet today, only about 1 percent of rare earth elements in old products are recycled, says Simon Jowitt, an economic geologist at the University of Nevada, Las Vegas.

"Copper wiring can be recycled into more copper wiring. Steel can just be recycled into more steel," he says. But a lot of rare earth products are "inherently not very recyclable."

Rare earths are often blended with other metals in touch screens and similar products, making removal difficult.

In some ways, recycling rare earths from tossed-out items resembles the challenge of extracting them from ore and separating them from each other. Traditional rare earth recycling methods also require hazardous chemicals such as hydrochloric acid and a lot of heat, and thus a lot of energy. On top of the environmental footprint, the cost of recovery may not be worth the effort given the small yield of rare earths. A hard disk drive, for instance, might contain just a few grams; some products offer just milligrams.

Chemists and materials scientists, though, are trying to develop smarter recycling approaches. Their techniques put microbes to work, ditch the acids of traditional methods or attempt to bypass extraction and separation.

Microbial miners

One approach leans on microscopic partners. *Gluconobacter* bacteria naturally produce organic acids that can pull rare earths, such as lanthanum and cerium, from spent catalysts used in petroleum refining or from fluorescent phosphors used in lighting. The bacterial acids are less environmentally harmful than hydrochloric acid or other traditional metal-leaching acids, says Yoshiko Fujita, a biogeochemist at Idaho National Laboratory in Idaho Falls. Fujita leads research into reuse and recycling at the Critical Materials Institute. "They can also be degraded naturally," she says.

In experiments, the bacterial acids can recover only about a quarter to half of the rare earths from spent catalysts and phosphors. Hydrochloric acid can do much better — in some cases extracting as much as 99 percent. But bio-based leaching might still be profitable, Fujita and colleagues reported in 2019 in ACS *Sustainable Chemistry & Engineering*.

In a hypothetical plant recycling 19,000 metric tons of used catalyst a year, the team estimated annual revenues to be roughly $1.75 million. But feeding the bacteria that produce the acid on-site is a big expense. In a scenario in which the bacteria are fed refined sugar, total costs for producing the rare earths are roughly $1.6 million a year, leaving around just $150,000 in profits. Switching from sugar to corn stalks, husks and other harvest leftovers, however, would slash costs by about $500,000, raising profits to about $650,000.

Other microbes can also help extract rare earths and take them even further. A few years ago, researchers discovered that some bacteria that metabolize rare earths produce a protein that preferentially grabs onto these metals. The protein, lanmodulin, can separate rare earths, such as neodymium from dysprosium, two components of rare earth magnets. A lanmodulin-based system might eliminate the need for the many chemical solvents typically used in such separation. And the waste left behind — the protein — would be biodegradable. But whether the system will pan out on a commercial scale is unknown.

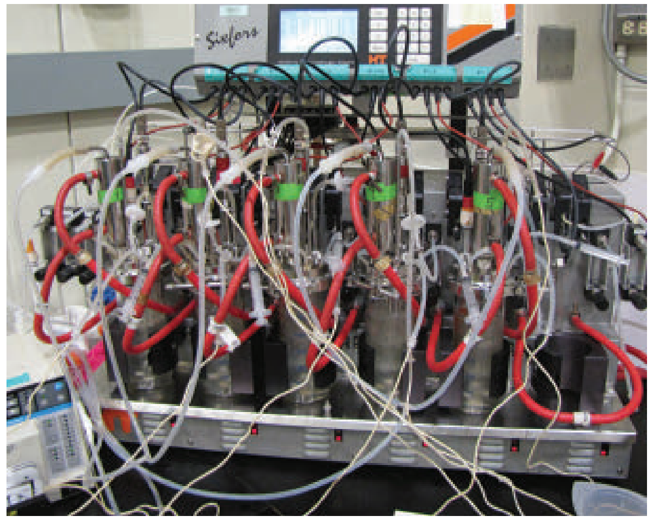
Electronic waste

Another approach already being commercialized skips the acids and uses copper salts to pull the rare earths from discarded magnets, a valuable target. Neodymium-iron-boron magnets are about 30 percent rare earth by weight and the single largest application of the metals in the world. One projection suggests that recovering the neodymium in magnets from U.S. hard disk drives alone could meet up to about 5 percent of the world's demand outside of China before the end of the decade.

Nlebedim led a team that developed a technique that uses copper salts to leach rare earths out of shredded electronic waste that contains magnets. Dunking the e-waste in a copper salt solution at room temperature dissolves the rare earths in the magnets. Other metals can be scooped out for their own recycling, and the copper can be reused to make more salt solution. Next, the rare earths are solidified and, with the help of additional chemicals and heating, transformed into powdered minerals called rare earth oxides. The process, which has also been used on material left over from magnet manufacturing that typically goes to waste, can recover 90 to 98 percent of the rare earths, and the material is pure enough to make new magnets, Nlebedim's team has demonstrated.

In a best-case scenario, using this method to recycle 100 tons of leftover magnet material might produce 32 tons of rare earth oxides and net more than $1 million in profits, an economic analysis of the method suggests.

That study also evaluated the approach's environmental impacts. Compared with producing one kilogram of rare earth oxide via one of the main types of mining and processing currently used in China, the copper salt method has less than half the carbon footprint. It produces an average of about 50 kilograms of carbon dioxide equivalent per kilogram of rare earth oxide versus 110, Nlebedim's team reported in 2021 in ACS *Sustainable Chemistry & Engineering*.



One experimental recycling approach uses organic acids made by bacteria to extract rare earths from waste products. This reactor at the Idaho National Laboratory prepares an organic acid mixture for such recycling.

