Why We Get Sick in Winter | This Volcanic Eruption Touched Space

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ JANUARY 28, 2023

The Climate Fix

Here's how we can solve our planet's greatest challenge

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— Jeff Orlowski-Yang
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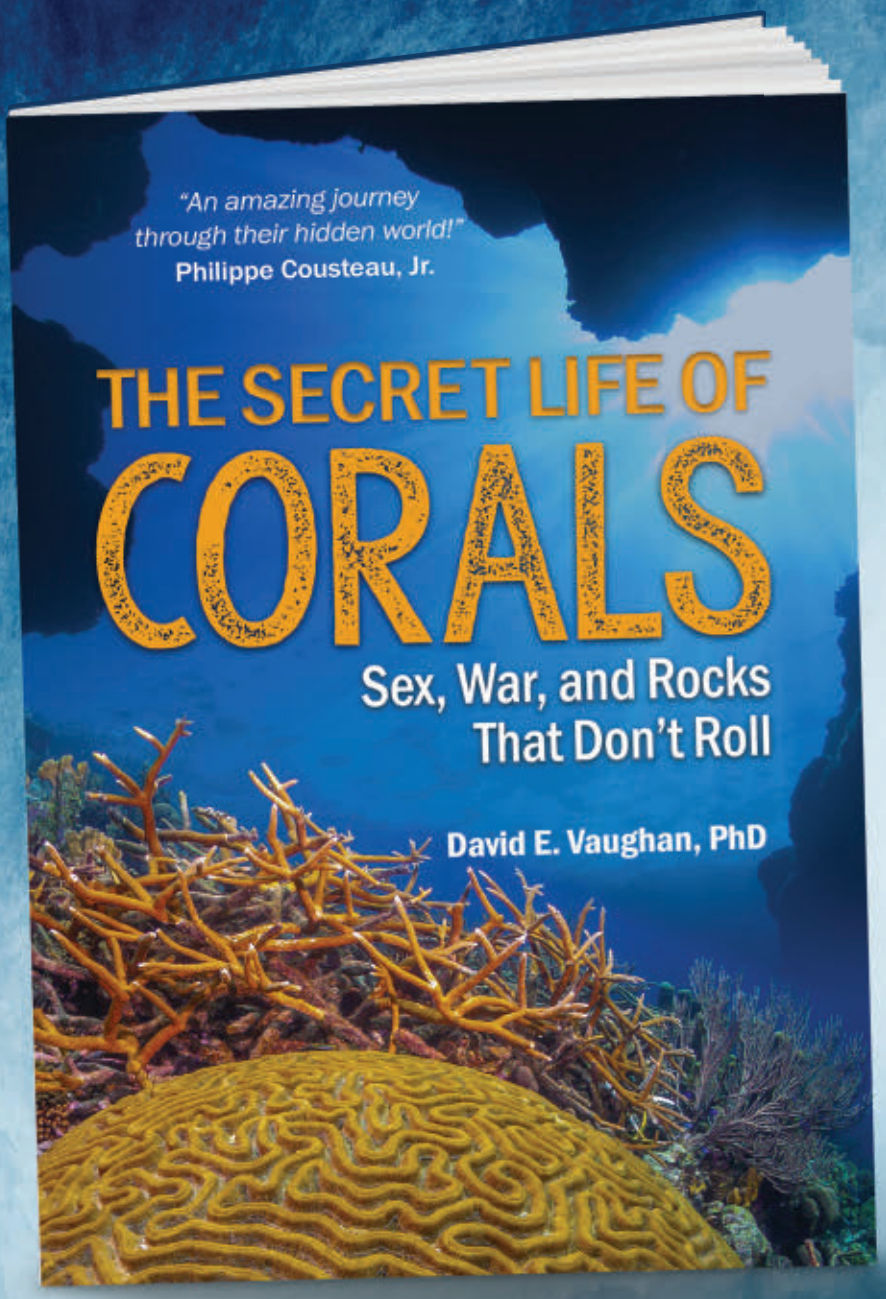

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COVER Curbing climate change means getting more electricity from renewable sources, such as wind power. *Erik Isakson/Tetra images/Getty Images*

FROM TOP: D. LEWIS; THE CHINESE UNIV. OF HONG KONG, CARNEGIE MELLON UNIV.; GABRIEL UGUETO/SMITHSONIAN

Yes, we can meet the climate change challenge

More than a century ago, scientists proved that carbon dioxide in Earth's atmosphere could act like a thermostat—adding more CO_2 would turn up the heat, removing it would chill the planet. But back then, most scientists thought that Earth's climate system was far too large and stable to change quickly, that any fluctuations would happen over such a long timescale that it wouldn't matter much to everyday life (SN: 3/12/22, *p.* 16).

Now all it takes is a look at the Weather Channel to know how wrong scientists were. Things are changing fast. Last year alone, Europe, South Asia, China, Japan and the American West endured deadly, record-breaking heat waves (SN: 12/17/22 & 12/31/22, *p.* 38). As I write this, torrential rains are bringing death and destruction to California. And with levels of climate-warming gases continuing to increase in the atmosphere, extreme weather events will become even more frequent.

Given the vastness of this threat, it's tempting to think that any efforts that we make against it will be futile. But that's not true. Around the world, scientists and engineers; entrepreneurs and large corporations; state, national and local governments; and international coalitions are acting to put the brakes on climate change. Last year, the United States signed into law a $369 billion investment in renewable energy technologies and other responses (SN: 12/17/22 & 12/31/22, *p.* 28). And the World Bank invested $31.7 billion to assist other countries.

In this issue, contributing correspondent Alexandra Witze details the paths forward: which responses will help the most, and which remain challenging (Page 22). Shifting to renewable energy sources like wind and solar should be the easiest. We already have the technology, and costs have plunged over the last decade. Other approaches that are feasible but not as far along include making industrial processes more energy efficient, trapping greenhouse gases and developing clean fuels. Ultimately, the goal is to reinvent the global energy infrastructure. Societies have been retooling energy infrastructures for centuries, from water and steam power to petroleum and natural gas to nuclear power and now renewables. This next transformation will be the biggest yet. But we have the scientific understanding and technological savvy to make it happen.

This cover story kicks off a new series for *Science News*, The Climate Fix. In future issues, we will focus on covering solutions to the climate crisis, including the science behind innovations, the people making them happen, and the social and environmental impacts. You'll also see expanded climate coverage for our younger readers, ages 9 and up, at *Science News Explores* online and in print.

With this issue, we also welcome our new publisher, Michael Gordon Voss. He comes to us with deep knowledge of the media industry, experience in both for-profit and nonprofit publishing and a love of science. Before joining Science News Media Group, Voss was publisher of *Stanford Social Innovation Review*, and vice president and associate publisher at *Scientific American*. With his arrival, publisher Maya Ajmera takes on her new role as executive publisher. Under her leadership, we have seen unprecedented growth. We're fortunate to have these two visionaries directing our business strategy amid a rapidly changing media environment. —*Nancy Shute, Editor in Chief*

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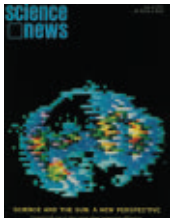


Excerpt from the January 27, 1973 issue of *Science News*

50 YEARS AGO

Early man in America

"Early Americans lived among and hunted mammoth, camel, extinct horse and bison as far back as 15,000 years. Now there is mounting evidence for a second breakthrough that will push the history of man in America back to 30,000 years—and possibly further."

UPDATE: The question of when humans first set foot in the Americas is still hotly debated. Recent fossil and archaeological evidence suggests the first inhabitants arrived tens of thousands of years ago. For instance, humanlike footprints in New Mexico date to about 20,000 years ago (*SN: 11/6/21, p. 12*). And stone tools found in a cave hint that humans resided in Mexico roughly 30,000 years ago (*SN: 7/3/21 & 7/17/21, p. 16*). Some archaeologists argue that stones caked with mastodon bone residue that were found in California were tools used by humans or their close relatives around 130,000 years ago, although that claim remains controversial (*SN Online: 12/4/20*). Pinning down the timeline of human settlement could reveal how people spread across North and South America.

Researchers first identified and described the snake clitoris by studying the genital anatomy of two female common death adders, one of which is shown here.

RETHINK

Scientists have finally found the snake clitor-hiss

Female snakes have clitorises too, a new study finds. The research raises the possibility that the sex lives of snakes are more complicated and diverse than previously understood, scientists report in the Dec. 21 *Proceedings of the Royal Society B*.

Clitorises are found in a wide range of vertebrate life, from crocodiles to dolphins (*SN: 2/12/22, p. 12*). One exception is birds, which lost their clitorises over the course of their evolution. Female snakes appeared to have lost the sex organ too, which was puzzling, since their close lizard relatives have paired clitorises, called hemiclitorises. Male

MYSTERY SOLVED

How some cheeses get their funky flavors

There are more than 1,000 varieties of cheese worldwide, but what exactly makes some cheeses like Parmesan taste fruity and others, such as Brie and Camembert, taste musty has remained a bit of a mystery. Now, scientists have pinned down specific types of bacteria that produce flavor compounds in surface mold-ripened cheeses. The findings, described November 10 in *Microbiology Spectrum*, could help cheesemakers tweak flavor profiles to better match consumer preferences.

A cheese's flavor depends on more than the type of milk and starter bacteria used to make the fermented dairy delight. A constellation of organisms that move in during the cheese-ripening process also contribute to the flavor. Morio Ishikawa, a food microbiologist at the Tokyo University of Agriculture, likens these nonstarter bacteria to an orchestra. "We can perceive the tones played by the orchestra of cheese as a harmony, but we do not know what instruments each of them is responsible for."

To show that specific types of bacteria produced specific flavors, Ishikawa and colleagues unleashed each type of microbe onto its own unripened cheese sample and observed how flavor compounds in the cheese changed over 21 days. Notably, *Pseudoalteromonas*, a genus of bacteria found in a variety of cheeses, produced the greatest number of flavor compounds. Esters, ketones and sulfurs made by the microbes impart fruity, moldy and oniony flavors. The findings, Ishikawa says, might help cheesemakers conduct new orchestras that would play new harmonies. —*Allie Wilkinson*

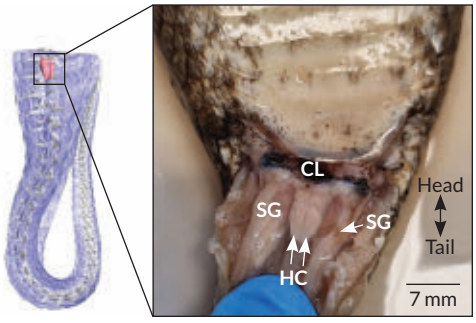
FROM TOP: LUKE ALLEN, M.J. FOLWELL *ET AL/PROCEEDINGS OF THE ROYAL SOCIETY B* 2022; JOHNGOLLOP/E+/GETTY IMAGES PLUS

lizards and snakes have accompanying paired phalli, or hemipenises.

This element of female snake sexual anatomy went unexamined in detail for so long partly because hemiclitorises can be fragile and easy to miss but also because female genitalia have historically been considered taboo, says evolutionary biologist Megan Folwell of the University of Adelaide in Australia. "Even in humans, the proper function and significance of the human clitoris was still being discussed in 2006," Folwell says.

Conflicting accounts of snake hemiclitorises in some scientific papers led Folwell to take a detailed look. She first examined a female common death adder (*Acanthophis antarcticus*). When she dissected the tail, she found dual organs that were completely different from the hemipenises found in male snakes. And unlike lizard hemiclitorises, the snake's couldn't turn out externally.

To confirm she wasn't looking at lumps of some other tissue, Folwell and colleagues examined sections of the organs under a microscope and with X-rays. The hemiclitorises were full of collagen rather than the muscle fibers that run through hemipenises. The hemiclitorises also had heaps of nerves and a robust blood supply, Folwell says, suggesting the organs were sensitive to touch.



A digital reconstruction (left) of a female common death adder's tail shows the location of the hemiclitorises (pink) at the base. A dissected view of the region (right) shows the snake's genital anatomy (CL = cloaca, SG = scent glands, HC = hemiclitorises).

An analysis of eight more snake species across four families revealed a dizzying array of clitoral diversity. Some hemiclitorises filled the space of the tail while others were so teeny tiny that an untrained eye could have easily missed them. And some were positioned atop the scent glands while others were sandwiched between.

Snakes are thought to have evolved from lizard ancestors. The findings show that, evolutionarily speaking, the snake clitoris "wasn't lost; it was just changed," says evolutionary biologist Diane Kelly of the University of Massachusetts Amherst.

Snake hemiclitorises may be stimulated during courtship and mating behaviors—such as the twisting together of tails—making the female receptive to more mating events, upping the chances of fertilization, Folwell suspects. It has long been thought that male snakes drive mating through coercion, she says. "It may be a little bit closer toward seduction in some species." —*Jake Buehler*

THE –EST

Insect ears go back 160 million years

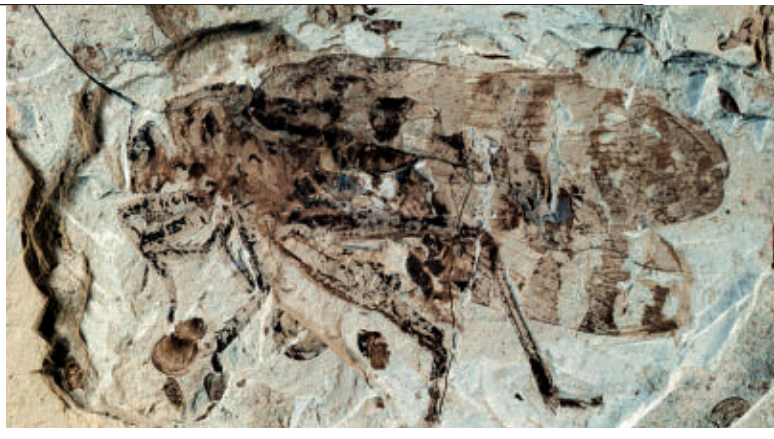
Over 100 million years ago, the chirps of insects known as katydids provided a soundtrack to Earth's nights. Now, fossils reveal what the katydid ears that heard the chirps looked like.

Twenty-four fossils of roughly 160 million-year-old katydids unearthed in China represent the earliest known insect ears, researchers report in the Dec. 20 *Proceedings of the National Academy of Sciences*.

These ancient sensors—identical to the ones found on today's katydids—may have picked up short-range, high-frequency calls, helping the insects hide from predators.

Insects were the first land dwellers to send sound waves through the air, allowing the creatures to communicate over longer distances than sight allows (*SN Online*: 7/15/21). While some insects use antennae to detect vibrations in the air, katydids have mammal-like ears that use an eardrum to hear. Yet because well-preserved insect eardrums are rare in the fossil record, it's unclear how katydid ears evolved, say paleontologist Chunpeng Xu of the Chinese Academy of Science's Nanjing Institute of Geology and Paleontology and colleagues.

Analyses of the Chinese fossils push the known record of male and female katydid ears' ability to listen for potential mates or male competitors to the mid-Jurassic, between 166 million and 157 million years ago. The previous record holders, katydids found in Colorado, are around 50 million years old.



This male katydid fossil from China is one of 24 that reveal the earliest known insect ears. The sensors may have helped katydids communicate over short distances and thus hide from eavesdropping predators.

What's more, sound-producing structures on 87 fossilized male katydid wings dating from about 242 million to 228 million years ago may have generated high-frequency calls up to 16 kilohertz. (Humans, by comparison, can hear frequencies up to roughly 20 kHz.) High-frequency chirps don't travel far, which would have allowed katydids to communicate over short distances. Such a trait may have been useful because mammal hearing was improving around the same time, Xu says. Limiting the range of some calls could have helped katydids hide from eavesdroppers on the hunt for an insect feast. —*Erin Garcia de Jesús*

FROM TOP: M.J. FOLWELL *ET AL*/*PROCEEDINGS OF THE ROYAL SOCIETY B* 2022; BO WANG

ANIMALS

Glass frogs make their blood vanish

Hiding red blood cells in the liver while asleep boosts clarity

BY SUSAN MILIUS

As tiny glass frogs fall asleep for the day, they take almost 90 percent of their red blood cells out of circulation.

The colorful cells cram into hideaway pockets inside the frog liver, which disguises the cells behind a mirrorlike surface, a new study finds. Biologists have known that glass frogs (*Hyalinobatrachium fleischmanni*) have translucent skin, but temporarily hiding bold red blood brings a new twist to vertebrate camouflage (SN: 7/8/17 & 7/22/17, *p.* 5).

"The heart stopped pumping red, which is the normal color of blood, and only pumped a bluish liquid," says evolutionary biochemist Carlos Taboada of Duke University, one of the discoverers of the hidden blood.

What may be even more amazing to humans — prone to circulatory sludge and clogs — is that the frogs hold almost all their red blood cells packed together for hours with no blood clots, says co-discoverer Jesse Delia, a biologist now at the American Museum of Natural History in New York City. Wake the frog up, and cells just unpack themselves and get circulating again.