IDAHO NATIONAL LAB

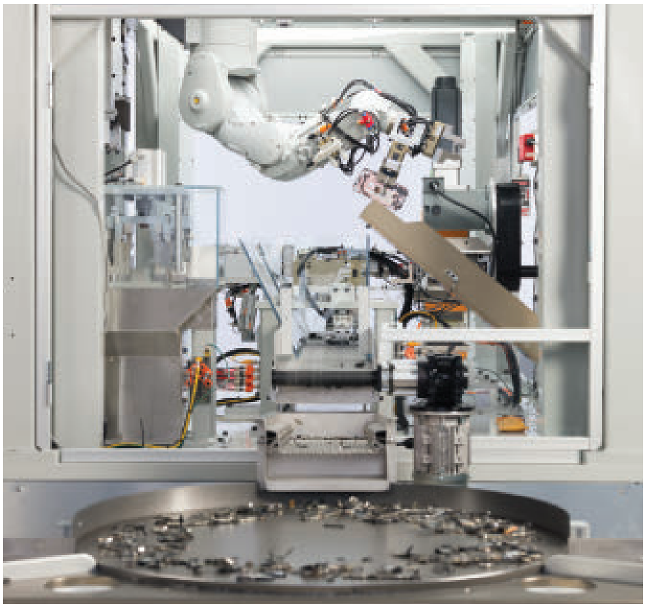
But it's not necessarily greener than all forms of mining. One sticking point is that the process requires toxic ammonium hydroxide and roasting, which consumes a lot of energy, and it still releases some carbon dioxide. Nlebedim's group is now tweaking the technique. "We want to decarbonize the process and make it safer," he says.

Meanwhile, the technology seems promising enough that TdVib, an Iowa company that designs and manufactures magnetic materials and products, has licensed it and built a pilot plant. The initial aim is to produce two tons of rare earth oxides per month, says Daniel Bina, TdVib's president and CEO. The plant will recycle rare earths from old hard disk drives from data centers.

Noveon Magnetics, a company in San Marcos, Texas, is already making recycled neodymium-iron-boron magnets. In typical magnet manufacturing, the rare earths are mined, transformed into metal alloys, milled into a fine powder, magnetized and formed into a magnet. Noveon knocks out those first two steps, says company CEO Scott Dunn.

After demagnetizing and cleaning discarded magnets, Noveon directly mills them into a powder before building them back up as new magnets. Unlike with other recycling methods, there's no need to extract and separate the rare earths out first. The final product can be more than 99 percent recycled magnet, Dunn says, with a small addition of virgin rare earth elements — the "secret sauce," as he puts it — that allows the company to fine-tune the magnets' attributes.

Compared with traditional magnet mining and manufacturing, Noveon's method cuts energy use by about 90 percent, Miha Zakotnik, Noveon's chief technology officer, and other researchers reported in 2016 in *Environmental Technology & Innovation*.



To help with recycling, Apple developed the robot Daisy (shown), which can dismantle 23 models of iPhones.

Another 2016 analysis estimated that for every kilogram of magnet produced via Noveon's method, about 12 kilograms of carbon dioxide equivalent are emitted. That's about half as much of the greenhouse gas as conventional magnets.

Dunn declined to share what volume of magnets Noveon currently produces or how much its magnets cost. But the magnets are being used in some industrial applications, for pumps, fans and compressors, as well as some consumer power tools and other electronics.

Overcoming logistics

Even as researchers clear technological hurdles, there are still logistical barriers to recycling.

"We don't have the systems for collecting end-of-life products that have rare earths in them," Fujita says, "and there's the cost of dismantling those products." For a lot of e-waste, before rare earth recycling can begin, you have to get to the bits that contain those precious metals.

Noveon has a semiautomated process for removing magnets from hard disk drives and other electronics.

Apple is also trying to automate the recycling process. The company's Daisy robot can dismantle iPhones. And in 2022, Apple announced a pair of robots called Taz and Dave that facilitate the recycling of rare earths. Taz can gather magnet-containing modules that are typically lost during the shredding of electronics. Dave can recover magnets from taptic engines, Apple's technology for providing users with tactile feedback when, say, tapping an iPhone screen.

Even with robotic aids, it would still be a lot easier if companies just designed products in a way that made recycling easy, Fujita says.

No matter how good recycling gets, Jowitt says there's no getting around the need to ramp up mining. But he agrees recycling is necessary. "We're dealing with intrinsically finite resources," he says. "Better we try and extract what we can rather than just dumping it in the landfill." ■

Explore more

- Yoshiko Fujita, Scott K. McCall and Daniel Ginosar. "Recycling rare earths: Perspectives and recent advances." *MRS Bulletin*. March 2022.

Turning coal waste into precious metals

In Appalachia's coal country, researchers envision turning toxic waste into treasure. The pollution left behind by abandoned mines is an untapped source of rare earth elements.

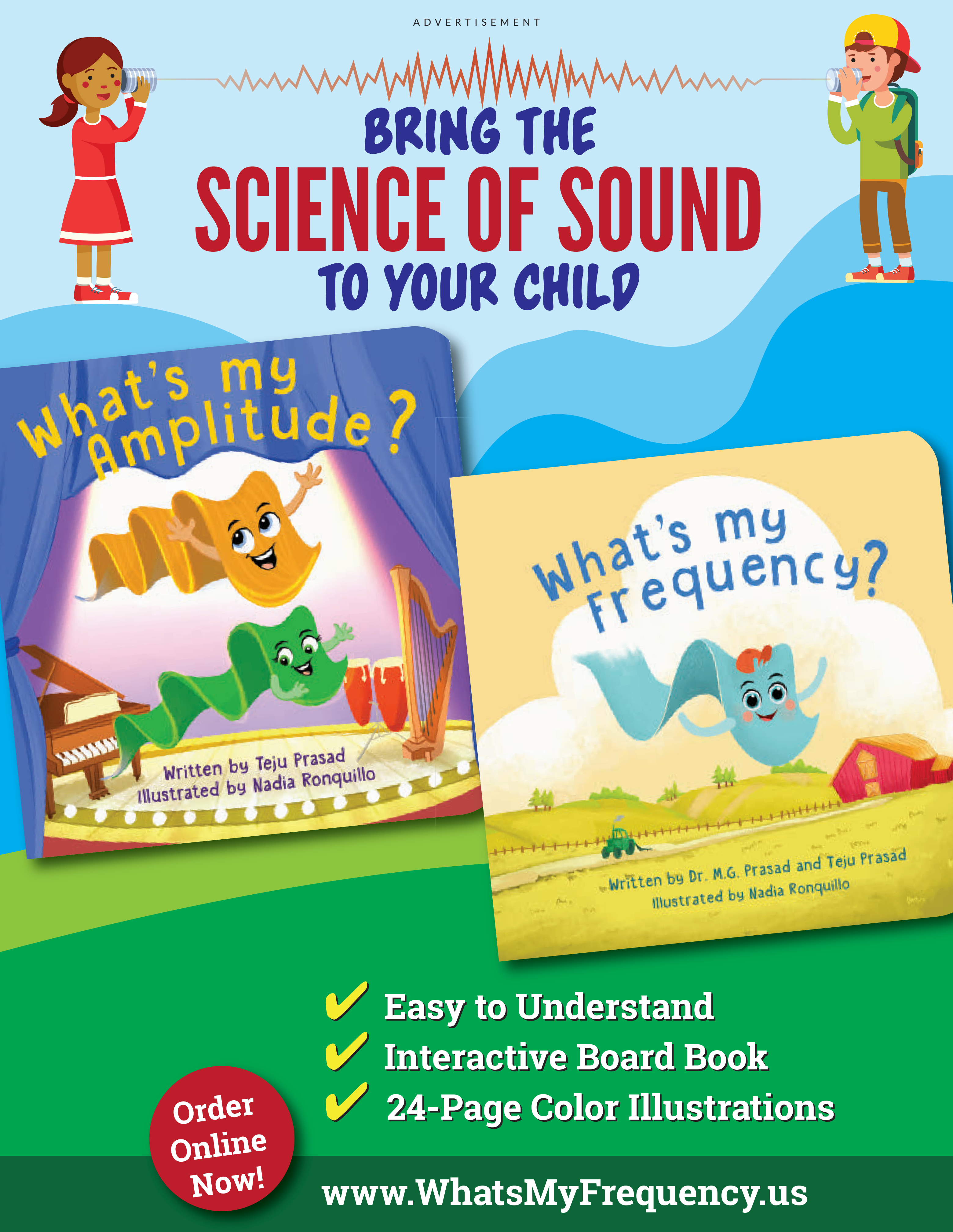
With global demand skyrocketing and China having a near-monopoly on rare earth production (see Page 14), there's a lot of interest in finding alternative sources.