Hiding those red blood cells can double or triple the transparency of glass frogs, Taboada, Delia and colleagues report in the Dec. 23 *Science*. That greenish transparency can matter a lot for the snack-sized frogs, which spend the day hiding like little shadows on leaves in the forest canopy.

What got Delia wondering about transparency was a photo emergency. He had studied glass frog behavior, but had never even seen them asleep. "They go to bed, I go to bed — that was my life for years," Delia says. When he needed some charismatic portraits, however, he put some frogs in lab dishes and at last saw how the animals sleep the day away.

"I couldn't see any red blood in the circulatory system," Delia says. "I shot a video of it — it was crazy."

When a glass frog wakes up and starts moving around, the blood that it had hidden in its liver while sleeping (left) starts to circulate once more, decreasing the tiny frog's transparency (right).

J. DELIA

As he pitched his project to a Duke University biological optics lab for support, Delia was stunned to discover that another young researcher was pitching the same lab to study transparency in glass frogs. "I was like, oh, man," he says. But the leader of the lab, Sönke Johnsen, told Delia and his rival, Taboada, that they had different skill sets and should tackle the problem together. "I think we were hardheaded at first," Delia says. "Now I consider him as close as family."

To show what red blood cells do in living frogs made a tough puzzle. Light microscopy wouldn't work for seeing through the mirrorlike outer tissue of the liver. Nor would anything that woke up the frogs, because the red blood cells would rush out through the body. Even anesthetizing the frogs kept the liver trick from working.

The answer Delia and Taboada found comes from a technique called photoacoustic imaging. It reveals hidden interiors thanks to the subtle vibrations created by light striking various molecules and causing slight energy releases. Duke biomedical engineer Junjie Yao joined team glass frog to tailor the technique to frog livers, taking special care not to wake the animals in the process.

Frogs aren't the only animals to go glassy, nor the most extreme, says fish biologist Sarah Friedman of the National Oceanic and Atmospheric Administration's Alaska Fisheries Science Center in Seattle. She tweeted an image in June of a newly caught blotched snailfish (*Crystallichthys cyclospilus*), most of its body clear enough to show flesh tones in Friedman's hand as she cradled it. And that's not even the best example. Larval tarpon fish and eels, glassfishes and a kind of Asian glass catfish "are almost perfectly transparent," says Friedman, who wasn't involved in the new study.

But these marvels have the advantage of living in water, she says. Glassiness seems to evolve more readily in the sea than on land. Light often has to bend less when passing between flesh and water than between flesh and air. Still, having a transparent body is pretty cool, on land or sea. ■

ASTRONOMY

Telescope spots earliest galaxies yet

James Webb's glances back in time are reshaping cosmology

BY LISA GROSSMAN

BALTIMORE — The James Webb Space Telescope is living up to its promise as a wayback machine. The spectacularly sensitive observatory is finding and confirming galaxies more distant, and therefore existing earlier in the universe's history, than any seen before.

The telescope, also known as JWST, has confirmed extreme distances to four galaxies, one of which sets a record for cosmic remoteness by shining about 13.475 billion years ago, astronomers reported December 12 at the First Science Results from JWST conference. Dozens of other galaxies may have been spotted as they were just 550 million years or less after the Big Bang, meaning the light from those galaxies traveled at least 13.1 billion years before reaching the telescope.

Taken together, the new observations suggest galaxies formed earlier and faster than previously thought. "We're entering a new era," says astronomer Swara Ravindranath of the Space Telescope Science Institute in Baltimore.

That new era is thanks in part to JWST's ability to see very faint infrared light (SN: 10/9/21 & 10/23/21, p. 26). For the most distant objects, like the first stars and galaxies, their visible light is stretched by the relentless expansion of the universe into longer infrared wavelengths that are invisible to human eyes and some previous space telescopes. But now, measurements that were recently impossible are suddenly easy with JWST, researchers say.

"JWST is the most powerful infrared telescope that's ever been built," astrophysicist Jane Rigby said at the conference. Rigby, of NASA's Goddard Space Flight Center in Greenbelt, Md., is the JWST operations project scientist. "Almost across the board, the science performance is better than we expected."

Even in the very first image, released in July, astronomers spotted galaxies whose light originated 13 billion years ago or more (SN: 8/13/22, p. 30). But those distances were estimates. To measure the distances precisely, astronomers need spectra, measurements of how much light the galaxies emit across many wavelengths. Those measurements are slower and more difficult to make than pictures.

"Thanks to this glorious telescope, we're now getting spectra … for hundreds of galaxies at once," said astronomer Emma Curtis-Lake of the University of Hertfordshire in England.

Among those are four of the earliest galaxies ever seen, some of which existed less than 400 million years after the Big Bang, Curtis-Lake and colleagues reported at the meeting and in a paper posted December 11 at arXiv.org. The team spotted these record holders in a patch of sky that the Hubble Space Telescope once scoured for ultra-remote galaxies.

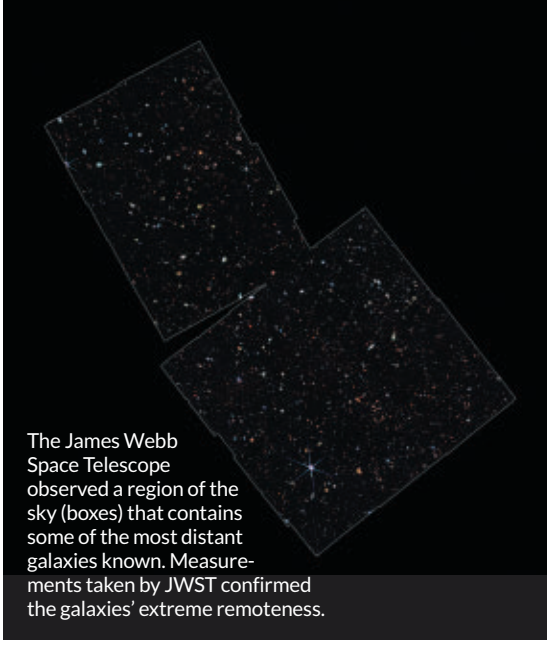
The previous distance record holder, which was first spotted by Hubble, existed between 13.3 billion and 13.4 billion years ago, or about 400 million years after the Big Bang (SN: 2/29/20, p. 30). JWST confirmed the distance to that galaxy and came back with three more, two of whose light comes from as early as 325 million years after the Big Bang.

The galaxies are also surprisingly pristine, lacking in elements heavier than hydrogen and helium.

"We don't see that in the present-day universe," says Ravindranath, who was not involved in the new discovery. It could mean that not many of the galaxies' stars have died in supernova explosions that spread heavy elements around the universe, which suggests the galaxies' original stars were not extremely massive.

In another part of the sky, JWST has spotted 26 galaxies that may have existed no more than 550 million years or earlier after the Big Bang, astronomer Steven Finkelstein of the University of Texas at Austin and colleagues reported at the meeting and in a paper posted November 13 at arXiv.org.

The first of these to be discovered, dubbed Maisie's galaxy after Finkelstein's daughter, appears to have existed just 370 million years after the Big Bang, the researchers reported in the Dec. 1 *Astrophysical Journal Letters*. The earliest galaxy in the survey might have existed for as much as 130 million years before Maisie. Those galaxies' distances still need to be confirmed with spectra.



The James Webb Space Telescope observed a region of the sky (boxes) that contains some of the most distant galaxies known. Measurements taken by JWST confirmed the galaxies' extreme remoteness.

NASA, ESA, CSA, M. ZAMANI/WEBB/ESA

And distant galaxies that lie behind a massive galaxy cluster called Abell 2744 are also more numerous and distant than expected, astrophysicist Guido Roberts-Borsani of UCLA said at the meeting.

Before JWST observed the cluster, astronomers predicted the telescope should find effectively zero galaxies from 13.3 billion years ago. "We found two," Roberts-Borsani said. "So something's a little bit weird." Perhaps galaxies form earlier and faster than thought, although it's possible that JWST just looked at a particularly galaxy-rich patch of the sky, he said.

Finding all these new galaxies is exciting because they could be responsible for making the universe transparent to visible light, a process astronomers call reionization. Before the first stars ignited, the universe was filled with a hot dense soup of particles. The first stars and galaxies bathed the universe in ultraviolet light, splitting electrons off hydrogen atoms and allowing light to zip through until it reached JWST.

The new data, Roberts-Borsani said, "give us constraints on when this process started, when it ended, and ultimately which [galaxies] were the culprits." ■

HEALTH & MEDICINE

Why it's easy to catch viruses in winter

Low humidity and temperatures may make infections more likely

BY TINA HESMAN SAEY

When bitter winds blew and temperatures dropped, my grandmother would urge me to come inside. "You'll catch your death of cold out there," she'd say.

Sure, freezing to death is possible. But doctors and other health experts have long stressed that *being* cold won't give you a cold. Still, winter is undisputedly cold and flu season. It's also a period when COVID-19 spreads more.

But if the chill doesn't matter, why does the spread of so many respiratory viruses peak during the season?

"I've spent the last 13 years looking into this question," says Linsey Marr, a civil and environmental engineer at Virginia Tech in Blacksburg who studies viruses in the air. "The deeper we go, the more I realize we don't know [and] the more there is to figure out."

There is some evidence that winter's short days may make people more susceptible to infection, says infectious diseases researcher Jeffrey Shaman of the Columbia University Mailman School of Public Health. Less sunlight means people make less vitamin D, which is required for some immune responses. But that's just one piece of the puzzle.

Scientists are also looking at what other factors make winter a sickening season.

Illness may spread more indoors

My grandma's well-intentioned urging to come in from the cold may have instead increased the risk that I'd get sick.

Colds, influenza and respiratory syncytial virus, or RSV, are all illnesses that are more prevalent at certain times of year when people spend more time inside. That includes winter in temperate climates, where there are distinct seasons, and rainy seasons in tropical zones. COVID-19 also spreads more indoors than outside.

Those diseases are caused by viruses that are transmitted primarily through inhaling small droplets known as aerosols. That's a change in thinking. Until recently, many scientists thought that such viruses spread mainly via touching tainted surfaces (SN: 12/18/21 & 1/1/22, p. 19).

"When you're outdoors, you're in the ultimate well-ventilated space," says epidemiologist David Fisman of the University of Toronto Dalla Lana School of Public Health. Viruses exhaled outside are diluted quickly with clean air.

But inside, aerosols and the viruses they contain can build up. "When you're in a poorly ventilated space, the air you breathe in is often air that other people have breathed out," he says.

Viruses come along with that exhaled air, so it makes sense that proximity to potentially contagious individuals would aid transmission, Shaman says.

But there is more to the story, says sinus and nasal specialist Benjamin Bleier of Harvard Medical School. "In modern society, we're indoors all year round," he says. To drive the seasonal pattern seen year after year, something else must be making people more susceptible to infection and increasing the amount of virus circulating.

Dry air gives some viruses a boost

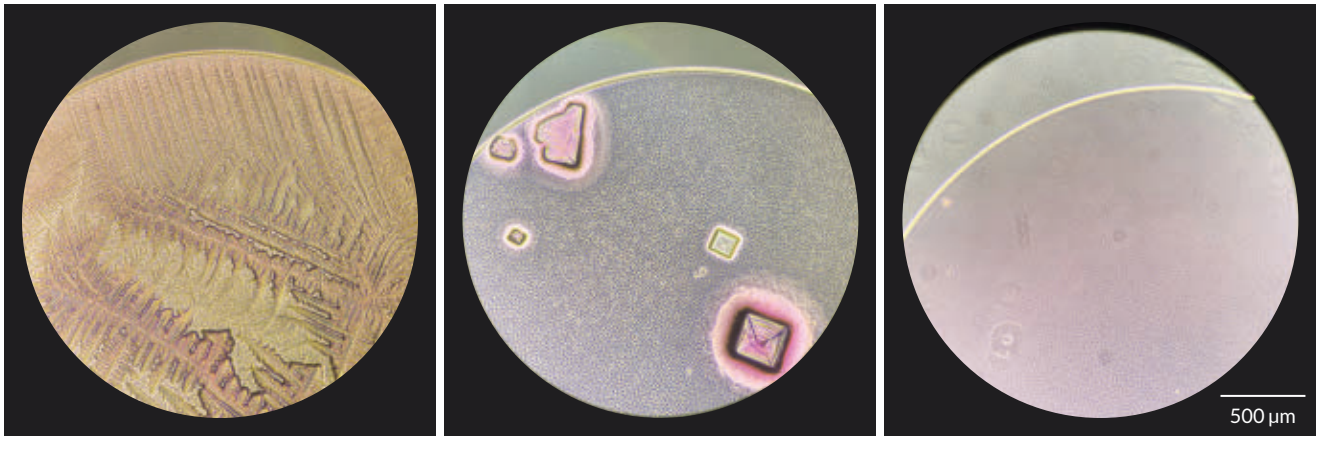
For viruses that thrive in winter, the reason may have as much to do with humidity as with temperature.

"There are some viruses that like it warm and wet, and some viruses like it dry and cold," says aerobiologist Donald Milton of the University of Maryland School of Public Health in College Park. For instance, rhinoviruses — one of the many types of viruses that cause colds — survive better when it's humid, and cases typically peak in early fall, he says.

Marr and other researchers have found that viruses that surge in the winter, including influenza viruses and the coronavirus SARS-CoV-2, which causes COVID-19, survive best when the relative humidity falls below about 40 percent.

Viruses aren't usually floating around naked, Marr says. They are encased in droplets of fluid, such as saliva, which contain bits of mucus, proteins, salt and other substances that may determine if the virus survives drying.

When the humidity is higher than



At a low humidity level of 40 percent, airborne droplets dry quickly, preserving viruses under a feathery crystalline lattice (left microscope image). At an intermediate humidity level of 65 percent, crystals form inside liquid droplets (middle), but those crystals may inactivate viruses, not preserve them. At a high humidity level of 85 percent (right), droplets remain liquid, allowing viruses to survive better than at mid-level humidity.

JANIE FRENCH/LAKDAWALA LAB/UNIV. OF PITTSBURGH SCHOOL OF MEDICINE

40 percent, droplets dry slowly. Such slow drying kills viruses such as influenza A and SARS-CoV-2, Marr and colleagues reported in a paper posted July 27 at bioRxiv.org. During slow drying, salt and other things that may harm the virus become more concentrated. What happens at the molecular scale to inactivate the virus remains unclear.

But flash-drying in parched air preserves those viruses. "If the air is very dry, the water quickly evaporates," Marr says. "It's almost like things are frozen in place."

Drier, smaller aerosols are also more buoyant and may hang in the air longer, increasing the chance that someone will breathe them in, Fisman says.

What's more, dry air can tear down some of our defenses against viruses. Studies in lab animals suggest that dry air can trigger death of cells lining airways, leaving cracks where viruses can invade.

Mucus in the airways can trap viruses and help protect against infection. But breathing cold, dry air can also slow the system that usually moves mucus out of the body, giving viruses time to escape the mucus trap and invade cells, Fisman says.

Cold foils the body's virus fighters

Being cold may not give you a cold, but it could make you more susceptible to catching one.

Normally, the immune system has a trick for warding off viruses, Bleier and colleagues have found. Cells in the nose and elsewhere in the body are studded with surface proteins that can detect viruses. When one of these sensor proteins detects a virus, it signals the cell to release tiny bubbles called extracellular vesicles.

The bubbles work as a diversion, Bleier says. Viruses may go after the vesicles instead of infecting cells.

If a virus docks with one of the bubbles, it's in for a surprise: Inside the vesicles are virus-killing bits of RNA called microRNAs. One of those microRNAs known as *miR-17* can kill two types of rhinoviruses and a cold-causing coronavirus, Bleier and colleagues report December 6 in the *Journal of Allergy and Clinical Immunology*.

Researchers measured bubbles released from human nasal cells grown in lab dishes at 37° Celsius, our typical body temperature. Then the team lowered the thermostat to 32° C. Cells released about 42 percent fewer vesicles at the lower temperature. What's more, the vesicles carried fewer weapons. Vesicles can pack in about 24 percent more microRNA at body temperature than when it is cooler.

Tips for preventing infection

But even in the cold, dry winter, there are things people can do to protect against viruses. Using a humidifier might help slow the drying of virus-laden droplets, killing the viruses. "Any increase in humidity should be beneficial," Shaman says. "You get a lot of bang for your buck if you go from very dry to dry."

If you're worried about pumping too much moisture into your home when it's cold outside — and risking the humidity condensing in cold spaces and fueling mold — there are alternatives. Milton advocates using exhaust fans to boost ventilation and HEPA filters to filter viruses out of the air (*SN Online*: 7/25/22).

Bleier advises wearing a mask. Not only do masks filter out viruses, masks also keep warm, moist air in front of the nose, which could help bolster the immune system, his team's work suggests. ■

PHYSICS

Mock wormholes transmit messages

One-way missives could travel through closing passages

BY JAMES R. RIORDON

If you ever happen to fall through a wormhole in outer space, you won't be coming back. It will snap shut behind you. But you may have just enough time to send a message to the rest of us from the other side, researchers report in the Nov. 15 *Physical Review D*.