Pulling rare earths from coal waste offers a two-for-one deal: By retrieving the metals, you also help clean up the mining's dirty legacy. When some of the rock left over from mining is exposed to air and water, sulfuric acid forms and pulls heavy metals from the rock. This acidic soup can pollute waterways (like the one shown in Pennsylvania) and harm wildlife.

Paul Ziemkiewicz, director of the West Virginia Water Research Institute in Morgantown, points to several benefits of recovering rare earths from what's called acid mine drainage. Unlike ore dug from typical rare earth mines, the drainage is rich with the most-needed rare earth elements. Plus, extraction from acid mine drainage doesn't generate the radioactive waste that's typically a by-product of rare earth mines. And from a practical standpoint, existing facilities to treat acid mine drainage could be used to collect the rare earths for processing. "Theoretically, you could start producing tomorrow," he says.

From a few hundred sites already treating acid mine drainage, nearly 600 metric tons of rare earth elements and cobalt — another in-demand metal — could be produced annually, Ziemkiewicz and colleagues estimate.
— Erin Wayman

FROM TOP: APPLE; NATHANIEL WARNER/NSF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THE RARE EARTHS: Luminous and Magnetic

What makes these metals so special? **By Nikk Ogasa**

In Frank Herbert's space opera *Dune*, a precious natural substance called spice melange grants people the ability to navigate vast expanses of the cosmos to build an intergalactic civilization.

In real life here on Earth, a group of natural metals known as the rare earths has made possible our own technology-powered society. Demand for these crucial components in nearly all modern electronics is skyrocketing.

Rare earths fulfill thousands of different needs — cerium, for instance, is used as a catalyst to refine petroleum, and gadolinium captures neutrons in nuclear reactors. But these elements' most outstanding capabilities lie in their luminescence and magnetism.

We rely on rare earths to color our smartphone screens, fluoresce to signal authenticity in euro banknotes and relay signals through fiber-optic cables across the seafloor. They are also essential for building some of the world's strongest and most reliable magnets. They generate sound waves in your headphones, boost digital information through space and shift the trajectories of heat-seeking missiles. Rare earths are also driving the growth of green technologies, such as wind energy and electric vehicles, and may even give rise to new components for quantum computers.

"The list just goes on and on," says synthetic chemist Stephen Boyd. "They're everywhere."

Superpower source

The rare earths are the lanthanides — lutetium and all 14 elements between lanthanum and ytterbium across one row of the periodic table — plus scandium and yttrium, which tend to occur in the same ore deposits and have similar chemical properties to the lanthanides. These gray to silvery metals are often malleable with high melting and boiling points.

Their secret powers lie in their electrons. All atoms have a nucleus surrounded by electrons, which inhabit zones called orbitals. Electrons in the orbitals farthest from the nucleus are the valence electrons, which participate in chemical

In August, China finished constructing a maglev train line that uses magnets made from rare earth alloys to levitate train cars without consuming electricity.

XINHUA/ALAMY STOCK PHOTO

reactions and form bonds with other atoms.

Most lanthanides possess another important set of electrons called the "f-electrons," which dwell in a Goldilocks zone located near the valence electrons but slightly closer to the nucleus. "It's these f-electrons that are responsible for both the magnetic and luminescent properties of the rare earth elements," says Ana de Bettencourt-Dias, an inorganic chemist at the University of Nevada, Reno.

Lights and colors

Along some coasts, the night sea occasionally glows bluish green as bioluminescent plankton are jostled in the waves. Rare earth metals also radiate light when stimulated. The trick is to tickle their f-electrons, de Bettencourt-Dias says.

Using an energy source like a laser or lamp, scientists and engineers can jolt one of a rare earth's f-electrons into an excited state and then let it fall back into lethargy, or its ground state. "When the lanthanides come back to the ground state," she says, "they emit light."

Each rare earth reliably emits precise wavelengths of light when excited, de Bettencourt-Dias says. This dependable precision allows engineers to carefully tune electromagnetic radiation in many electronics. Terbium, for instance, emits light at a wavelength of about 545 nanometers, making it good for constructing green phosphors in television, computer and smartphone screens. Europium, which has two common forms, is used to build red and blue phosphors. All together, these phosphors can paint screens with most shades of the rainbow.

Rare earths also radiate useful invisible light. Yttrium is a key ingredient in yttrium-aluminum-garnet, or YAG, a synthetic crystal that forms the core of many high-powered lasers. Engineers tune the wavelengths of these lasers by lacing YAG crystals with another rare earth. The most popular variety are neodymium-laced YAG lasers, which are used for everything from slicing steel to removing tattoos to laser range-finding. Erbium-YAG laser beams are a good option for minimally invasive surgeries because they're readily absorbed by water in flesh and thus won't slice too deep.

Beyond lasers, lanthanum is crucial for making the infrared-absorbing glass in night vision goggles. "And erbium drives our internet," says Tian Zhong, a molecular engineer at the University of Chicago. Much of our digital information travels through optical fibers as light with a wavelength of about 1,550 nanometers — the same wavelength erbium emits. The signals in fiber-optic cables dim as they travel far from their source. Because those cables can stretch for thousands of kilometers across the seafloor, erbium is added to fibers to boost signals.

Mighty magnets

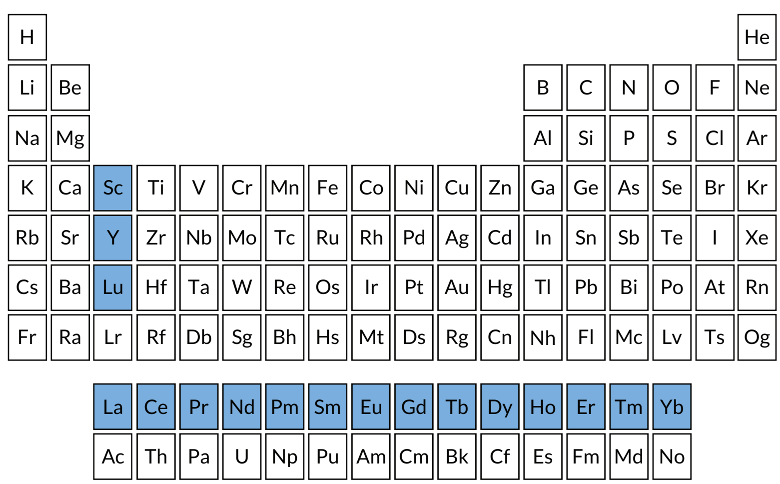
In 1945, scientists constructed ENIAC, the world's first programmable, general purpose digital computer (*SN: 2/23/46, p. 118*). Nicknamed the "Giant Brain," ENIAC weighed more than four elephants and had a footprint roughly two-thirds the size of a tennis court.

Less than 80 years later, the ubiquitous smartphone — boasting far more computing power than ENIAC ever did — fits snugly in our palms. Society owes this miniaturization of electronic technology in large part to the exceptional magnetic power of the rare earths. Tiny rare earth magnets can do the same job as larger magnets made without rare earths.

It's those f-electrons at play. Rare earths have many orbitals of electrons, but the f-electrons inhabit a specific group of seven orbitals called the 4f-subshell. In any subshell, electrons try to spread themselves out among the orbitals within. Each orbital can house up to two electrons. But since the 4f-subshell contains seven orbitals, and most rare earths contain fewer than 14 f-electrons, the elements tend to have multiple orbitals with just one electron. Neodymium atoms, for instance, possess four of these loners, while dysprosium and samarium have five. Crucially, these unpaired electrons tend to point — or spin — in the same direction, Boyd says. "That's what creates the north and the south poles that we classically understand as magnetism."

Since these lone f-electrons flitter behind a shell

All together The rare earths are a group of 17 elements (highlighted in blue on the periodic table). A subset of rare earths known as the lanthanides (lutetium, Lu, plus the row starting with lanthanum, La) each contain a subshell that typically houses f-electrons, which bestow the elements with magnetic and luminescent properties.



E. OTWELL

Euro banknotes contain fluorescent fibers with rare earth elements to stifle counterfeiting. In the banknotes above, the fibers fluoresce three colors, including red, which is emitted by the rare earth europium.

JANUSZ PIEŃKOWSKI/ALAMY STOCK PHOTO

of valence electrons, their synchronized spins are somewhat shielded from demagnetizing forces such as heat and other magnetic fields, making them great for building permanent magnets, Zhong says. Permanent magnets, like the ones that hold up pictures on a fridge door, passively generate magnetic fields that arise from their atomic structure, unlike electromagnets, which require an electric current and can be turned off.

But even with their shielding, the rare earths have limits. Pure neodymium, for example, readily corrodes and fractures, and its magnetic pull begins to lose strength above 80° Celsius. So manufacturers alloy some rare earths with other metals to make more resilient magnets, says Durga Paudyal, a theoretical physicist at Ames National Laboratory in Iowa. This works well because some rare earths can orchestrate the magnetic fields of other metals, he says. Just as weighted dice will preferentially land on one side, some rare earths like neodymium and samarium exhibit stronger magnetism in certain directions because they contain unevenly filled orbitals in their 4f-subshells. This directionality, called magnetic anisotropy, can be leveraged to coordinate the fields of other metals like iron or cobalt to formulate robust, extremely powerful magnets.

The most powerful rare earth alloy magnets are neodymium-iron-boron magnets. A three-kilogram neodymium alloy magnet can lift objects that weigh over 300 kilograms, for instance. More than 95 percent of the world's permanent magnets are made from this rare earth alloy. Neodymium-iron-boron magnets generate vibrations in smartphones, produce sounds in earbuds and headphones, enable the reading and writing of data in hard disk drives and generate the magnetic fields used in MRI machines. And adding a bit of dysprosium to these magnets can boost the alloy's heat resistance, making it a good choice for the rotors that spin in the hot interiors of many electric vehicle motors.

Samarium-cobalt magnets, developed in the 1960s, were the first popular rare earth magnets. Though slightly weaker than neodymium-iron-boron magnets, samarium-cobalt magnets have superior heat and corrosion resistance, so they're put to work in high-speed motors, generators, speed sensors in cars and airplanes, and in the moving parts of some heat-seeking missiles. Samarium-cobalt magnets also form the heart of most traveling-wave tubes, which boost signals from radar systems and communications satellites. Some of these tubes are transmitting data from the Voyager 1 spacecraft — currently the most distant human-made object — over 23 billion kilometers away.

Because they are strong and reliable, rare earth magnets are supporting green technologies. They're in the motors, drivetrains, power steering and many other components of electric vehicles. Tesla's use of neodymium alloy magnets in its farthest-ranging Model 3 vehicles has sparked supply chain worries; China provides the vast majority of the world's neodymium (see Page 14).

Rare earth magnets are also used in many offshore wind turbines to replace gearboxes, which boosts efficiency and decreases maintenance. In August, Chinese engineers introduced "Rainbow," the world's first maglev train line based on rare earth magnets that enable the trains to float without consuming electricity.