No one has yet seen a wormhole, but theoretically the passages could provide shortcuts to distant parts of the universe, or to other universes entirely, if they exist (*SN*: 8/29/20, p. 12). Physicists knew that one of the most commonly theorized types of wormholes would be extremely unstable and would collapse if any matter entered it. But it wasn't clear how fast that might happen or what it means for something, or someone, heading into it.

Now, a computer simulation shows how that type of wormhole would respond when something travels through it.

In the simulation, "you build a probe and you send it through," says physicist Ben Kain of the College of the Holy Cross in Worcester, Mass. "You're not necessarily trying to get it to come back, because you know the wormhole is going to collapse — but could a light signal get back in time before a collapse? And we found that it is possible."

Previous studies have argued that wormholes could stay open for repeated trips back and forth, Kain says, provided the portals were supported by a theoretical form of matter called "ghost matter."

Ghost matter is expected to respond to gravity in exactly the opposite way to normal matter. For instance, a ghost matter apple would fall up from a tree branch instead of down. While allowed by Einstein's general theory of relativity, ghost matter almost certainly doesn't exist in reality, Kain says.

Nevertheless, Kain and colleagues simulated ghost matter traveling through a wormhole and found that it caused the hole to expand as expected. Normal matter, on the other hand, triggered a collapse that pinched the hole closed and left a black hole–like object behind. But the collapse happened slowly enough that a fast-moving probe would be able to transmit light-speed signals back to our side just before the wormhole closed.

The idea should be approached with a fair bit of skepticism, says physicist Sabine Hossenfelder of the Munich Center for Mathematical Philosophy. "Lots of things you can do mathematically have nothing to do with reality," she says.

Still, Kain thinks the effort might reveal whether traversable wormholes that don't rely on ghost matter are possible. ■

EARTH

The Tonga volcano erupted into space

The 2022 blast also spawned a record-breaking lightning blitz

BY CAROLYN GRAMLING

When the Hunga Tonga-Hunga Ha'apai volcano in the South Pacific Ocean erupted on January 15, 2022, the event was one for the record books — in several ways.

The eruption of the submarine volcano was so explosive that it injected water vapor high enough to touch space, a first-of-its-kind observation for an earthly volcano. The event also produced the greatest concentration of lightning ever detected and released so much energy that its disturbance in the ionosphere, a charged layer of Earth's atmosphere, rivaled that of a solar geomagnetic storm.

The January 15, 2022, eruption of the Hunga Tonga-Hunga Ha'apai volcano in the Pacific Ocean shot water vapor into outer space.

TONGA GEOLOGICAL SURVEY TEAM/WIKIMEDIA COMMONS (CC BY 3.0)

Space physicists, meteorologists, oceanographers and others described these superlatives at a news conference on December 12 and in several presentations at the American Geophysical Union's fall meeting.

"These are once-in-a-lifetime … observations," said space physicist Larry Paxton of the Johns Hopkins University Applied Physics Laboratory in Laurel, Md.

He and colleagues examined data collected by satellites monitoring the ultraviolet part of the electromagnetic spectrum. On the day of the big eruption, Paxton said, there was a spot in the satellite data where there was a temporary decrease in far-ultraviolet emissions. The spot coincided with the volcano's location.

The ultraviolet satellites don't see anything in the atmosphere below about 100 kilometers above sea level, what's typically thought of as the boundary of space. That means that some sort of emitted material — most likely water vapor from the undersea volcano — had reached high enough into space to briefly absorb those particles of light, the researchers reported.

The volcano woke up in December 2021. By early January, the eruption was already "one of the most prolific lightning producers" on the planet, said Chris Vagasky, a meteorologist at Vaisala Inc., an environmental instruments company headquartered in Vantaa, Finland.

Using Vaisala's Global Lightning Detection Network, Vagasky and colleagues estimated that on January 15 alone, the day of the big blast, there were at least 400,000 lightning flashes at and around the volcano, at a rate of roughly 5,000 flashes a minute — an order of magnitude higher than generally observed in Earth's most powerful thunderstorms, Vagasky said. "This was the most extreme lightning event that had ever been detected by the global network," which was established in 2009.

Some of the volcano's explosive energy

ENVIRONMENT

Indigenous people make 'dark earth'

Ancient Amazonians probably created the fertile soil too

BY FREDA KREIER

Indigenous people in the Amazon may have been deliberately creating fertile soil for farming for thousands of years.

At archaeological sites across the Amazon basin, patches of unusually fertile soil dot the landscape. Scientists have long debated the origin of this "dark earth," which is darker in color than surrounding soils and richer in carbon.

Today, Indigenous Kuikuro people in central Brazil make similar soil, researchers reported December 16 at the American Geophysical Union's fall meeting.

The fact that Kuikuro people make dark earth is a "pretty strong argument" that long-ago Amazonians also made it, says Paul Baker, a geochemist at Duke University who was not involved in the research.

In doing so, ancient inhabitants of the Amazon may have inadvertently stored massive quantities of carbon in the soil, says study presenter Taylor Perron, an earth scientist at MIT. The technique, he says, could provide a blueprint for developing sustainable carbon sequestration methods to help fight climate change.

The Western world has long viewed the Amazon as a vast wilderness that was relatively untouched before Europeans showed up. At the center of this argument is the idea that the Amazon's soil, which, like other tropical soils, is poor in nutrients, precluded people from developing agriculture at a large scale.

But a slew of archeological finds in recent decades — including the discovery of ancient urban centers in the Amazon basin of modern-day Bolivia — has shown that ancient people actively shaped the region (SN: 7/2/22, p. 32).

The bulk of dark earth found so far dates to between about 2,500 and 500 years ago, Perron says. Some archaeologists argue that people intentionally made dark earth while others contend that it was laid down through natural processes.

To explore that question, Perron and colleagues reviewed interviews of Kuikuro people conducted by a Kuikuro filmmaker. Those conversations revealed that Kuikuro villagers actively make dark earth — *eegepe* in Kuikuro — using ash, food scraps and controlled burns. "When you plant where there is no *eegepe*, the soil is weak," elder Kanu Kuikuro explained in one of the interviews. "That is why we throw the ash, manioc peelings and manioc pulp."

The researchers collected soil from Kuikuro villages and archaeological sites in Brazil's Xingu River basin. Dark

made it to the ionosphere, the layer of Earth's atmosphere where charged plasma coexists with other atmospheric particles. Atmospheric pressure waves from the eruption propagated into space, shifting the plasma around.

Those plasma shifts then rippled along Earth's magnetic field lines, disturbing plasma thousands of kilometers away.

In the vicinity of the volcano, that effect on the ionosphere from the January 15 eruption surpassed the impact of a minor solar geomagnetic storm on January 14. "Despite a simultaneous geomagnetic storm, the volcano dominated changes in ionospheric dynamics," said Claire Gasque, a space physicist at the University of California, Berkeley.

"Most people think of space weather as being caused by solar influences," Gasque said. But these data suggest a volcano can have just as much power.

The volcano may yet break other records as scientists continue studying data from the powerful explosion. ■

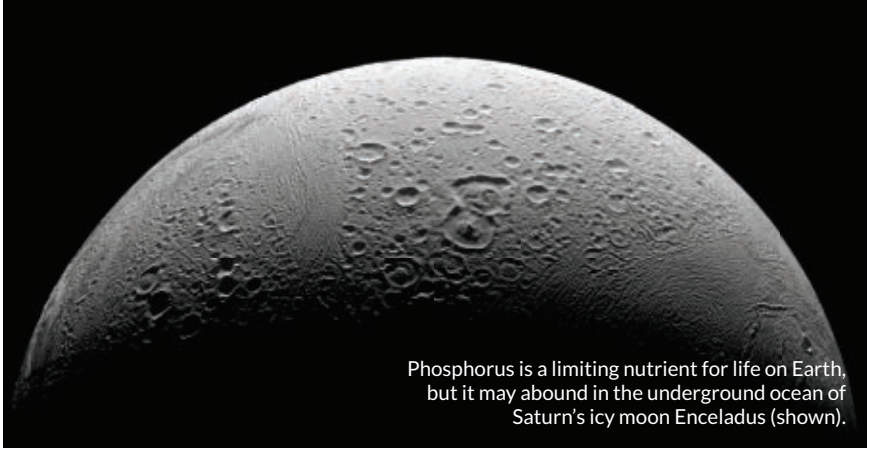
Editor's note: Claire Gasque is the daughter of Science News *news director Macon Morehouse, who wasn't involved in assigning or editing this article.*

earth from ancient and modern sites have "striking similarities," Perron says. Both are far less acidic than surrounding soils—probably thanks to the neutralizing effect of ash—and have more nutrients.

For instance, dark earth holds twice as much carbon as surrounding soils on average. Infrared scans of the Xingu region suggest the area is pockmarked with dark earth and may contain as much as nine megatons more carbon than previously thought, the researchers reported. If these figures hold true across the Amazon, dark earth could hold as much carbon as the United States emits annually, Perron says.

That estimate is a "huge extrapolation from a very small dataset," Baker cautions.

Perron agrees, but he notes that with the rising concentration of greenhouse gases in the atmosphere, making dark earth, or something like it, could both mitigate climate change and support agriculture in the tropics. ■



Phosphorus is a limiting nutrient for life on Earth, but it may abound in the underground ocean of Saturn's icy moon Enceladus (shown).

JPL-CALTECH/NASA, SPACE SCIENCE INSTITUTE

PLANETARY SCIENCE

Key life ingredient found on Enceladus

The moon may be awash in phosphorus, the backbone of DNA

BY NIKK OGASA

On Saturn's icy moon Enceladus, the last key ingredient for life has been discovered. The moon's underground ocean contains phosphorus, a building block of DNA and RNA. And the concentration may be thousands of times greater than in Earth's ocean, planetary scientist Yasuhito Sekine reported December 14 at the American Geophysical Union's fall meeting.

"We knew that Enceladus had most of the elements that are essential for life as we know it—carbon, hydrogen, nitrogen, oxygen and sulfur," says Morgan Cable, an astrobiologist at the Jet Propulsion Laboratory in Pasadena, Calif., who was not involved in the research. With the confirmation of phosphorus, "Enceladus now appears to meet all of the criteria for a habitable ocean."

Many researchers consider Enceladus to be among the most likely places in the solar system to host extraterrestrial life. It's a world encased in ice, with an ocean of salty water hidden beneath (SN: 12/9/17, p. 18). What's more, in 2005 NASA's Cassini spacecraft observed jets blasting vapor and ice grains out of Enceladus' icy shell. In that spacefaring spray, scientists have detected organic molecules.

But until now, researchers weren't sure if phosphorus also existed on Enceladus. On Earth's surface, the element is relatively scarce. Much of the phosphorus is locked away in minerals, and its availability often controls the pace at which life can proliferate.

So Sekine, of the Tokyo Institute of Technology, and colleagues analyzed chemical data collected by the now-defunct Cassini of particles in Saturn's E ring, a halo of material ejected from Enceladus' jets.

Some ice grains in the E ring are enriched in a phosphorus compound called sodium phosphate, the researchers found. They estimate that a kilogram of water from Enceladus' ocean contains roughly 1 to 20 millimoles of phosphate, a concentration thousands of times greater than in Earth's big blue ocean.

At the floor of Enceladus' ocean, phosphate may arise from reactions between seawater and a phosphate-bearing mineral called apatite, Sekine said, before being ejected through geysers into space. Apatite often inhabits carbonaceous chondrites, some of the most primitive space rocks in the solar system.

Many other icy ocean worlds may contain apatite as well, Sekine said. So they too could also carry high levels of phosphate in their oceans. That richness could be a boon for any potential alien organisms.

Though the findings are promising, they give rise to a glaring conundrum, Sekine said. "If life exists [on] Enceladus, why [does] such [an] abundance of chemical energy and nutrients remain?" After all, here on Earth, any available phosphorus is rapidly scavenged by life.

It's possible that the moon is simply barren of life, Sekine said. But there's another, more hopeful explanation: Life on frigid Enceladus, he said, may simply consume the nutrient at a sluggish pace. ■

PALEONTOLOGY

Ichthyosaur graveyard was a nursery

The ancient marine reptiles bred at a site in what's now Nevada

BY CAROLYN GRAMLING

Some 230 million years ago, massive dolphinlike reptiles called ichthyosaurs gathered to breed in safe waters — just like many modern whales do.

That's the conclusion that scientists arrived at after studying a mysterious ichthyosaur graveyard in Nevada's Berlin-Ichthyosaur State Park. The park is home to the world's richest assemblage of fossils of *Shonisaurus popularis*, one of the largest ichthyosaurs ever discovered (SN: 8/24/02, p. 122).

"This is something we see in modern marine vertebrates — gray whales make [the] trek to Baja California every year" to breed, says paleontologist Randall Irmis of the Natural History Museum of Utah in Salt Lake City. The sheltered, warm water offers safety for the whales (SN: 1/19/80, p. 40).

The new finding, described in the Dec. 19 *Current Biology*, shows that this behavior "goes back at least 230 million years," Irmis says. "It really connects the past to the present in a big way."

The idea of birthing areas for ichthyosaurs has been proposed previously and is even well-known enough to often be incorporated into artists' renderings of the creatures, says Erin Maxwell, a paleontologist at the State Museum of Natural History in Stuttgart, Germany, who wasn't involved in the work. But this study, she says, "is the first to support these speculations with data."

Nevada's ichthyosaur fossil trove has puzzled paleontologists for decades. One curiosity is the many ichthyosaur fossils that are clustered in what's now the park but about 230 million years ago was part of a tropical sea. Another oddity is that the site seems as if it were almost entirely populated by giant, 14-meter-long adult *S. popularis*. And then there's the question of what caused the animals' deaths.

Scientists have previously suggested that the reptiles had congregated together for some unknown reason before something caused their mortality en masse.

Several pockets, or quarries, of specimens are scattered across the park. All told, Irmis and colleagues identified 112 ichthyosaur individuals in these quarries, including at one site where park officials had left previously discovered bones half-encased in the rock for public viewing.

That death snapshot meant that scientists could examine how the fossils were arranged relative to one another, which offered insight into the reptiles' behavior, says paleontologist Neil Kelley of Vanderbilt University in Nashville.

Kelley, Irmis and colleagues used digital cameras and a laser scanner to collect hundreds of measurements of the bone bed with the half-buried reptiles, combining the data into a 3-D model of the site. The team also studied the sizes and shapes of bones from across the park, including some now in museum collections. And the researchers analyzed the chemical makeup of the surrounding rocks and pored over older photographs and field notes.

These scraps of evidence helped point to what might have brought these creatures together: breeding.

Though almost all of the *S. popularis* skeletons in the park are full-grown adults, the site does have a few tiny ichthyosaur remains, the scientists found. Using micro-computed tomography, a 3-D imaging technique that uses X-rays to see inside the fossils, the researchers discovered that some bones were those of embryonic and newborn *S. popularis*.

The finding suggests that the site may have been a birthing ground. That could explain why there were so many of the same creatures in the same place alongside newborns, the researchers say.

The site also seems to have been a birthing ground for a long time. Rather than all dating to roughly the same time, different quarries are separated by at least hundreds of thousands of years, the researchers found.

As for what killed the reptiles, "we don't know," Irmis says.

Previous hypotheses included harmful algal blooms or large-scale volcanic activity. But the new rock chemistry data eliminated those events as culprits.

Some of the animals in each quarry could have still died en masse. Being grouped in one place to breed may have left the reptiles vulnerable to a sudden catastrophic event that buried them in sediment, such as an undersea landslide.

But the fossil finds might also represent "just normal mortality over time," Irmis says, given how the creatures seem to have come to the site again and again. ■

For generations, ancient dolphinlike reptiles called *Shonisaurus popularis* (shown in this artist's rendition) returned to the same location to breed, researchers say.

GABRIEL UGUETO/SMITHSONIAN

ARCHAEOLOGY

Supply chains fueled the Bronze Age

Mediterranean rulers sourced a crucial metal from Central Asia

BY BRUCE BOWER

Long-distance supply chains, vulnerable to disruptions from wars and disease outbreaks, may have formed millennia before anyone today gasped at gas prices or gawked at empty store shelves.

Roughly 3,650 to 3,200 years ago, herders and villagers who mined tin ore fueled long-distance supply chains that transported the metal from Central Asia and southern Turkey to merchant ships serving societies clustered around the Mediterranean, a new study finds.

Remote communities located near rare tin deposits tapped into an intense demand among ancient urban civilizations for a metal that, along with copper, was needed to produce bronze, researchers report in the Dec. 2 *Science Advances*.

Tin access transformed herders and part-time cultivators into powerful trade partners of Late Bronze Age states and rulers, say archaeometallurgist Wayne Powell of Brooklyn College in New York City and colleagues. Until now, it has been difficult to demonstrate the existence of such an ancient, long-distance tin supply chain or its geographic origins.

Powell's group builds its argument on previous archaeological evidence that mobile groups in Central Asia spread crop cultivation across much of Asia more than 4,000 years ago (SN: 5/3/14, *p.* 15) and pioneered popular clothes-making innovations by 3,000 years ago (SN: 3/12/22, *p.* 14). Land routes used by those groups would have connected Central Asian tin ore sources to the Mediterranean, the researchers say.

Writing on clay tablets from Bronze Age sites in what's now Turkey and Iraq refers to tin arriving from far to the east as early as around 3,900 years ago. But precise sources for eastern tin have proved elusive.

The new evidence of an ancient tin pipeline stretching more than 3,000 kilometers from mining sites in present-day Tajikistan and Uzbekistan to merchant ships carrying processed tin in the eastern Mediterranean is particularly striking, says coauthor Michael Frachetti, an anthropologist at Washington University in St. Louis.

"That complex tin network was an early version of modern-day supply chains for commodities such as gas and oil," Frachetti says.

An ancient shipwreck discovered in 1982 off Turkey's southern coast enabled the new study. Known as the Uluburun shipwreck, the vessel dates to around 3,300 years ago, and is one of the oldest known shipwrecks. Its cargo included one metric ton of tin. The metal had been cast into portable, distinctively shaped pieces called ingots.

Powell's group documented chemical fingerprints of 105 tin ingots, nearly all of those found in the Uluburun shipwreck. Ingot IDs were based on distinct combinations of different forms, or isotopes, of tin, lead and trace elements in the ingots. Data on the isotopic profiles of tin ore deposits in different parts of Eurasia have become available over the last few years, allowing the researchers to match the ingots' tin to deposits, Powell says.

Powell, Frachetti and colleagues traced the origins of about one-third of the Uluburun tin ingots to an ore deposit in Tajikistan and several others nearby in Uzbekistan. Previous excavations indicate that herding groups used stone hammers to mine tin from outcrops at those sites.

Most of the remaining shipwreck ingots were linked to small tin deposits in southeastern Turkey's Taurus Mountains. Mountain communities controlled by the ancient Hittite kingdom probably collected tin from those deposits, Frachetti says (SN: 4/28/18 & 5/12/18, *p.* 32). Until now, many researchers have assumed that Turkish tin sources were depleted by the Late Bronze Age.

Despite the new evidence, geographic origins of the Uluburun tin ingots remain unclear, says archaeometallurgist Daniel Berger of Curt-Engelhorn-Centre of Archaeometry in Mannheim, Germany. Berger, who studies Bronze Age tin sources with another research group, did not participate in the new study.

Tin cargo (shown) aboard an ancient shipwreck off Turkey may have come from Central Asia.

CEMAL PULAK/TEXAS A&M UNIV.

Tin ores typically contain low lead levels, but the shipwreck ingots display high levels. Lead was probably added, deliberately or via accidental contamination, to tin somewhere on its way to the Mediterranean, he suggests. If so, that potentially complicates the attempt by Powell's group to combine tin and lead isotopes to identify tin sources.

Isotopic signatures of tin within the same ore deposits vary greatly, and overlap exists between different deposits, Berger says. So tin isotopes by themselves cannot definitively identify tin sources of the Uluburun ingots.

"Tracing the tin sources of the Bronze Age is and remains one of the most challenging problems in archaeology," Berger says. Efforts to identify chemical and molecular properties of different Eurasian tin deposits are still in the early stages.

Last February, Berger and colleagues reported that tin ingots from a Late Bronze Age shipwreck found off Israel's coast displayed an isotopic connection to tin deposits in southwestern England. Further research is also needed to confirm that finding, he says. ■

PSYCHOLOGY

Social scientists rethink 'flourishing'

Positive psychology's concept of well-being may be too exclusive

BY SUJATA GUPTA

Languishing. The term captured the zeitgeist in 2021 when organizational psychologist Adam Grant of the University of Pennsylvania penned an article in the *New York Times* titled, "There's a name for the blah you're feeling: It's called languishing."

"Languishing," Grant wrote, "is the neglected middle child of mental health. It's the void between depression and flourishing — the absence of well-being."

The idea struck a chord, and Grant's ode to languishing went on to become the *Times*' most read article of the year. Even I, generally suspicious of fads, felt the idea's lure. Yes, I thought, that explains a lot.

But I began to question my gut reaction after stumbling across several articles on flourishing in the December *SSM-Mental Health* — all part of a series spearheaded by medical anthropologist Sarah Willen.

The study of how and why people flourish anchors the field of positive psychology and includes related areas of research into happiness, well-being and resilience. In this research, flourishing refers to an optimal state of mental well-being, where one is happy, satisfied with life and has a sense of purpose.

Positive psychologists tend to believe that anyone can flourish if they just try hard enough, says Willen, of the University of Connecticut in Storrs. Consequently, she says, these researchers tend to downplay systemic barriers to flourishing, such as those related to race or class.

These psychologists "presume that people have a good measure of control over what they are able to do in life," Willen says. But her own research, and that of others, shows that societal forces limit that control for many people.

In one article in the *SSM-Mental Health* series, Willen zooms in on how Grant's column and the wider discourse on flourishing fail to take into account the structural inequalities that may make some people more likely to languish.

The rise of positive psychology

Positive psychology is a relatively young field. In the late 1990s, when psychologist Martin Seligman of the University of Pennsylvania took over as president of the American Psychological Association, he sought to switch psychology's traditional focus on mental illness to mental well-being. Since then, positive psychology has emerged as a leading paradigm for research into mental health.

The field has garnered enormous public and private investments: The Templeton Foundation, for example, partially funds the Global Flourishing Study, a $43.4 million initiative at Harvard University that will look at flourishing across time among roughly 240,000 participants from 22 countries.

Meanwhile, the study of flourishing has moved beyond psychology. The concept shows up frequently in research on preventive medicine and physical health, and in K-12 schools through what's known as positive education, where, the idea goes, positive schools and positive teachers who "transmit optimism, trust and a hopeful sense of the future…are the fulcrum for producing more well-being in a culture," Seligman wrote in a 2018 report.

But some researchers remain skeptical of positive psychology. For one, the field largely emphasizes individual-level, not societal, changes to help people flourish, such as practicing gratitude and volunteering. That focus risks reducing the study of flourishing to simple self-help tricks, Willen says. What's more, this individualized view of flourishing helps fuel the self-help industry, Willen and others say.

"Positive psychology is a billion-dollar industry, and selling positivity as they do is incredibly lucrative and culturally seductive," says Oksana Yakushko, a practicing psychologist in Santa Barbara, Calif.

But, she says, the field ignores many people's realities. "I am troubled by the sociopolitical implications of selling this positive psychology ideology in a world where human beings are consistently abused, traumatized and stressed because they are not white, wealthy, able-bodied, Western, heterosexual, etc."

What it means to flourish

With positive psychology capturing money and attention, Willen began thinking about how to push back against the movement. Decades of research into public health have made clear that thriving in life depends at least as much on a person's environment and circumstances as their individual attributes, she says.

> "Positive psychology is a billion-dollar industry, and selling positivity as they do is incredibly lucrative and culturally seductive."
>
> **OKSANA YAKUSHKO**

So from 2018 to 2019, Willen and colleagues conducted a qualitative study of flourishing. They recruited a group of 167 people living in Cleveland. The team sought to understand how people conceive of flourishing by asking a subgroup of 80 participants, who better represented the county demographics overall than the full group, a series of open-ended questions. The first was: Would you describe yourself as someone who's flourishing at this point in your life? Why or why not?

About half of the people in the subgroup said they were flourishing, the team reported in the December *SSM-Mental Health*. But there were stark racial and socioeconomic disparities in the responses.

Sixty-seven percent of white respondents reported flourishing compared with 48 percent of Black respondents. Similarly, 88 percent of respondents with incomes over $100,000 said they were flourishing compared with 46 percent of respondents with incomes below $30,000.

Responses to another question — What

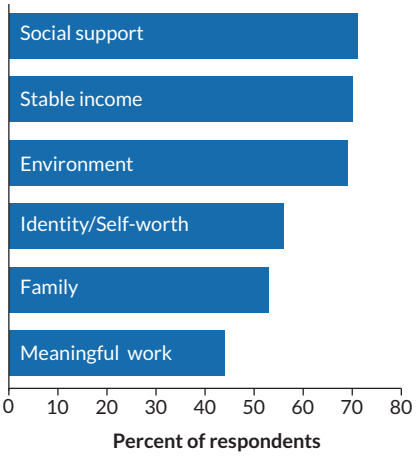
do people need, in general, to flourish? — illuminated how participants' understanding of flourishing often veered from that of positive psychologists.

Positive psychologists tend to define someone as flourishing if they report having generally positive relationships and emotions, meaning and purpose in their life, self-acceptance or high self-esteem and deep engagement in their life's activities. Among participants in Willen's study, such relationships and feeling good about oneself were important to flourishing, but meaning and purpose showed up less frequently.

Most crucially, the study participants mentioned two aspects of flourishing that rarely figure into positive psychologists' definitions of the term: a stable income and strong social determinants of health, or environment. The latter includes access to food, housing, education, a sense of safety and low levels of discrimination or oppression.

If policy makers' goal is to help as many people flourish as possible, then initiatives should focus on reducing inequality and mitigating those systemic barriers to well-being rather than more individualized measures, Willen says.

Factors needed to flourish in life



How to thrive When 80 people were asked what factors are key to flourishing, six responses rose to the top (shown). Of those factors, two — a stable income and one's environment — aren't typically included in positive psychologists' definitions, a sign that researchers may be overlooking aspects of flourishing.
SOURCE: S.S. WILLEN *ET AL/SSM-MENTAL HEALTH* 2022

E. OTWELL

The privilege to flourish

Disagreement between anthropologists like Willen and positive psychologists is largely one of world view, says Harvard University epidemiologist Tyler VanderWeele, who co-leads the Templeton-funded Global Flourishing Study. While Willen's team argues that one's circumstances may put happiness, or flourishing, out of reach, VanderWeele sees that world view as self-defeating.

Financial stability is one of six facets of flourishing that VanderWeele and colleagues are measuring in their global study of the concept. But for him, that facet is no more important than the other facets: happiness, mental and physical health, meaning and purpose, character and virtue, and close social relationships.

"We do need to worry about structural conditions, financial means and trying to ensure opportunities for everyone to flourish and the means necessary for that.... [But] I don't think those trump the other aspects of well-being," says VanderWeele, who coauthored a rebuttal to the series in an upcoming issue of *SSM-Mental Health*.

Focusing too much on factors outside any one individual's control, such as racism or poverty, VanderWeele says, can be disempowering. Focusing on smaller factors, such as crafting one's job to their liking or getting more involved in one's community by volunteering, however, hands that power back to the people.

This is not a debate between equals, Willen counters. With so much momentum behind their movement, positive psychologists have captured the narrative. And their self-help view of how to flourish is becoming The View, she says.

After Adam Grant's article appeared in the *Times*, Willen witnessed how concepts drawn from positive psychology — in this case, languishing — take on a life of their own as they enter the public domain.

That bird's-eye view arose thanks to the Pandemic Journaling Project, an initiative Willen and other researchers launched in May 2020 to enable people from all walks of life to document how they were coping. Through those journal entries, the scientists observed which people glommed onto the idea that they were languishing — and who did not. Tellingly, entrants who mentioned the term skewed overwhelmingly white and educated — a limited cohort that also reflects the readership of the *Times*, Willen says.

Grant uses his own arguably privileged experience of the moment to make sweeping claims about how people were experiencing the crisis, Willen says. He then uses those claims to write about how all people can overcome the blahs.

Specifically, Grant recommends people find flow. "Flow is that elusive state of absorption in a meaningful challenge or a momentary bond, where your sense of time, place and self melts away," he writes. Such flow can arise by binge-watching shows and movies, playing word games and, more broadly, pursuing uninterrupted time for oneself.

But, Willen asks, just who has had the luxury to pursue such remedies for languishing? And who, struggling with precarities in work, health and other domains, has instead experienced something darker, something more akin to suffering?

Grant maintains that Willen is creating a "false dichotomy" between personal and systemic solutions to flourishing. Simpler behavioral interventions serve as crucial stopgap measures in challenging times, Grant says. "It would be awfully cruel to tell readers suffering through a pandemic that they should just wait for social policies to change."

But most people aren't even aware of how individualized solutions to flourishing are overshadowing more systemic solutions, Willen says. Bringing that oversight to public attention is vital. "Unless we step back and ask ourselves whose voice is missing," she says, "we risk internalizing a distorted account of history."

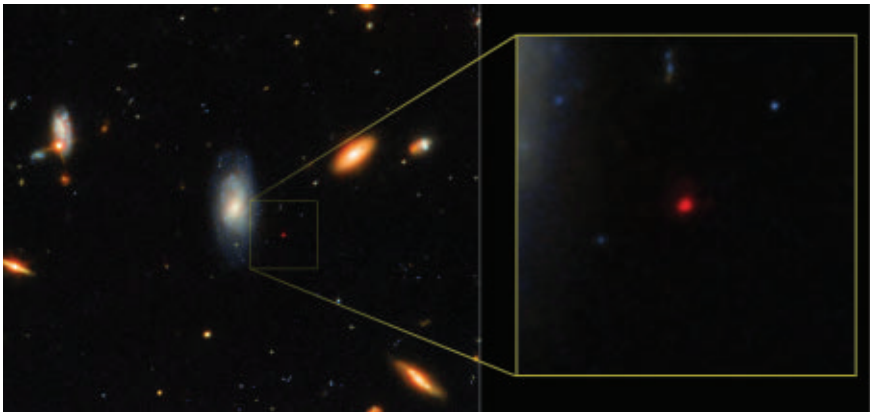
Her words remind me of the adage: History is written by the victors. It's a thought echoed on the Pandemic Journaling Project's website. "Usually, history is written only by the powerful," read the introductory words. "When the history of COVID-19 is written, let's make sure that doesn't happen." ■

ASTRONOMY

Gamma-ray burst breaks the rules

Long signal fingers neutron star smashups as a source

BY LISA GROSSMAN



Near a far-off galaxy (center in this Hubble Space Telescope image, left), the Gemini North telescope saw a neutron star merger's hallmark glow (red, inset) following an odd gamma-ray burst.

Astronomers have spotted a bright gamma-ray burst that upends previous theories of how these energetic cosmic eruptions occur.

For decades, researchers thought that GRBs, as the bursts are known, came in two flavors: long ones lasting two seconds or longer and short ones winking out more quickly. Each type has been linked to different cosmic events. But about a year ago, two NASA space observatories caught a short GRB in long GRB's clothing: It lasted nearly a minute but originated from a source known to produce short GRBs.

"We had this black-and-white vision of the universe," says astrophysicist Eleonora Troja of the Tor Vergata University of Rome. "This is the red flag that tells us: Nope, it's not. Surprise!"

The burst, called GRB 211211A, is the first that unambiguously breaks the binary, Troja and colleagues report December 7 in five papers in *Nature* and *Nature Astronomy*.

Before the discovery of the burst, astronomers mostly thought that there were just two ways to produce a GRB. The collapse of a massive star just before it explodes in a supernova could make a long GRB (SN: 11/19/22, p. 5). Or a pair of dense stellar corpses called neutron stars could collide, merge and form a new black hole, releasing a short GRB.

But there have been some outliers. A surprisingly short GRB in 2020 seemed to come from a massive star's implosion (SN: 8/28/21, p. 18). And some long-duration GRBs dating back to 2006 lacked a supernova, raising questions about their origins.

"We always knew there was an overlap," says astrophysicist Chryssa Kouveliotou of George Washington University in Washington, D.C., who was not involved in the work. "There were some outliers which we did not know how to interpret."

There's no such mystery about GRB 211211A: The burst lasted more than 50 seconds and was clearly accompanied by a kilonova, the characteristic glow of new elements being forged after a neutron star smashup.

"Although we suspected it was possible that extended-emission GRBs were mergers … this is the first confirmation," says astrophysicist Benjamin Gompertz of the University of Birmingham in England, who describes observations of the burst in *Nature Astronomy*. "It has the kilonova, which is the smoking gun."

NASA's Swift and Fermi space telescopes detected the explosion on December 11, 2021, near a galaxy about 1.1 billion light-years from Earth. "We thought it was a run-of-the-mill long gamma-ray burst," says astrophysicist Wen-fai Fong of Northwestern University in Evanston, Ill.

It was relatively close to Earth, as GRBs go. That allowed Fong's and Troja's groups to independently observe the burst in great detail using telescopes on the ground, the teams report in *Nature*.

As the weeks wore on and no supernova appeared, the researchers grew confused. Observations revealed that whatever had made the GRB had also emitted much more optical and infrared light than is typical for the source of a long GRB.

After ruling out other explanations, the teams compared the burst's aftereffects with the first kilonova ever observed. The match was nearly perfect. "That's when many people got convinced we were talking about a kilonova," Troja says.

Now the question is, what happened? Typically, two neutron stars collapse into a black hole almost immediately upon merging. The gamma rays come from superheated material falling into the black hole, but the material is scant and the black hole gobbles it up within about two seconds. That GRB 211211A kept its light going for almost a minute is odd.