In the future, rare earths may even advance quantum computing. While conventional computers use binary bits (those 1s and 0s), quantum computers use qubits, which can occupy two states simultaneously. As it turns out, crystals containing rare earths make good qubits, since the shielded f-electrons can store quantum information for long periods of time, Zhong says. One day, computer scientists might even leverage the luminescent properties of rare earths in qubits to share information between quantum computers and birth a quantum internet, he says.

It may be too early to predict exactly how the rare earth metals will continue to influence the expansion of these growing technologies. But it's probably safe to say: We're going to need more rare earths. ■

Explore more

■ V. Balaram. "Rare earth elements: A review of applications, occurrence, exploration, analysis, recycling, and environmental impact." *Geoscience Frontiers*. July 2019.

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CONVERSATIONS WITH MAYA

GAYLE WILSON
Former first lady of California, 1991–1999, and an advocate for STEM education

Maya Ajmera, President & CEO of the Society for Science and Publisher of Science News, chatted with Gayle Wilson, an alumna of the 1960 Science Talent Search (STS) and an advocate for children's health care and STEM education. She is the former first lady of California, a position she served in from 1991 to 1999. While first lady, Wilson helped found COSMOS, a summer program that connects high schoolers with prominent STEM researchers in the University of California school system. Wilson has also served on a variety of nonprofit boards, including the Society for Science's Board of Trustees. She currently is a member of the Society's Honorary Board. We are thrilled to share an edited summary of their conversation.

How did your participation in the Science Talent Search influence you? Do you have any memories you can share?
Looking back, it was a defining moment in my life. Did I know it then? No. But in hindsight, it was definitely a turning point in my life. It gave me the confidence and encouragement to major in science in college. My father had died of cancer when I was a senior, and I think that was the reason I decided I wanted to go to medical school. So, when I went to Stanford, I majored in biology.

One fun memory from that STS week in Washington, D.C., was the opportunity to go to Capitol Hill to have lunch with my congressman, Rep. John Rhodes. And because one of the other STS finalists was from Texas, we got to meet then-majority leader, Sen. Lyndon Johnson. Little did I know that years later I would end up back in Washington, D.C., married to a U.S. senator.

Fast forward to when I was first lady of California. Every year, I opened the California State Science Fair. In my remarks, I talked about my love of science, but I didn't usually talk about being an STS finalist, where I was from or who my teachers had been. At one year's fair, I shared that I went to North Phoenix High School in Arizona, and that my chemistry teacher, Mr. Brown, was the one who encouraged me to enter the Science Talent Search. After my comments, two of the science teachers in the audience came up to me and said they had become science teachers because of Mr. Brown. He obviously touched a lot of lives.

You studied biology at Stanford, graduating with Phi Beta Kappa honors. How was your college experience, and did you continue pursuing your research interest?
I didn't pursue research in college. At the time, women were not encouraged in science majors, let alone medical school. I remember one of my Stanford professors saying to me, "You're just going to take a man's place in medical school." Were there some women who went on in science? Yes. But it took a lot of motivation, determination and discipline for women in my generation to go to law school or medical school. I admire them, but I didn't do it.

Your husband, Pete Wilson, served eight years as a U.S. senator, from 1983 to 1991, as well as two terms as the governor of California, from 1991 to 1999. What was one of your proudest accomplishments as first lady?
When my husband was a senator, I was encouraged to view the STS Public Exhibition of Projects at the National Academy of Sciences. I loved talking to the current STS finalists, and I also attended the Awards Ceremony each year, which

brought back many fond memories.

In 1984, I met Admiral Hyman Rickover, father of the nuclear Navy, who was also viewing STS research projects. He later invited me to join the board of what became the Center for Excellence in Education (CEE). I was on the CEE board for 20 years. The Center runs a six-week program called the Research Science Institute (RSI) at MIT. At the time, it accepted 50 American students and 20 international students. I recall looking at the RSI and thinking that California might have one or two students accepted each year. And I was convinced that every high school in California had at least one student who would benefit from a program like that.

So, I talked to the California governor's education adviser about what we could do in California. He said, "These are good ideas, Gayle, but there's no money." It took 13 years to launch COSMOS, the California State Summer School for Mathematics and Science.

As first lady, I am most proud of my involvement with the creation of COSMOS. The enacting legislation was passed in 1998, and bless my husband, he put a million dollars behind it. It was then passed on to the State Board of Education to design and implement. The University of California stepped up and said they would host it. COSMOS started on two UC campuses in summer 2000, and it's now on four campuses. This past summer, COSMOS hosted more than 1,000 high school students spread over the four campuses. Those students have joined more than 12,000 students as COSMOS alums.

That's an amazing legacy.

Maya, it's one thing to have an idea. It's another thing to get it implemented, and it's another for it to be sustained over a period of time. COSMOS celebrated its 22nd anniversary this past summer.

In the interval since you and your husband were at the center of public life, political and social divisions in this country have widened. With your experience working across the aisle, do you have any insights into what it might take to heal some of the divides?

I don't have any particular answers here, Maya, but I'll tell you what: Science should be nonpartisan. I have lobbied on Capitol Hill for Caltech and the NASA Jet Propulsion Laboratory, and I met with both Democrats and Republicans. The people I knew in Congress at the time didn't see scientific issues as partisan.

What advice do you have for young people just starting out in higher education or their careers who are hoping to make a positive impact in the world?

When you are in college, get to know your professors. Don't just be another student sitting in the back, taking notes. Engage your professors. Get involved in your school in some way. Be intentional. Have a purpose. Also, tell people what your aspirations are. Don't be afraid to ask for advice.

Everyone has to find their own focus, and for me, it's been STEM education, especially for high school students. That really goes back to when I was a finalist in STS as a senior in high school. I might have taken a completely different direction in college without that recognition at that time in my life, a recognition that told me, "You're good at science. You should stay in science." And I did. Although I didn't go on in research or become a Nobel laureate, I've worked to ensure others will have that opportunity.

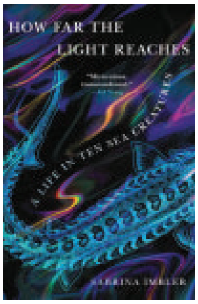
What books are you reading now and what books inspired you when you were younger?