It's possible that the neutron stars first merged into a single, larger neutron star, which briefly resisted the pressure to collapse into a black hole. That idea may have implications for the physics describing how difficult it is to crush neutron stars into forming a black hole, Gompertz says.

Another possibility is that a neutron star collided with a small black hole about five times as massive as the sun, and the process of the black hole eating the neutron star took longer.

Or a neutron star could have merged with a less dense but still very heavy white dwarf star, astrophysicist Bing Zhang of the University of Nevada, Las Vegas and colleagues suggest in *Nature*. The resulting object could be a highly magnetized neutron star called a magnetar that continued pumping energy into gamma rays, extending the life of the burst, Zhang says.

Whatever its origins, GRB 211211A is a big deal for physics, Kouveliotou says. Figuring out what exactly caused the burst could illuminate how heavy elements form. And some previously seen long GRBs thought to be from supernovas might actually be from mergers. ■

M. ZAMANI/INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF AND AURA, NASA, ESA

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Family Ties

A search for carvings on Australia's boab trees uncovers one Aboriginal family's link to the land

By Freda Kreier

This boab engraved with the image of a snake is one of 12 rediscovered during a 2021 expedition into the Tanami Desert in Australia. The carvings have cultural ties to the Jaru, an Aboriginal group from the Kimberley region of northwestern Australia.

D. LEWIS

Brenda Garstone is on the hunt for her heritage. Parts of her cultural inheritance are scattered across the Tanami Desert in northwestern Australia, where dozens of ancient boab trees are engraved with Aboriginal designs. These tree carvings — called dendroglyphs — could be hundreds or even thousands of years old yet have received almost no attention from Western researchers.

That is slowly starting to change. In the winter of 2021, Garstone — who is Jaru, an Aboriginal group from the Kimberley region of northwestern Australia — teamed up with archaeologists to find and document some of these carvings.

For Garstone, the expedition was a bid to piece together the disparate parts of her identity. These pieces were scattered 70 years ago when Garstone's mother and mother's siblings were taken from their family by the Australian government. An estimated one-tenth to one-third of Aboriginal children were taken from their families between 1910 and 1970.

Like many others, the siblings were sent to live at a Christian mission thousands of kilometers from home. It would take decades of effort and a series of unconnected events — including the gift of an heirloom and a researcher's quest to find out what happened to a missing 19th century European naturalist — for Garstone's family to reclaim its birthright.

When the siblings returned to their mother's homeland as teenagers, their extended family gave Garstone's aunt, Anne Rivers, a coolamon, a type of

shallow dish, decorated with two bottle trees, or boabs. Rivers, who was only 2 months old when she was sent away, was told that the trees were a part of her mother's Dreaming, the cultural story that connected her and her family to the land.

Now, in a study published in the December 2022 *Antiquity*, researchers have meticulously described 12 boabs with dendroglyphs in the Tanami Desert that have links to Jaru culture. And just in time: The clock is ticking for these engravings as their host trees succumb to the ravages of time and growing pressure from livestock and possibly climate change.

The race to document these engravings before it's too late isn't just a matter of studying an ancient art form. It's also a matter of healing the wounds inflicted by policies intended to erase the connection between Garstone's family and their homeland.

"To find evidence that ties us to the land has been amazing," she says. "The puzzle we've been trying to piece together is now complete."

An outback archive

Australian boabs (*Adansonia gregorii*) proved pivotal to reestablishing those ties. Found in the northwestern corner of Australia, boabs are easily recognizable by their massive trunks and iconic bottle shape.

Anthropologists have written about the existence of trees carved with Aboriginal symbols since the early 1900s. These records indicate that people were continually carving and recarving some trees until at least the 1960s. But compared with other forms of Aboriginal art — such as visually spectacular rock paintings also found in the area — "there does not appear to be a wide general awareness of this art form," says Moya Smith, curator of anthropology and archaeology at the Western Australian Museum in Perth, who was not involved with the study.

Darrell Lewis has come across his share of carved boabs. The historian and archaeologist at the University of New England in Armidale, Australia, has worked in remote stretches of northwestern Australia for half a century. Lewis has spotted engravings made by cattle drovers, World War II soldiers and Aboriginal peoples. He calls this eclectic bag of engravings "the outback archive" — a physical testament to the people who have made this rugged part of Australia their home.

In 2008, Lewis was searching the Tanami Desert for what he hoped would be his biggest addition to that archive. He'd heard rumors that a cattle drover working in the area a century earlier had found a firearm stashed in a boab marked with the letter "L." A roughly cast brass plate reportedly from the firearm — later bought by the National Museum of Australia — was stamped with the name of the famed German naturalist Ludwig Leichhardt, who disappeared in 1848 while traveling across western Australia.

Brenda Garstone accompanied a research team on an expedition to find boab trees — and their carvings — in the Tanami Desert. This boab is just 5.5 meters in circumference, making it the smallest carved tree found during the expedition.

Lewis was determined to find that tree. Though the Tanami was thought to be outside the boab's natural range, in 2007, he rented a helicopter and crisscrossed the desert in search of the secret stash of boabs. His flyovers revealed roughly 280 centuries-old boabs and hundreds of younger trees scattered across the desert.

"Even locals didn't know these trees were out there," he recalls.

His 2008 ground expedition to find the elusive "L" came up empty-handed. But the search did uncover dozens of boabs marked with dendroglyphs.

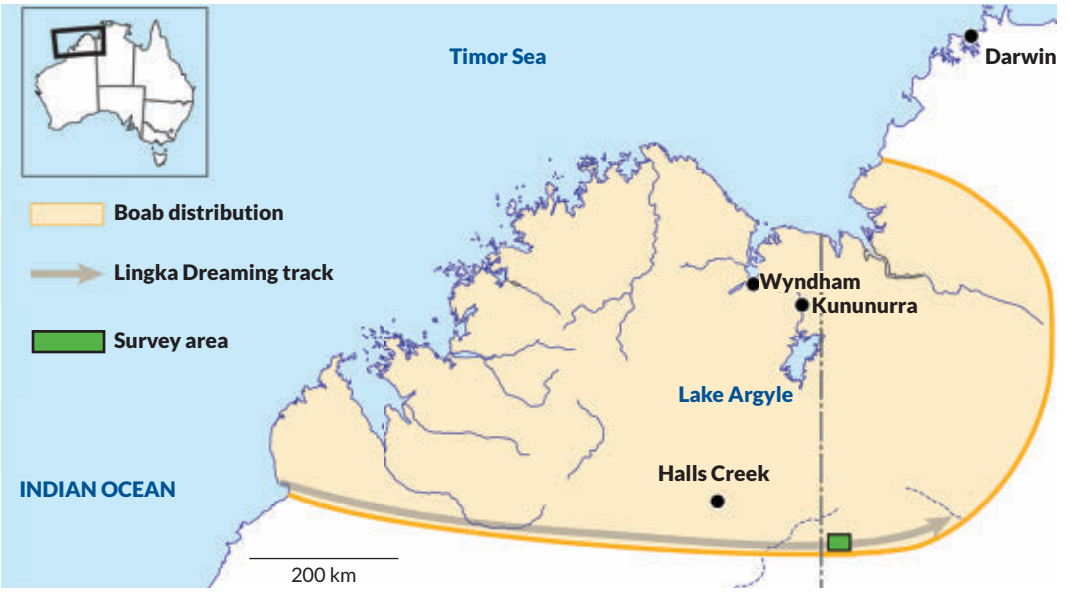
In a report for the National Museum of Australia, which had hired him to search for the "L" carving, Lewis recorded the location of these trees. That information sat untouched until the day it fell into the hands of Sue O'Connor, an archaeologist at Australian National University in Canberra.

Crumble into dust

In 2018, O'Connor was part of a group of archaeologists who were growing increasingly concerned about the survival of boabs. That year, scientists studying baobabs in Africa — a close relative of boabs — noticed that some of the older trees were dying out at a surprisingly high rate, potentially due to climate change (SN: 7/7/18, *p.* 11).

The news alarmed O'Connor. Dendroglyphs are often engraved on the largest and oldest boabs. While nobody knows exactly how old these trees can get, researchers suspect that their lifetimes

S. O'CONNOR



Finding lost carvings Boab trees grow in the northwestern corner of Australia. A survey (green rectangle) of a region southeast of Halls Creek revealed a patch of boab trees carved with dendroglyphs, which tie the region to the path (gray arrow) of the Lingka, or King Brown Snake, Dreaming. This ancient trail connects cultural sites and stories across hundreds of kilometers and mirrors the journey of Lingka, one of the spiritual beings that the Jaru and some other Aboriginal groups believe has shaped the landscape into its present form.

could be comparable to their African cousins, which can live up to 2,000 years.

When these long-lived trees do die, they pull a disappearing act. Unlike other trees, whose wood can be preserved for hundreds of years after death, boabs have a moist and fibrous interior that can quickly disintegrate. Lewis has witnessed boabs crumble into dust a couple years after dying. "You would never know there'd been a tree there," he says.

Whether Australian boabs are threatened by climate change is unclear. But the trees do come under attack from livestock, which peel back boabs' bark to get at the interior moisture. "We put all this together and thought, we better try and locate some of the carvings because they probably won't be there in a few decades," O'Connor says.

Lewis' report provided a good jumping-off point for this work. So O'Connor reached out to the historian and suggested they collaborate.

Around that same time, Garstone was four years into her research into her family's heritage. The long and meandering search led her to a small museum that a friend of Lewis' happened to run. When Garstone mentioned she was from Halls Creek—a town near where Lewis did his fieldwork in 2008—the curator told her about the carved boabs.

"I was like, 'What? That's a part of our Dreaming!'" she recalls.

Dreaming is a Western term used to refer to the vast diversity of Aboriginal stories that, among other things, recount how spiritual beings formed the landscape. Dreaming stories also pass down knowledge and inform rules of behavior and social interaction. These stories are often manifested in physical features of the land that mark the journeys of spiritual beings. These landmarks can be connected by paths called Dreaming tracks that form byways for people to travel across the country.

Garstone knew from the oral history passed down through her family that her grandmother had ties to the Bottle Tree Dreaming, as indicated by the trees painted on her aunt's coolamon. The Bottle Tree Dreaming is one of the easternmost manifestations of the Lingka Dreaming track. This particular path runs for hundreds of kilometers from the coast of the state of Western Australia into the neighboring Northern Territory. The track mirrors the journey that the King Brown Snake, a spiritual being, took across the landscape. (*Lingka* is the Jaru word for the King Brown Snake.)

Eager to confirm that the boabs were part of this Dreaming, Garstone, along with her mother, aunt and a scattering of other family members, joined the archaeologists on their mission to rediscover the boabs.

Into the Tanami

On a winter day in 2021, the group set out from the town of Halls Creek and set up camp on a remote pastoral station mainly populated by cattle and feral

camels. Every day, the team climbed into all-wheel drive vehicles and headed out to the last known location of the engraved boabs.

It was hard work. The crew often drove hours to the supposed position of a boab, only to have to stand on top of the vehicles and scan for trees in the distance. What's more, wooden stakes sticking out of the ground repeatedly shredded the vehicles' tires. "We were out there for eight or 10 days," O'Connor says. "It felt longer."

The expedition was cut short when the group ran out of tires—but not before finding 12 trees with dendroglyphs. To document the finds, the archaeologists took thousands of overlapping pictures, capturing an image of every centimeter of each tree.

The team also spotted grinding stones and other tools scattered around the base of the trees. Considering that large boabs provide shade in a desert with little cover, the prevalence of these objects suggests that people probably used the trees as resting spots as well as navigational markers while traveling across the desert, the researchers report in their study.

Some of the carvings on the boabs were of emu and kangaroo tracks. But an overwhelming majority of the engravings were of snakes, some of which undulated across the bark while others coiled onto themselves. The knowledge provided by Garstone and her family, along with historical records from the area, points toward the carvings being linked to the King Brown Snake Dreaming.

"It was surreal," Garstone says. Seeing the dendroglyphs confirmed the stories passed down in her family and is "pure evidence" of the ancestral connection to country, she says. The rediscovery has been healing, especially for her mother and aunt, both now in their 70s. "All of this was nearly lost because they didn't grow up in their homeland with their families," Garstone says.

Maintaining the connection

The work to find and document carved boabs in the Tanami and in other parts of the country has just begun. But this initial foray reveals the "vital importance" of scientists working in collaboration with First Nations knowledge holders, Smith says.

O'Connor is organizing another expedition to find the rest of the engravings that Lewis spotted, though she intends to take better wheels or—ideally—a helicopter. Garstone is planning on coming along with more of her extended family in tow.

In the meantime, O'Connor says that their work appears to have stimulated interest among researchers and other Aboriginal groups to rediscover the art form and preserve it for future generations.

Anne Rivers holds a shallow dish called a coolamon, passed down to her from her extended family. The boabs painted on the dish are a sign that her cultural heritage is connected to dendroglyphs in boabs found in the Tanami Desert (one shown below).

"Our connection to country is so important to maintain because it makes us who we are as First Nations people," Garstone adds. "To know that we have a rich cultural heritage and to have our own museum in the bush is something we will treasure forever." ■

Explore more

- Sue O'Connor *et al.* "Art in the bark: Indigenous carved boab trees (*Adansonia gregorii*) in north-west Australia." *Antiquity*. December 2022.

Freda Kreier is a freelance science journalist based in Washington, D.C.

FROM TOP: JANE BALME; S. O'CONNOR

A lot of the technology needed for a future with fewer carbon dioxide emissions is already available. The Ivanpah Solar Electric Generating System in the Mojave Desert focuses sunlight to generate steam. That steam spins turbines to make electricity.

ADAMKAZ/E+/GETTY IMAGES

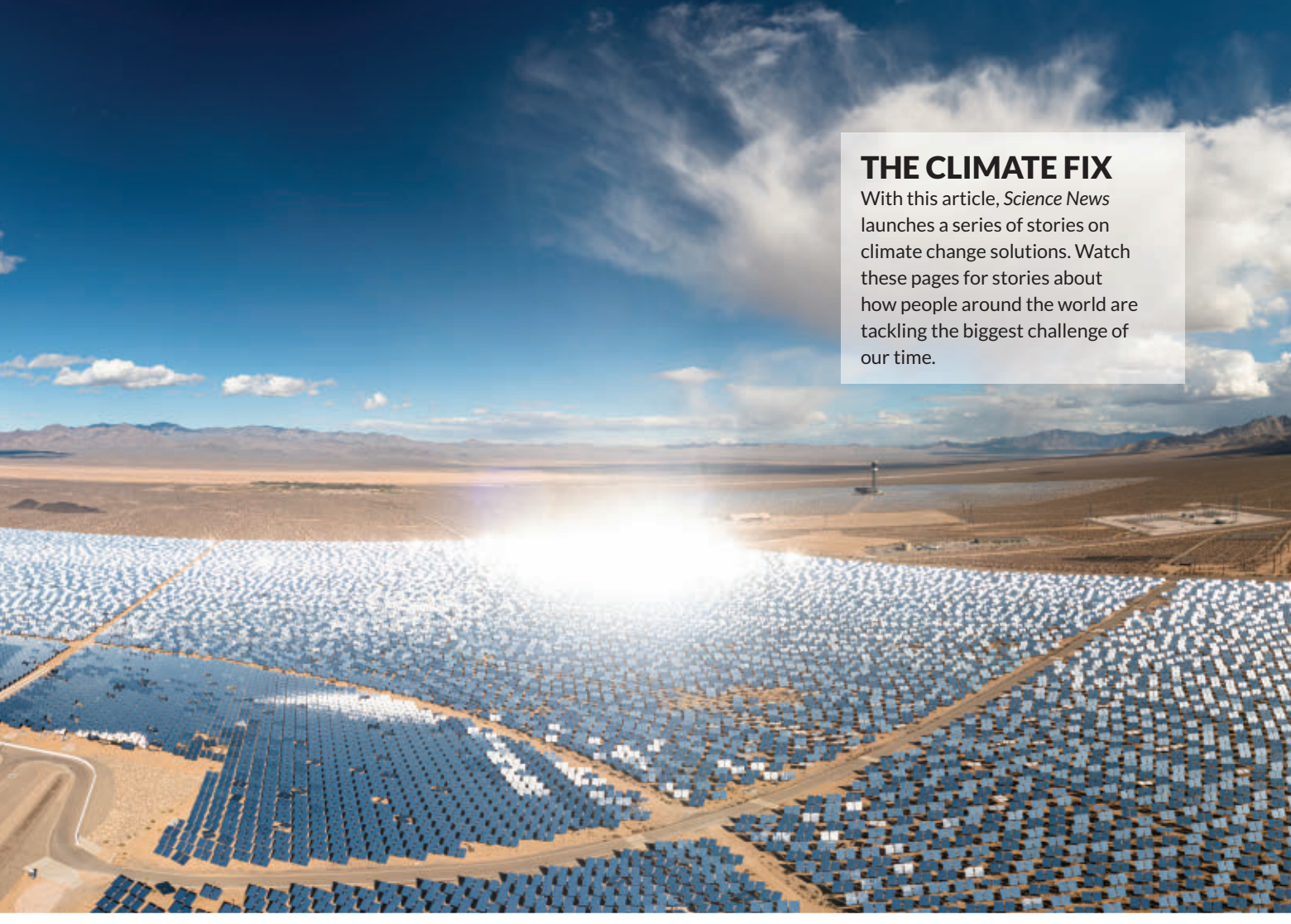
The Road to NET-ZERO

How we can cut emissions to curb climate change

By Alexandra Witze

Patricia Hidalgo-Gonzalez saw the future of energy on a broiling-hot day last September. An email alert hit her inbox from the San Diego Gas & Electric Company. "Extreme heat straining the grid," read the message, which was also pinged as a text to 27 million people. "Save energy to help avoid power interruptions."

It worked. People cut their energy use. Demand plunged, blackouts were avoided and California successfully weathered a crisis exacerbated by climate change. "It was very exciting to see," says Hidalgo-Gonzalez, an electrical engineer at the



THE CLIMATE FIX

With this article, *Science News* launches a series of stories on climate change solutions. Watch these pages for stories about how people around the world are tackling the biggest challenge of our time.

University of California, San Diego who studies renewable energy and the power grid.

This kind of collective societal response, in which we reshape how we interact with the systems that provide us energy, will be crucial as we figure out how to live on a changing planet.

Earth has warmed at least 1.1 degrees Celsius since the 19th century, when the burning of coal, oil and other fossil fuels began belching heat-trapping gases such as carbon dioxide into the atmosphere (SN: 3/12/22, p. 16). Scientists agree that only drastic action to cut emissions can keep the planet from blasting past 1.5 degrees of warming — a threshold beyond which the consequences become even more catastrophic than the rising sea levels, extreme weather and other impacts the world is already experiencing.

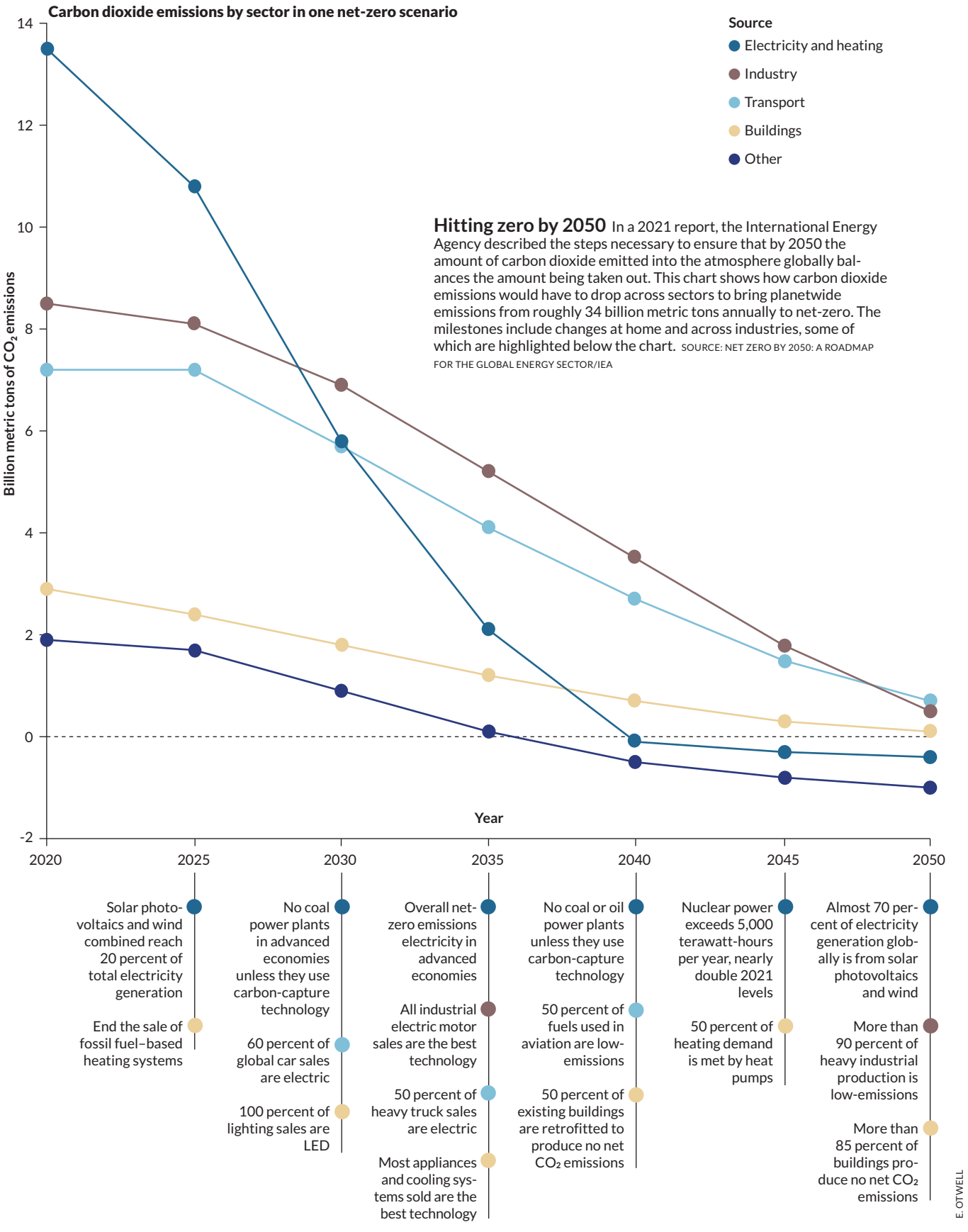
The goal is to achieve what's known as net-zero emissions, where any greenhouse gases still entering the atmosphere are balanced by those being removed — and to do it as soon as we can.

Scientists say it is possible to swiftly transform the ways we produce and consume energy. To show the way forward, researchers have set out paths toward a world where human activities generate little to no carbon dioxide and other greenhouse gases — a decarbonized economy.

The key to a decarbonized future lies in producing vast amounts of new electricity from sources that emit little to none of the gases, such as wind, solar and hydropower, and then transforming as much of our lives and our industries as possible to run off those sources. Clean electricity needs to power not only the planet's current energy use but also the increased demands of a growing global population.

Once humankind has switched nearly entirely to clean electricity, we will also have to counterbalance the carbon dioxide we still emit — yes, we will still emit some — by pulling an equivalent amount of carbon dioxide out of the atmosphere and storing it somewhere permanently.

Achieving net-zero emissions won't be easy. Getting to effective and meaningful action on climate change requires overcoming decades of inertia and denial about the scope and magnitude of the problem. Nations are falling well short of existing

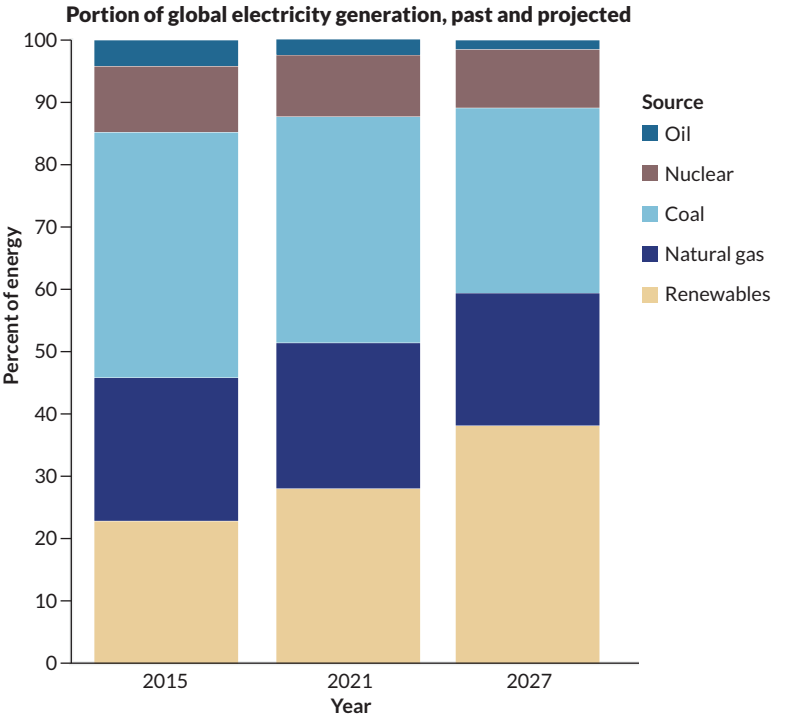


Hitting zero by 2050 In a 2021 report, the International Energy Agency described the steps necessary to ensure that by 2050 the amount of carbon dioxide emitted into the atmosphere globally balances the amount being taken out. This chart shows how carbon dioxide emissions would have to drop across sectors to bring planetwide emissions from roughly 34 billion metric tons annually to net-zero. The milestones include changes at home and across industries, some of which are highlighted below the chart. SOURCE: NET ZERO BY 2050: A ROADMAP FOR THE GLOBAL ENERGY SECTOR/IEA

pledges to reduce emissions, and global warming remains on track to charge past 1.5 degrees perhaps even by the end of this decade.

Yet there is hope. The rate of growth in CO_2 emissions is slowing globally — down from 3 percent annual growth in the 2000s to half a percent annual growth in the last decade, according to the Global Carbon Project, which quantifies greenhouse gas emissions. There are signs annual emissions could start shrinking. And over the last two years, the United States, by far the biggest cumulative contributor to global warming, has passed several pieces of federal legislation that include financial incentives to accelerate the transition to clean energy. "We've never seen anything at this scale," says Erin Mayfield, an energy researcher at Dartmouth College.

Though the energy transition will require many new technologies, such as innovative ways to permanently remove carbon from the atmosphere, many of the solutions, such as wind and solar power, are in hand — "stuff we already have," Mayfield says.



A growing share Renewable energy sources, such as solar, wind and hydropower, account for a larger share of global electricity generation today than they did in 2015 (28 percent versus 22.8 percent). The International Energy Agency predicts they'll account for more than 38 percent by 2027. SOURCE: IEA

The current state of CO_2

Of all the emissions that need to be slashed, the most important is carbon dioxide, which comes from many sources such as cars and trucks and coal-burning power plants. The gas accounted for 79 percent of U.S. greenhouse gas emissions in 2020. The next most significant greenhouse gas, at 11 percent of emissions in the United States, is methane, which comes from oil and gas operations as well as livestock, landfills and other land uses.

The amount of methane may seem small, but it is mighty — over the short term, methane is more than 80 times as efficient at trapping heat as carbon dioxide is, and methane's atmospheric levels have nearly tripled in the last two centuries. Other greenhouse gases include nitrous oxides, which come from sources such as applying fertilizer to crops or burning fuels and account for 7 percent of U.S. emissions, and human-made fluorinated gases such as hydrofluorocarbons that account for 3 percent.

Globally, emissions are dominated by large nations that produce lots of energy. The United States alone emits around 5 billion metric tons of carbon dioxide each year. It is responsible for most of the greenhouse gas emissions throughout history and ceded the spot for top annual emitter to China only in the mid-2000s. India ranks third.

Because of the United States' role in producing most of the carbon pollution to date, many researchers and advocates argue that it has the moral responsibility to take the global lead on cutting emissions. And the United States has the most ambitious goals of the major emitters, at least on paper. President Joe Biden has said the country is aiming to reach net-zero emissions by 2050. Leaders in China and India have set net-zero goals of 2060 and 2070, respectively.

Under the auspices of a 2015 international climate change treaty known as the Paris agreement, 193 nations plus the European Union have pledged to reduce their emissions. The agreement aims to keep global warming well below 2 degrees, and ideally to 1.5 degrees, above preindustrial levels. But it is insufficient. Even if all countries cut their emissions as much as they have promised under the Paris agreement, the world would likely blow past 2 degrees of warming before the end of this century.

Every nation continues to find its own path forward. "At the end of the day, all the solutions are going to be country-specific," says Sha Yu, an earth scientist at the Pacific Northwest National Laboratory and University of Maryland's Joint Global Change Research Institute in College Park, Md. "There's not a universal fix."

But there are some common themes for how to accomplish this energy transition — ways to focus our efforts on the things that will matter most. These are efforts that go beyond individual

E. OTWELL

consumer choices such as whether to fly less or eat less meat. They instead penetrate every aspect of how society produces and consumes energy.

Such massive changes will need to overcome a lot of resistance, including from companies that make money off old forms of energy as well as politicians and lobbyists. But if society can make these changes, it will rank as one of humanity's greatest accomplishments. We will have tackled a problem of our own making and conquered it.

Here's a look at what we'll need to do.

Make a lot more clean electricity

To meet the need for energy without putting carbon dioxide into the atmosphere, countries would need to dramatically scale up the amount of clean energy they produce. Fortunately, most of that energy would be generated by technologies we already have — renewable sources of energy including wind and solar power.

"Renewables, far and wide, are the key pillar in any net-zero scenario," says Mayfield, who worked on an influential 2021 report from Princeton University's Net-Zero America project, which focused on the U.S. economy.

"Renewables, far and wide, are the key pillar in any net-zero scenario."

ERIN MAYFIELD

The Princeton report envisions wind and solar power production roughly quadrupling by 2030 to get the United States to net-zero emissions by 2050. That would mean building many new solar and wind farms, so many that in the most ambitious scenario, wind turbines would cover an area the size of Arkansas, Iowa, Kansas, Missouri, Nebraska and Oklahoma combined.

Such a scale-up is only possible because prices to produce renewable energy have plunged. The cost of wind power has dropped nearly 70 percent, and solar power nearly 90 percent, over the last decade in the United States. "That was a game changer that I don't know if some people were expecting," Hidalgo-Gonzalez says.

Globally the price drop in renewables has allowed growth to surge; China, for instance, installed a record 55 gigawatts of solar power capacity in 2021, for a total of 306 gigawatts or nearly 13 percent of the nation's installed capacity to generate electricity. China is almost certain to have had another record year for solar power installations in 2022.

Challenges include figuring out ways to store and transmit all that extra electricity, and finding locations to build wind and solar power installations that are acceptable to local communities. Other types of low-carbon power, such as hydropower and nuclear power, which comes with its own public resistance, will also likely play a role going forward.

Get efficient and go electric

The drive toward net-zero emissions also requires boosting energy efficiency across industries and electrifying as many aspects of modern life as possible, such as transportation and home heating.

Some industries are already shifting to more efficient methods of production, such as steelmaking in China that incorporates hydrogen-based furnaces that are much cleaner than coal-fired ones, Yu says. In India, simply closing down the most inefficient coal-burning power plants provides the most bang for the buck, says Shayak Sengupta, an energy and policy expert at the Observer Research Foundation America think tank in Washington, D.C. "The list has been made up," he says, of the plants that should close first, "and that's been happening."

To achieve net-zero, the United States would need to increase its share of electric heat pumps, which heat houses much more cleanly than gas- or oil-fired appliances, from around 10 percent in 2020 to as much as 80 percent by 2050, according to the Princeton report. Federal subsidies for these sorts of appliances are rolling out in 2023 as part of the new Inflation Reduction Act, legislation that contains a number of climate-related provisions (SN: 12/17/22 & 12/31/22, *p.* 28).

Shifting cars and other vehicles away from burning gasoline to running off of electricity would also lead to significant emissions cuts. In a major 2021 report, the National Academies of Sciences, Engineering and Medicine said that one of the most important moves in decarbonizing the U.S. economy would be having electric vehicles account for half of all new vehicle sales by 2030. That's not impossible; electric car sales accounted for nearly 6 percent of new sales in the United States in 2022, which is still a low number but nearly double the previous year (SN: 12/18/21 & 1/1/22, *p.* 28).

Make clean fuels

Some industries such as manufacturing and transportation can't be fully electrified using current technologies — battery powered airplanes, for instance, will probably never be feasible for long-duration flights. Technologies that still require liquid fuels will need to switch from gas, oil and other fossil fuels to low-carbon or zero-carbon fuels.

One major player will be fuels extracted from plants and other biomass, which take up carbon dioxide as they grow and emit it when they die, making them essentially carbon neutral over their lifetime. To create biofuels, farmers grow crops, and

others process the harvest in conversion facilities into fuels such as hydrogen. Hydrogen, in turn, can be substituted for more carbon-intensive substances in various industrial processes such as making plastics and fertilizers—and maybe even as fuel for airplanes someday.

In one of the Princeton team's scenarios, the U.S. Midwest and Southeast would become peppered with biomass conversion plants by 2050, so that fuels can be processed close to where crops are grown. Many of the biomass feedstocks could potentially grow alongside food crops or replace other, nonfood crops.

Rein in other greenhouse gas emissions

Greenhouse gas emissions other than carbon dioxide will also need to be slashed. In the United States, the majority of methane emissions come from livestock, landfills and other agricultural sources, as well as scattered sources such as forest fires and wetlands. But about one-third of U.S. methane emissions come from oil, gas and coal operations. These may be some of the first places that regulators can target for cleanup, especially "super emitters" that can be pinpointed using satellites and other types of remote sensing.

In 2021, the United States and the European Union unveiled what became a global methane pledge endorsed by 150 countries to reduce emissions. There is, however, no enforcement of it yet. And China, the world's largest methane emitter, has not signed on.