I liked biographies when I was young. I specifically remember reading about Clara Barton and women in science. Today, I mostly read nonfiction. One of my favorite books is *Blood: An Epic History of Medicine and Commerce*, which is about the history of blood typing and blood banking, and how AIDS got into the blood supply. (My STS project was about blood typing.) Two other books I highly recommend, both by Thomas Hager: *The Demon Under the Microscope* and *The Alchemy of Air*.

There are many challenges facing the world today. What's keeping you up at night?

The decline of education in America. Getting a good education is indispensable for success today, and it has to start way before college. If you are not a proficient reader by third grade, you are going to have a hard time keeping up. Forty years ago, a national report called "A Nation at Risk" was published. It basically said that if a foreign country had designed our educational system, we would have considered it an act of war. I'm very worried about our educational system today, what our children are and are not being taught. Forty years ago, California had one of the best school systems in the country. Today, sadly, California's education system ranks among the lowest in the country.

Gayle Wilson, along with her fellow finalists Bill Cruse (left) and David Hearn (far right) met with then-Sen. Lyndon Johnson while competing in the 1960 Science Talent Search.



How Far the Light Reaches
Sabrina Imbler
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BOOKSHELF

Sea life offers a lens for self-exploration

In *How Far the Light Reaches*, Sabrina Imbler shows us that the ocean, in all its mystery and dazzling glory, is queer — that is, the life that takes shape there challenges how we landlubbers perceive ways of being. This collection of essays tells the stories of 10 sea creatures, with Imbler, a queer and mixed-race writer, weaving in stories of their own family, self-discovery, sexuality and healing. The profiled animals, often thought of as strange or alien, transform into recognizable emblems of identity, community and queer joy in this delectable amalgam of memoir and science journalism.

Imbler begins with a confession: "The truth is that I was asked to leave the Petco, but I told everyone I was banned." Thirteen-year-old Imbler had staged a protest in the store, attempting to convince customers not to buy goldfish bowls. The bowls, Imbler writes, condemn the fish to a truncated life in a transparent coffin, in which they will die isolated, starved of oxygen and poisoned with ammonia from their own urine.

But unencumbered by the confines of a bowl, the fish thrive. When bored pet owners dump goldfish in lakes or rivers, the fish can balloon to the size of jugs of milk. They are "so good at living they have become an ecological menace," breeding with abandon, uprooting bottom dwellers, and fomenting bacterial growth and algal blooms, Imbler writes.

Yet Imbler can't help but admire the feral goldfish's resilience: "I see something that no one expected to live not just alive but impossibly flourishing."

Survival among unthinkable circumstances is a theme common to all the profiled animals. Take the yeti crab (*Kiwa puravida*), which, after reading this book, I now proclaim a queer icon (step aside, the Babadook). In the frigid dark, about 1,000 meters below the sea surface, the crab finds solace near hydrothermal vents.

Such hot spots foster life in a desolate wasteland. Heat and chemicals from inside the Earth sustain an ecosystem of crabs, clams, mussels, tube worms and more. There, in true queer fashion, *K. puravida* "dances to live," Imbler writes. The yeti crab throws its claws in the air and waves 'em like it just don't care. In doing so, it is "farming" the bacteria that it eats, which cling to the crab's bristly claws. Waving the claws in a slow but steady rhythm ensures the bacteria get nutrients.

In telling the crab's story, Imbler reminisces on their quest to find community after moving to Seattle in 2016. Feeling alone among the mostly white people they met, Imbler discovered a monthly party called Night Crush, thrown by and for queer people of color. Night Crush became Imbler's own hydrothermal vent — an oasis warmed by people dancing in mesh, sequins, glitter and joy. "As queer people, we get to choose our families," Imbler writes. "Vent bacteria, tube worms, and yeti crabs just take it one step further. They choose what nourishes them."

Imbler looks to the sea to explore all aspects of family. The purple octopus (*Graneledone boreopacifica*), for instance, offers insights on motherhood. During a four-and-a-half-year brooding period, the longest known for any animal, the octopus starves herself to death, foregoing hunting to protect her eggs.

Through the octopus' saga, Imbler reflects on their own mother, who moved to the United States from Taiwan as a child. Imbler's mother felt like she was on "a new planet." To survive, she learned to want to be as white and "American" as possible, and as thin as possible — traumas inherited by Imbler, who developed an eating disorder.

In their recovery, Imbler has realized their mother's wish for them to be thin, though damaging, was, in a way, an act of love: "She wanted me to be skinny so things would be easier. White, so things would be easier. Straight, so things would be easy, easy, easy. So that unlike her, no one would ever question my right to be here, in America."

It is with that same grace, clarity and tenderness that Imbler crafts the book's other essays, whether it's meditating on their own gender expression through the cuttlefish's mastery of metamorphosis or examining their experience of sexual assault through the sand striker, an ambush predator of the seafloor.

Like a goldfish confined by a bowl, I am confined by my word count and can't say everything I want to about this must-read book. So I'll end on one final insight. In one essay, Imbler introduces salps. These jelly-like blobs exist as a colony of hundreds of identical salps joined in a chain. The creatures do not move in one synchronized effort. "Salps allow each individual to jet at its own pace in the same general direction," Imbler writes. "It is not as fast as coordinated strokes, but it's more sustainable long-term, each individual sucking and spurting as it pleases."

This idea of one collective, made up of individuals marching toward a common cause at their own pace, is one that queer people and other marginalized groups know well — whether creating community or protesting for civil rights. And it's a notion that Imbler imparts upon their reader: "We may all move at different paces, but we will only reach the horizon together." — *Aina Abell*

The purple octopus (*Graneledone boreopacifica*) takes motherhood to the extreme. Females starve themselves to watch over their eggs.

NOAA, MBARI/WIKIMEDIA COMMONS

NOVEMBER 5, 2022

SOCIAL MEDIA

A prized photo

A peek beneath the scales of a developing gecko's hand won first place in the 2022 Nikon Small World photomicrography competition, **Erin Garcia de Jesús** reported in "A glimpse inside a gecko's hand" (*SN: 11/5/22, p. 32*). Referencing the *Ghostbusters* character Egon Spengler, Facebook user **Sam Hedemann** quipped: "Art Gecko, very nice."