Nitrous oxides could be reduced by improving soil management techniques, and fluorinated gases by finding alternatives and improving production and recycling efforts.

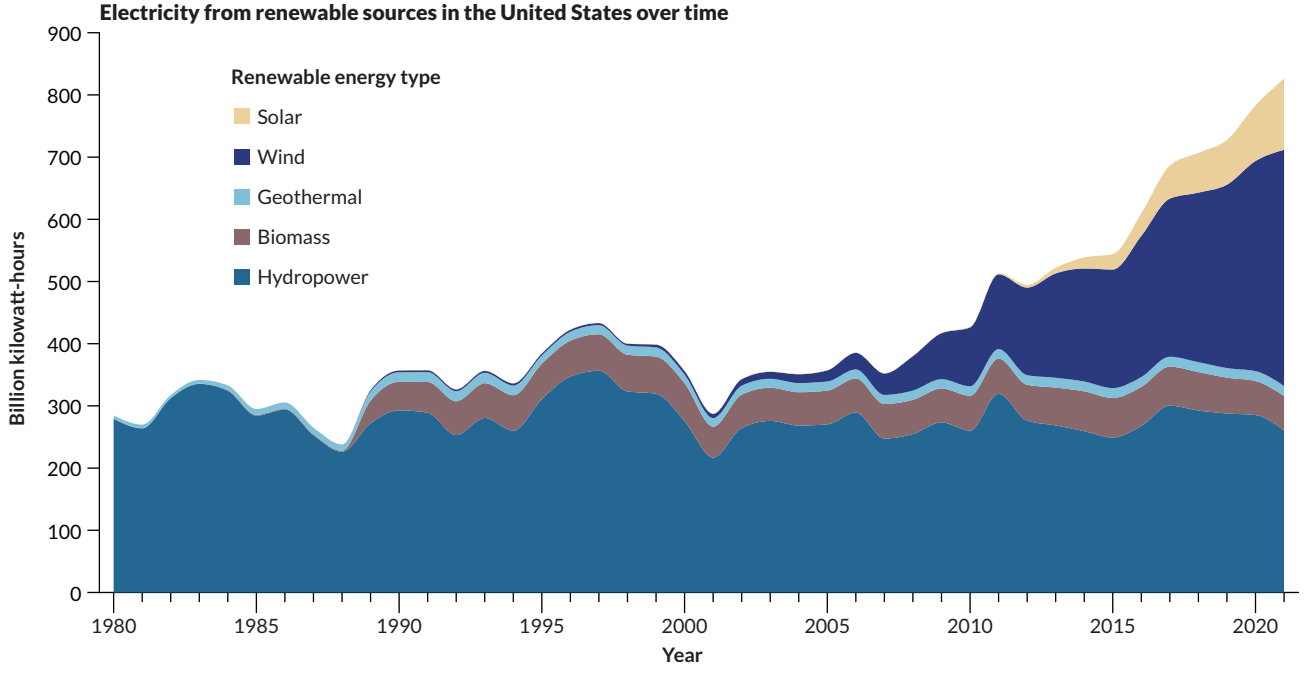
Sop up as much CO_2 as possible

Once emissions have been cut as much as possible, reaching net-zero will mean removing and storing an equivalent amount of carbon to what society still emits.

One solution already in use is to capture carbon dioxide produced at power plants and other industrial facilities and store it permanently somewhere, such as deep underground. Globally there are around 35 such operations, which collectively draw down around 45 million tons of carbon dioxide annually. About 200 new plants are on the drawing board to be operating by the end of this decade, according to the International Energy Agency.

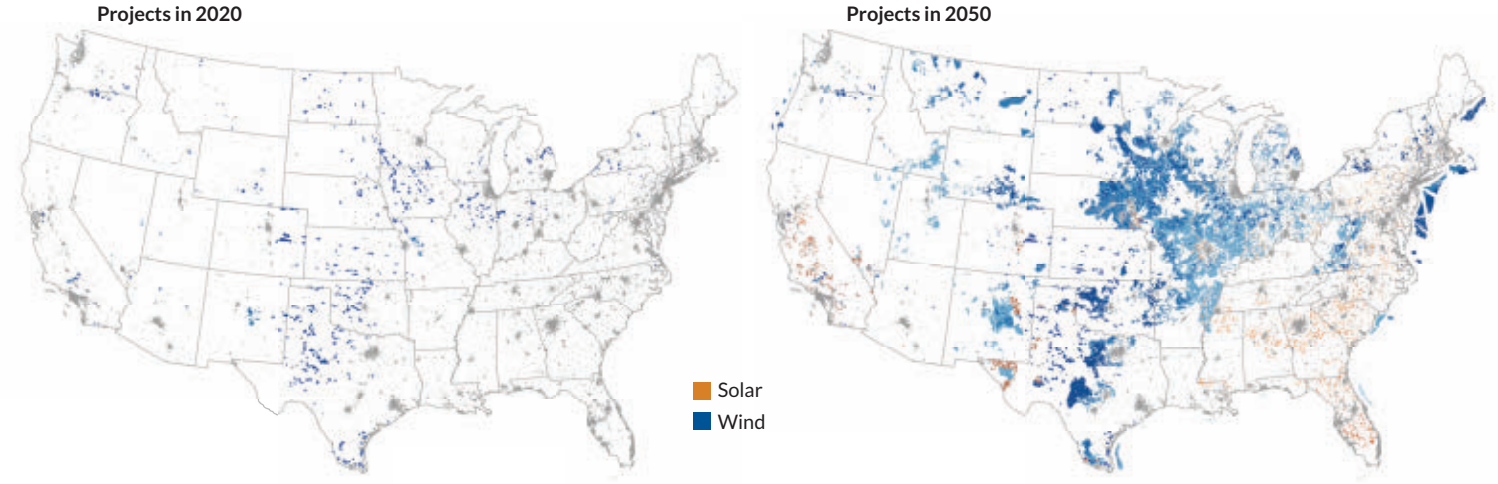
The Princeton report envisions carbon capture being added to almost every kind of U.S. industrial plant, from cement production to biomass conversion. Much of the carbon dioxide would be liquefied and piped along more than 100,000 kilometers of new pipelines to deep geologic storage, primarily along the Texas Gulf Coast, where underground reservoirs can be used to trap it permanently. This would be a massive infrastructure effort. Building this pipeline network could cost up to $230 billion, including $13 billion for early buy-in from local communities and permitting alone.

Another way to sop up carbon is to get forests



E. OTWELL

Catching sun and wind The amount of electricity generated from wind and solar power in the United States has surged in the last decade. The boost was made possible in large part by drops in the costs of producing that energy. SOURCE: U.S. ENERGY INFORMATION ADMINISTRATION



Power up Achieving net-zero would require a dramatic increase in solar and wind power in the United States. The maps above show the footprint of existing solar and wind infrastructure in the contiguous United States (left) and a possible footprint for a midrange scenario for 2050 (right). Gray shows population density of 100 people per square kilometer or greater.

and soils to take up more. That could be accomplished by converting crops that are relatively carbon-intensive, such as corn to be used in ethanol, to energy-rich grasses that can be used for more efficient biofuels, or by turning some cropland or pastures back into forest. It's even possible to sprinkle crushed rock onto croplands, which accelerates natural weathering processes that suck carbon dioxide out of the atmosphere.

Another way to increase the amount of carbon stored in the land is to reduce the amount of the Amazon rainforest that is cut down each year. "For a few countries like Brazil, preventing deforestation will be the first thing you can do," Yu says.

No time to waste

The Princeton team estimates that the United States would need to invest at least an additional $2.5 trillion over the next 10 years for the country to have a shot at achieving net-zero emissions by 2050. Congress has begun ramping up funding with two large pieces of federal legislation it passed in 2021 and 2022. Those steer more than $1 trillion toward modernizing major parts of the nation's economy over a decade — including investing in the energy transition to help fight climate change.

Between now and 2030, solar and wind power, plus increasing energy efficiency, can deliver about half of the emissions reductions needed for this decade, the International Energy Agency estimates. After that, the primary drivers would need to be increasing electrification, carbon capture and storage, and clean fuels such as hydrogen.

The trick is to do all of this without making people's lives worse. Developing nations need to be able to supply energy for their economies to develop. Communities whose jobs relied on fossil fuels need to have new economic opportunities.

Julia Haggerty, a geographer at Montana State University in Bozeman who studies communities that are dependent on natural resources, says that those who have money and other resources to support the transition will weather the change better than those who are under-resourced now. "At the landscape of states and regions, it just remains incredibly uneven," she says.

The ongoing energy transition also faces unanticipated shocks such as Russia's invasion of Ukraine, which sent energy prices soaring in Europe, and the COVID-19 pandemic, which initially slashed global emissions but later saw them rebound.

But the technologies exist for us to wean our lives off fossil fuels. And we have the inventiveness to develop more as needed. Transforming how we produce and use energy, as rapidly as possible, is a tremendous challenge — but one that we can meet head-on.

For Mayfield, getting to net-zero by 2050 is a realistic goal for the United States. "I think it's possible," she says. "But it doesn't mean there's not a lot more work to be done." ■

Explore more

- Net-zero America: Potential pathways, infrastructure, and impacts. Princeton University. 2021.
- Net zero by 2050: A roadmap for the global energy sector. International Energy Agency. 2021.

E. LESLIE, A. PASCALE, J.D. JENKINS/PRINCETON'S NET-ZERO AMERICA STUDY, ANNEX D: SOLAR AND WIND GENERATION TRANSITIONS

REGENERON SCIENCE TALENT SEARCH

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CONGRATULATIONS TO THE TOP 300 SCHOLARS OF 2023

Society for Science is proud to announce this year's Top 300 scholars in the Regeneron Science Talent Search, the oldest and most prestigious science and math competition in the United States for high school seniors. The scholars were selected from 1,949 entrants and come from 194 American and international high schools in 35 U.S. states and China. Each scholar receives a $2,000 award with an additional $2,000 going to their respective schools.

Mariam Abdelbarr • Amelia Abell • Kamisi Adetunji • Ashwika Agrawal • Bhargav Raviseshachandra Annem • Stavya Arora • Alvan Caleb Arulandu • Aaditya Krishna Arun • Shivani Babu • Sruthi Balasubramanian • Sasha Beth Bandler • Samir Batheja • Okezue Alexander Bell • Shriya P. Bhat • Rohan Tan Bhowmik • Tyler Logan Bissoondial • Kristi Biswas • Ariella Maia Blackman • Raka Bose • Katie Brandler • Emma Bunch • Rodrigo Cantu Valadez • George Cao • Allison Chan • Sheng-Chun (Angus) Chang • Stephanie Yien Chang • Hiral Milind Chavre • Alex Chen • Andrew Chen • Angela Chen • Corona Chen • Kenneth Chen • Luke Wen-Tsu Chen • Matthew Chen • Michael Chen • Aaron Cho • Hannah Cho • Ella Cohen-Kashi • Skylar Rachel Cowen • Rohini Elora Das • Lauren Davidson • Samara Davis • Madeleine de Belloy • Cindy DeDianous • August Deer • Vihaan Dheer • Nadya Jasmine Dhillon • Jennifer Carmen Di Capua • Ali El Moselhy • Nathan Elias • Ho Tin (Alex) Fan • Hua Fang • Jacob Elias Feldman • Luke Feldman • Austin Feng • Angie Fogarty • Lucca Forrest • Lisa Fung • Angela Li Gao • Sarah Gardner • Isabella Angelina Gega • Advay Goel • AriAnnah Goodwin • Carly Googel • Ambika Grover • Claire Gu • Hannah Guan • Sabrina Guo • Arya Gupta • Ronit Gupta • Madison Han • Varun Hariprasad • Fenghuan (Linda) He • Elizabeth Hong • James Hou • Ethan Hsu • Alexis Hu • Emily Hu • Michelle Hua • Angela Huang • Michael Huang • William Huang • Anu Iyer • Aashika Jagadeesh • Rishab Kumar Jain • Tanish Jain • Linden Chi James • Sarah Delia Jennings • Catherine Kexuan Jiao • Alexander Jin • Dana Kagan • Aryan Thomas Kalluvila • Zachary David Kam • Lara Jean Kendall • Archita Khaire • Amav Khambete • Thaddaeus Kiker • Elane Kim • Emily Kim • Evan Kim • Matthew S. Kim • Remington Kim • Ryan Hwang Kim • Sungmin Kim • Sameer Ullal Kini • Sravan Kodali • Harish Krishnakumar • Hari Hemanth Krishnamurthy • Gouri Krishnan • Sean Krivitsky • Elif Camila Kulahlioglu • Veda Kutagula • Nishant Lahiri • Ashley Lam • Alexander Lan • Hannah Laney • Alan Lee • Jeylin Lee • Julianne Lee • Ryan Lee • Jacob Leshnower • Daniel Levin • Jessica Li • Jiahui (Stella) Li • Michelle Li • Pinyu Liao • Yuru Lin • Elon Litman • Anna Lumin Liu • Bryant Liu • Derek X. Liu • Xin Qi Liu • Elvin Lo • Maxwell Love • Holland Low • Alvin Lu • Cindy Lu • Melinda Mengjia Lu • Joshua Luo • Leon Luo • Jesse Lynch • Alan Peijun Ma • Hanqi Ma • Alexis Téa MacAvoy • Vladimir Mamchik • Darsh Sandip Mandera • Krish Maniar • Naia Luz Marcelino • Miah Christina Margiano • Marissa Lilianna Martinez • Mason C. Matich • Remi Paige Matza • Arul Rhik Mazumder • Angela Mei • Samantha Maya Milewicz • Chloe Jane Miller • Lindsay Miller • Andrew Christopher Minagar • Max Misterka • Amishi Mittal • Luke Zhang Mo • Kiele Morgan • Neel Moudgal • Ishika Nag • Lavanya Natarajan • Ayush Nayak • Sean Nesamoney • Marc Nichitiu • Elizabeth Nyamwange • Oziomachukwu Chidubem Obi • Emily Ocasio • Madeline Oh • Siddhu Pachipala • Natalia Pahlavan • Apoorva Panidapu • Vera Pankevich • Minseok Eli Park • Jeeya Yogesh Patel • Shloke Patel • Sohi Patel • Fiona Peng • Ian Peng • Ben Persily • Amy Pham • Alyssa Ponrartana • Ashwin Prabhakar • Benjamin Punzalan • Ibrahim Qadri • Allen M. Qian • Akhila Ram • Gitanjali Rao • Kaif Ur Rehman • Joseph Miguel Robertazzi • Ashley Ruan • Amit Saha • Rhea Sakaria • Cami Sandell • Sonya Savelyev • Samantha Schaevitz • Bella Rose Marie Schremmer • Jack C. Schultz • Sruthi Sentil • Arvind Seshan • Anika Shah • Divyash Viral Shah • Roni Shaham • Nathan Shan • Hari Shankar • Ambica Sharma • Bryson Shaub • Leah Sherbansky • Amogh Shetty • Bryan Shi • Yu Shin • Jasmine Shone • Samyak Shrimali • Joshua Logan Shunk • Dheyala Simrin • Ridhima Singh • Dario Gaitzi Soatto • Neil Song • Armaan Srireddy • Saurish Srivastava • Jason M. Starr • Diego Emilio Suchenski Loustaunau • Amber Sun • Christopher Sun • Julia Sun • Aadhav Sundar • Lynn R. Tao • Rachel Tao • Minnahil Tariq • Jaden Tepper • Akshata Tiwari • Nikhil Trepeta • Vivek Turakhia • Sachleen Tuteja • Suraj Vaddi • Emma Van Praagh • Keshav Varadarajan • Adi Vatsavai • Ganesh Venu • Deeya Viradia • Patrick Michael Wahlig • Alex Wang • Charles Han Wang • Claire Wang • Eric Wang • Grace Li Wang • Jason Christopher Wang • Joshua Wang • Junyi Wang • Kevin Ro Wang • Rich Wang • Xina Wang • Yue Wang • Emmy Wei • Nolan Wen • Julia Westwater Brodsky • Jacob Winick • Celine Wu • Samuel Hong Wu • Vivian Wu • Emily Xing • Andy Xu • Ellen Xu • Ganning Xu • Jeffrey Xu • Lance Yunhao Xu • Shirley Xu • Felicia Yan • Alex Yang • Amy Yang • Anna Yang • Anna Yang • Benjamin Yue Yang • Grace Yang • Ryan Yunrui Yang • Tyler Benjamin Yang • Victor Yin • Andrew Yu • Edward Yu • Jean Yu • Temmie Yu • Andrew Yuan • Maxx Yung • Holy Mary Zaher • Andrew Y. Zhang • Kathleen Zhang • Raymond Ming Zhang • Tianyi (Tina) Zhang • Eileen Zheng • Brian Zhou • Ethan Zhou • Allison Youwen Zhu • Kevin Zhu • Sally Zhu • Sophie Zhu • Nicole Emma Zlotnikov • Liam Zuckerman

EXPERIENCES

Add these new science attractions to your 2023 travel itinerary

If you're a museum aficionado itching for a new place to explore, 2023 has you covered. New science museums and exhibitions are opening, and some zoos are expanding. This sampling of destinations to check out in the new year or beyond has something for everyone, whether you're a wildlife lover, space nerd or history buff.
—Erin Wayman

Richard Gilder Center for Science, Education and Innovation | American Museum of Natural History

NEW YORK CITY

OPENS: FEBRUARY 17

This multistory building will add tons of new exhibit space to the more than 150-year-old museum. Visitors can explore an insectarium that includes one of the world's largest displays of live leaf-cutting ants and come face-to-face with dozens of butterfly species in a vivarium. Meanwhile, the interconnectedness of life will be on display in the immersive, 360-degree "Invisible Worlds" exhibition.

Galápagos Islands | Houston Zoo

HOUSTON

OPENS: EARLY 2023

If you can't travel to the Galápagos Islands, a trip to Texas might be the next best thing. Giant tortoises, iguanas, penguins, sea lions, sharks and other creatures will inhabit this new exhibition that will re-create the land and marine ecosystems of the archipelago made famous by Charles Darwin.

Aquarium | Kansas City Zoo

KANSAS CITY, MO.

OPENS: SEPTEMBER 2023

The 34 exhibits of this new aquarium will allow visitors to glimpse a wide variety of ocean locales without having to leave the Midwest. Underwater residents will include sea urchins and sea anemones in a warm intertidal zone, fish swimming in a coral reef, comb jellies floating in the open ocean and sea otters playing along a rocky shore.

SPACE | Franklin Institute

PHILADELPHIA

OPENS: FALL 2023

To design this new two-story gallery dedicated to the future of space exploration, exhibit planners met with local students and teachers to find out what they wanted to learn. The result is an experience that, among other things, will showcase the current and future technologies needed to live and work in space as well as the many career paths into the aerospace industry.

Visitors to the Grand Egyptian Museum will be greeted by a giant, 3,200-year-old statue of King Ramses II (shown here in 2019 during the museum's construction).

Bird House | Smithsonian's National Zoo

WASHINGTON, D.C.

OPENS: TO BE ANNOUNCED

With a focus on bird migration and conservation in the Americas, the zoo's new bird house will feature three aviaries: The first will show how the Delaware Bay is a key refueling spot for migratory shorebirds, the second will demonstrate how seasonal wetlands in the Midwest serve waterfowl and the third will illustrate how a tropical coffee farm can provide respite for songbirds in winter.

Grand Egyptian Museum

OUTSIDE CAIRO

OPENS: TBA

Last year marked the 100th anniversary of the discovery of King Tut's tomb (SN: 11/19/22, p. 14). This year, thousands of artifacts from the tomb—along with tens of thousands of other archaeological finds from ancient Egypt—will go on display when this museum, located within view of the Pyramids of Giza, opens. More than a decade in the making, it will be one of the largest archaeological museums in the world.

Robot & AI Museum

SEOUL, SOUTH KOREA

OPENS: TBA

Though details are still scant, this museum dedicated to furthering public knowledge of robotics, artificial intelligence and machine learning is expected to open later this year.

KHALED DESOUKI/AFP VIA GETTY IMAGES

NOVEMBER 19, 2022 & DECEMBER 3, 2022

Finger-licking good

Nocturnal lemurs called aye-ayes pick their noses for snotty snacks using their middle fingers (shown below), which probably reach all the way to the back of the throat, **Maria Temming** reported in "Aye-ayes take nose picking to the extreme" (*SN: 12/3/22, p. 4*). Reader **Kent Lange** quipped: "Who nose what further research will discover?"

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In full swing

*The swaying feeling in jazz music that compels feet to tap may arise from near-imperceptible delays in musicians' timing, **Nikk Ogasa** reported in "Jazz gets its swing from small, subtle delays" (SN: 11/19/22, p. 5).*

Reader **Oda Lisa**, a self-described intermediate saxophonist, has noticed these subtle delays while playing. "I recorded my 'jazzy' version of a beloved Christmas carol, which I sent to a friend of mine," **Lisa** wrote. "She praised my effort overall, but she suggested that I get a metronome because the timing wasn't consistent. My response was that I'm a slave to the rhythm that I hear in my head. I think now I know why."

On the same page

*Murky definitions and measurements impede social science research, **Sujata Gupta** reported in "Fuzzy definitions mar social science" (SN: 11/19/22, p. 10).*

Reader **Linda Ferrazzara** found the story thought-provoking. "If there's no consensus on the terms people use … then there can be no productive discussion or conversation. People end up talking and working at cross-purposes with no mutual understanding or progress," **Ferrazzara** wrote.

Fly me to the moon

*Space agencies are preparing to send the next generation of astronauts to the moon and beyond. Those crews will be more diverse in background and expertise than the crews of the Apollo missions, **Lisa Grossman** reported in "Who gets to go to space?" (SN: 12/3/22, p. 20).*

"It is great to see a broader recognition of the work being done to make spaceflight open to more people," reader **John Allen** wrote. "Future space travel will and must accommodate a population that represents humanity. It won't be easy, but it will be done."

The story also reminded **Allen** of the Gallaudet Eleven, a group of deaf adults who participated in research done by NASA and the U.S. Navy in the 1950s and '60s. Experiments tested how the volunteers responded (or didn't) to a range of scenarios that would typically induce motion sickness, such as a ferry ride on choppy seas. Studying how the body's sensory systems work without the usual gravitational cues from the inner ear allowed scientists to better understand motion sickness and the human body's adaptation to spaceflight.

Sweet dreams are made of this

*A memory-enhancing method that uses sound cues may boost an established treatment for debilitating nightmares, **Jackie Rocheleau** reported in "Learning trick puts nightmares to bed" (SN: 12/3/22, p. 11).*

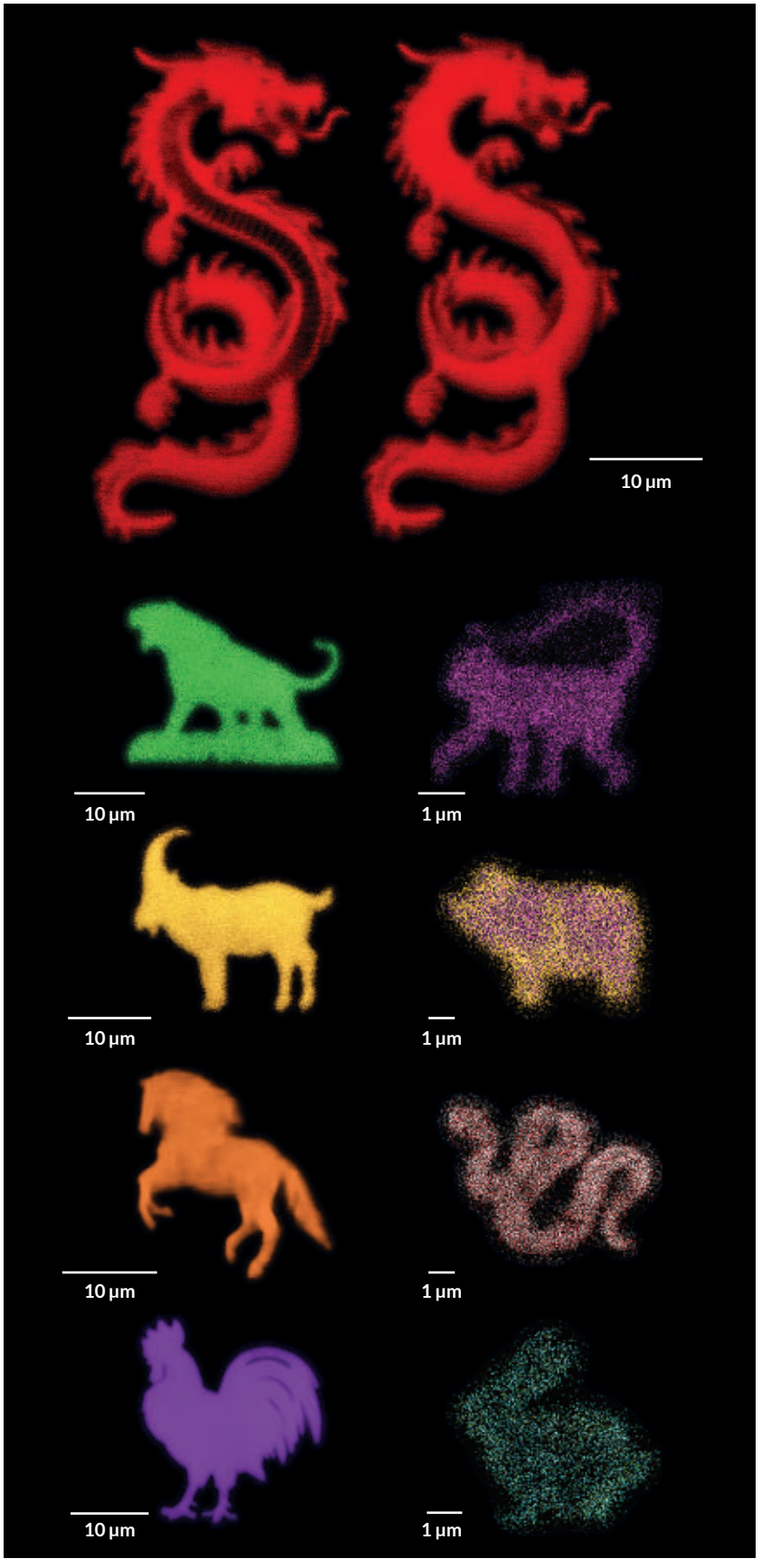
Reader **Helen Leaver** shared her trick to a good night's sleep: "I learned that I was having strong unpleasant adventures while sleeping, and I would awaken hot and sweaty. By eliminating the amount of heat from bedding and an electrically heated mattress pad, I now sleep well without those nightmares."

Pest perspectives

*In "Why do we hate pests?" (SN: 12/3/22, p. 26), **Deborah Balthazar** interviewed former* Science News Explores *staff writer Bethany Brookshire about her new book,* Pests. *The book argues that humans — influenced by culture, class, colonization and much more — create animal villains.*

The article prompted reader **Doug Clapp** to reflect on what he considers pests or weeds. "A weed is a plant in the wrong place, and a pest is an animal in the wrong place," **Clapp** wrote. But what's considered "wrong" depends on the humans who have power over the place, he noted. "Grass in a lawn can be a fine thing. Grass in a garden choking the vegetables I'm trying to grow becomes a weed. Mice in the wild don't bother me. Field mice migrating into my house when the weather cools become a pest, especially when they eat into my food and leave feces behind," **Clapp** wrote.

The article encouraged **Clapp** to look at pests through a societal lens: "I had never thought of pests in terms of high-class or low-class. Likewise, the residual implications of [colonization]. Thanks for provoking me to consider some of these issues in a broader context."



A 'Shrinky Dinks' take on nanoengineering

High-tech shrink art could be the key to making tiny electronics, 3-D nanostructures or even secret-message holograms. A new approach to making tiny structures relies on shrinking them after building them, rather than making them small to begin with, biological scientist Yongxin Zhao and colleagues report in the Dec. 23 *Science*.

The secret is spongelike hydrogels that expand or contract in response to surrounding chemicals (SN: 2/13/10, p. 5). By inscribing patterns in the hydrogels with a laser and then shrinking the gels to about one-thirteenth their original size, the researchers created designs with details as small as 25 nanometers across. At that level of precision, the team could create letters small enough to write this article along the circumference of a typical human hair.

To showcase the technology, the team fabricated a zoo of Chinese zodiac animals (some shown at left in false color). The red dragons (top) demonstrate the precision of the laser-etching before shrinking: Each of the stripes on the left dragon's belly is just 200 nanometers thick. A not-yet-shrunken graphene tiger, goat made of gold, polystyrene horse and rooster made of fluorescent dye (all far left) exhibit some of the materials the researchers could deposit. At near left are some of the final products: a silver monkey, a gold-silver-alloy pig, a titanium dioxide snake and an iron oxide rabbit. These animals went through the whole process—etching, shrinking and depositing—before ending up roughly the size of a red blood cell.

The researchers also created holograms within a hydrogel to encode secret information. Shrinking a hydrogel hologram makes it unreadable. "If you want to read it, you have to expand the sample" to its original size, says Zhao, of Carnegie Mellon University in Pittsburgh. Knowing how much to expand it is like a key to unlock the information inside.

But the most exciting aspect of the research, Zhao says, is the range of materials that researchers can use. "We will be able to combine different types of materials together and make truly functional nanodevices." —*James R. Riordon*

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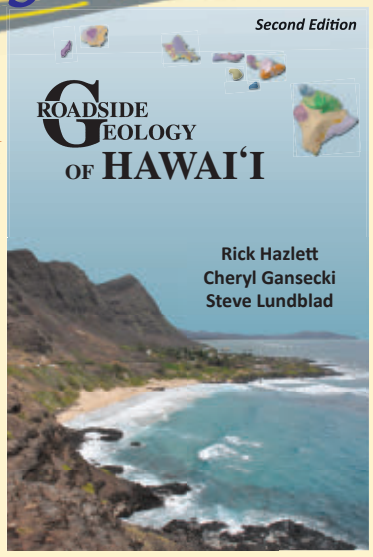

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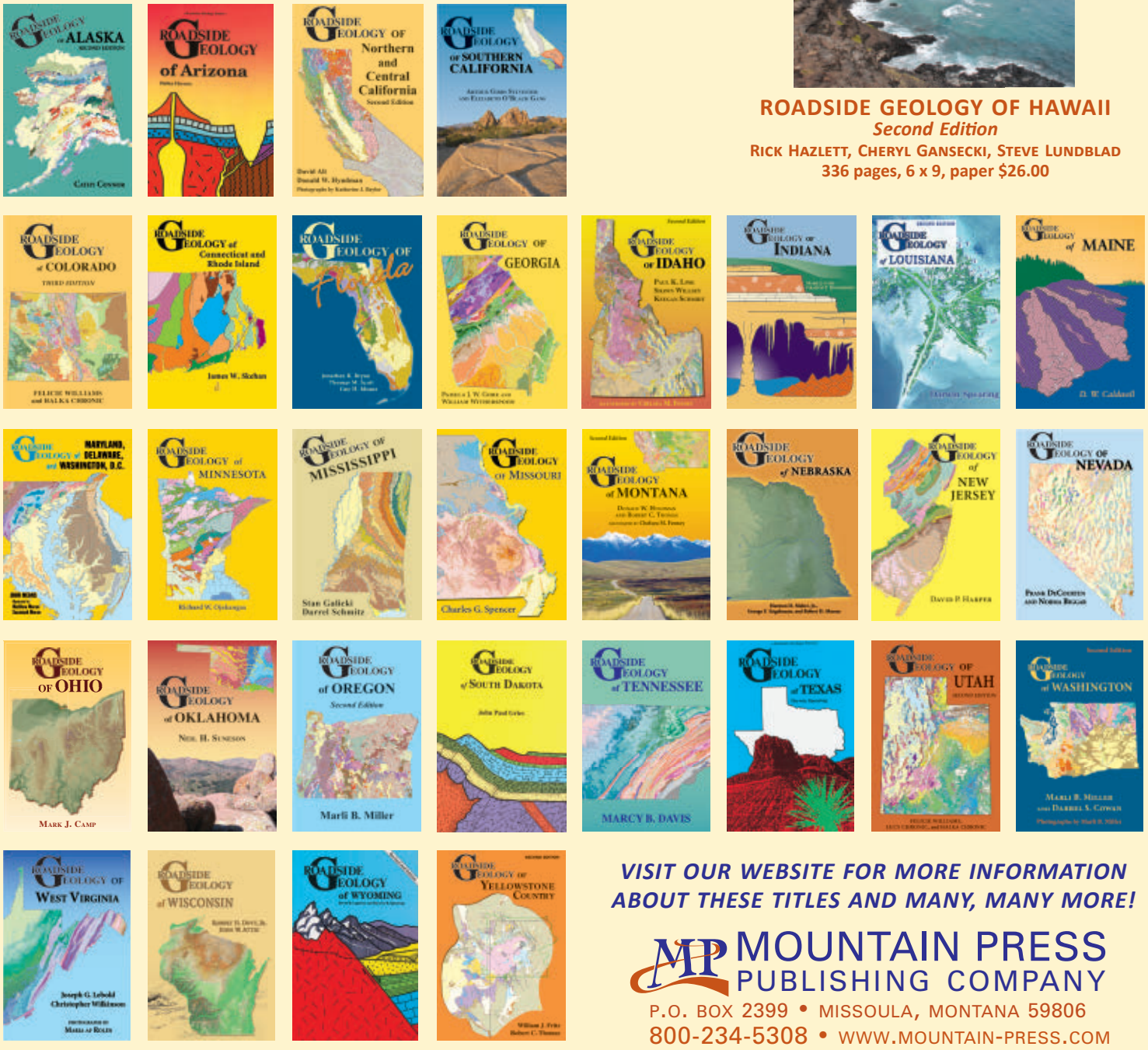

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