GRIGORII TIMIN AND MICHEL MILINKOVITCH/UNIV. OF GENEVA, NIKON SMALL WORLD

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Against the current

In the race to fertilize an egg, bull sperm that swim in groups travel on a more direct path than sperm traveling alone, ***James R. Riordon*** *reported in "Sperm in groups outswim loners"* (SN: 11/5/22, p. 14*)*.

Given that sperm can't see where they're going, reader **Donald Bruns** wondered how the cells know the way to go.

Sperm make their way to an egg by swimming against a current of mucus that streams through the cervix and away from the uterus. That fluid flows in a thin layer on the surface of the female reproductive tract's walls, **Riordon** says. The drag between the head of the sperm and the wall slows the sperm down and swings its tail downstream. This makes the sperm tend to swim into the oncoming current, he says.

Reader **Jerry Durkan** wondered if sperm in groups reduce resistance by swimming closely behind each other. Known as drafting, the method is popular among cyclists.

"Despite the superficial similarities between groups of sperm and bicycle pelotons, the researchers caution that the parallels don't run too deep," **Riordon** says. "The fluid dynamics that sperm deal with are very different from the ones that cyclists face. Sperm swim upstream, so it's the fluid that tells them where to go and affects how they bunch, unlike cyclists who follow a preset path that has nothing to do with the surrounding air."

Resolving rejection

Clusters of human nerve cells called organoids that were implanted into rat brains bloomed and influenced rat behavior, ***Laura Sanders*** *reported in "Human nerve cells thrive in rat brains"* (SN: 11/5/22, p. 6*)*.

Reader **Linda Ferrazzara** asked how the researchers kept the rat brains from rejecting the human cells.

"Rejection can be a big problem in these sorts of experiments," **Sanders** says. "In this case, the researchers used rats that carried a mutation that impaired their immune systems. These immunocompromised rats were less likely to reject the human cells that were implanted in their brains."

Organoids could one day help treat various human conditions. Many problems, including rejection, still need solving, "but the field is moving fast," **Sanders** says. A separate experiment reported last summer got around the rejection problem a different way. Researchers in Tokyo grew an organoid from the healthy colon cells of a patient with ulcerative colitis, a disease marked by inflammation in the gut. The scientists implanted the organoid into the same patient, in hopes that it will help grow more healthy colon tissue and improve the patient's symptoms.

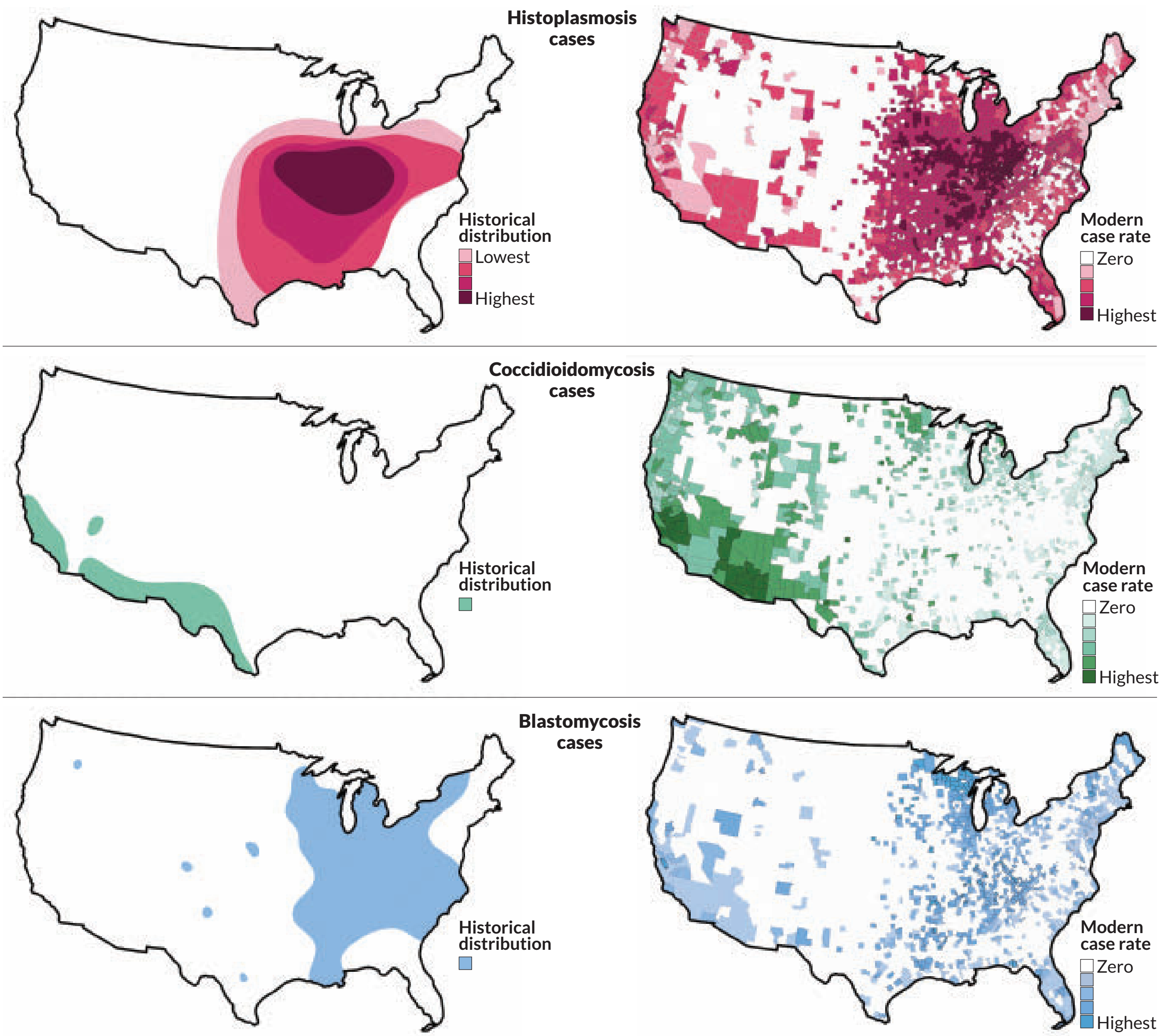
Catch of the day

In a first, researchers filmed a fox fishing for food, ***Freda Kreier*** *reported in "A cunning fox catches fish, stunning researchers"* (SN: 11/5/22, p. 4*)*.

Reader **Doug Miller** shared a potential sighting of a fox's fishy behavior. "We saw a fox with a large fish in his mouth behind the pond that was in back of our house in Illinois. We didn't see how he got it, but it looked like a freshly caught fish, and the fox looked happy!"

Editor's note

On November 17, *Science* retracted the study described in "Signs of Majorana fermion detected" (SN: 8/19/17, *p.* 8) due in part to "serious irregularities and discrepancies" in the analysis of the raw and published data. Three of the study's coauthors agree with the retraction, while 14 do not. Two coauthors did not respond, and one is now deceased.



Where fungal lung infections have spread

Three types of fungi that cause serious lung infections and were thought to be confined to certain regions of the United States are now widespread.

In 1955, *Histoplasma* fungi grew mainly in Midwest soil and in parts of the East and South, and that's where histoplasmosis infections primarily occurred (top row, left map). But Medicare records from 2007 through 2016 indicate that 47 states and Washington, D.C., had cases of histoplasmosis above a certain threshold (top right), researchers report November 11 in *Clinical Infectious Diseases*.

These fungi are now "a lot more common than we think they are," says Andrej Spec, an infectious diseases doctor at Washington University School of Medicine in St. Louis. Doctors using maps from the 1950s and '60s may fail to diagnose infections in patients who live outside of the fungi's historical borders. Such missed or delayed diagnoses can have deadly consequences.

Spec and colleagues drew updated maps for *Histoplasma* cases and for two other fungi whose ranges have expanded, probably because of climate change. Coccidioidomycosis cases, caused by *Coccidioides*, have spread from their 1955 roots in the Southwest (middle left) to 35 states (middle right). *Coccidioides* includes fungi that cause valley fever. Meanwhile, *Blastomyces* was primarily found in the Midwest and East (bottom left). But from 2007 through 2016, 40 states reported blastomycosis cases (bottom right).

When diagnosing infections, doctors are taught to look for "horses," not "zebras," meaning focus on common infectious organisms, not rare ones, Spec says. "We've talked about these [fungi] as zebras … but they're not zebras. They're Clydesdales. Clydesdales aren't the most common horse you'll see, but they're still horses." He hopes the updated maps encourage doctors to test for the fungi more often. *— Tina Hesman Saey*

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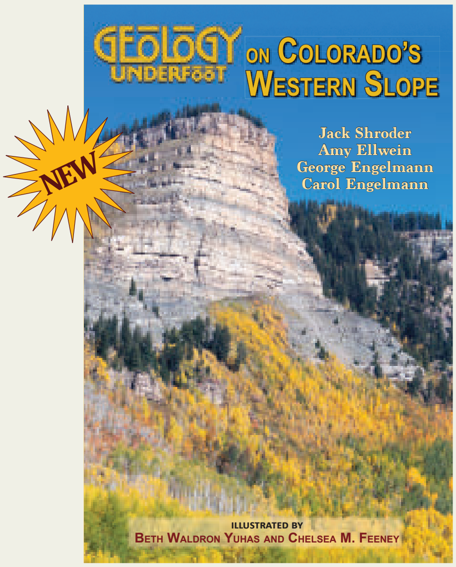

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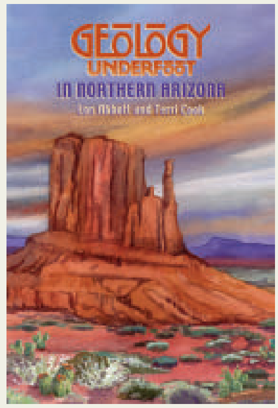

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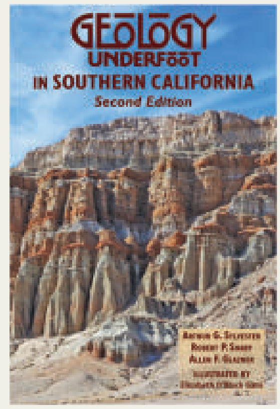

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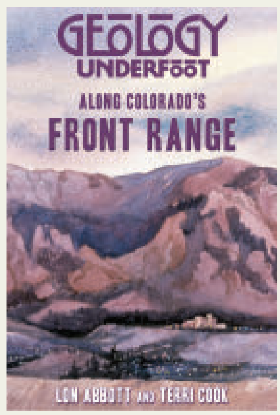

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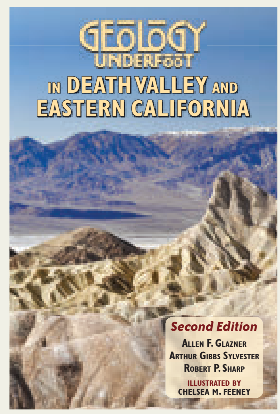

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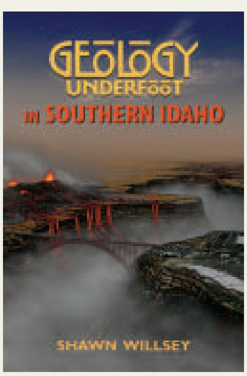

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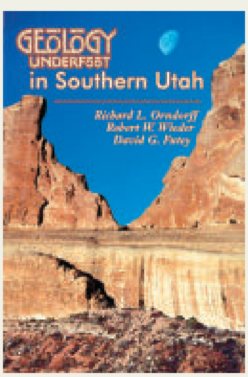

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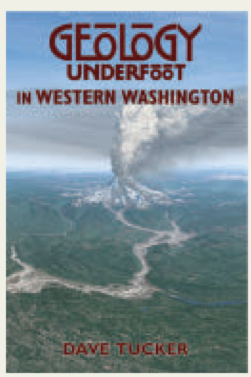

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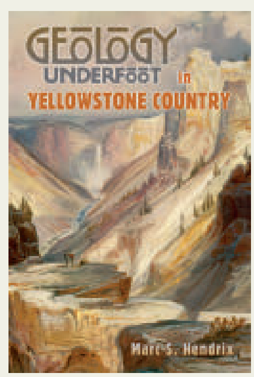

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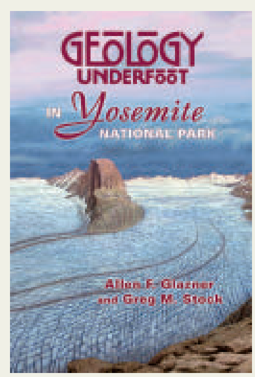

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