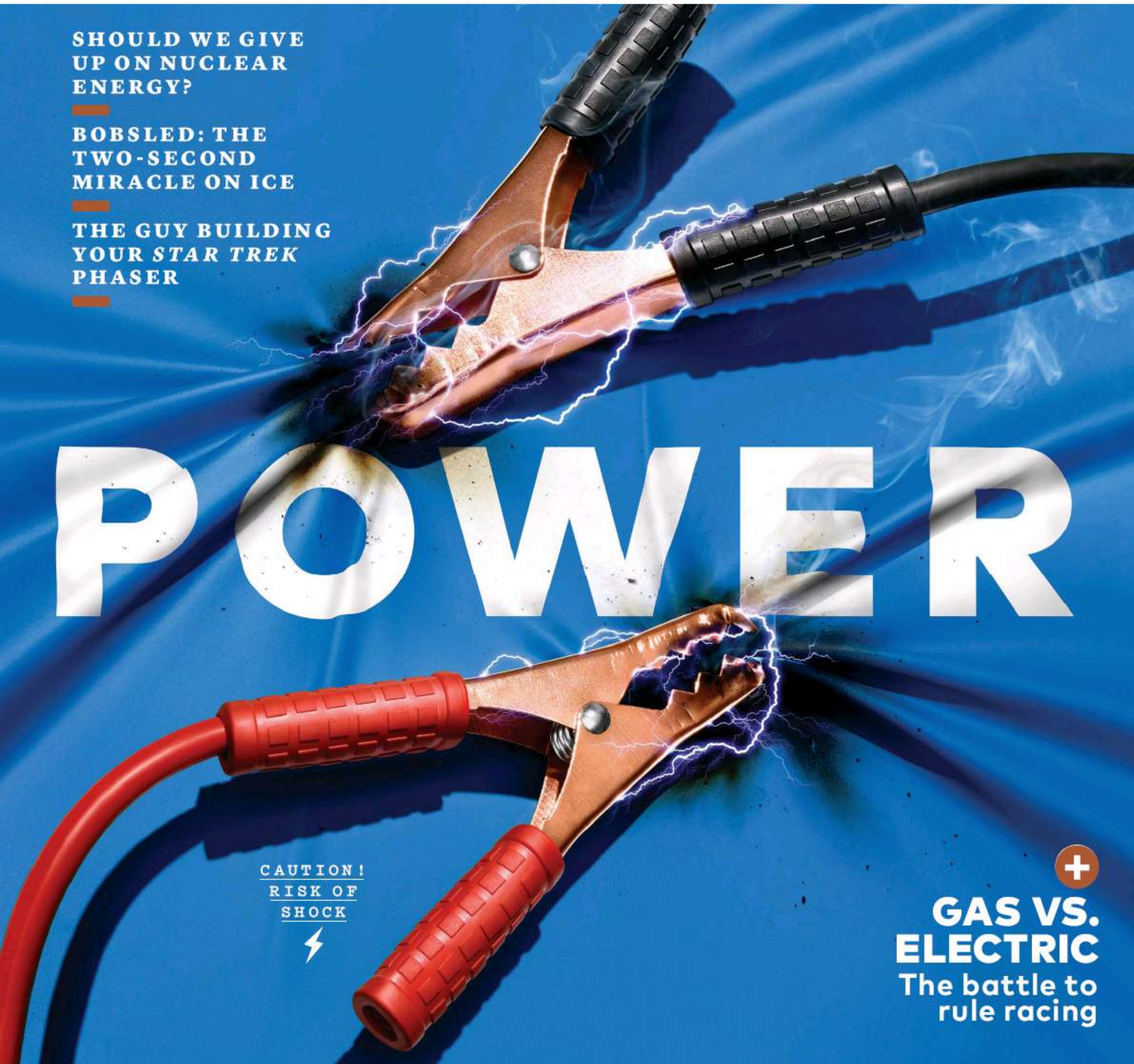
SOLAR PANELS/SOLAR FLARES/PREDATORS/SALESMEN?

POPULAR SCIENCE

January/
February
2018



SHOULD WE GIVE UP ON NUCLEAR ENERGY?

BOBSLED: THE TWO-SECOND MIRACLE ON ICE

THE GUY BUILDING YOUR *STAR TREK* PHASER

+

GAS VS. ELECTRIC

The battle to rule racing

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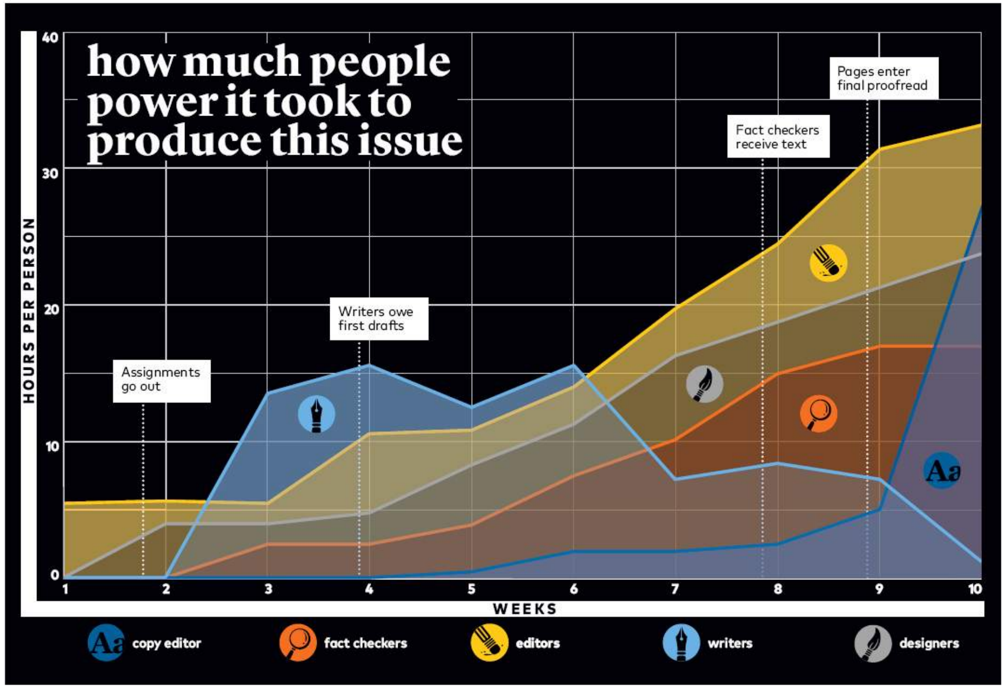

cover photograph by The Voorhes / infographic by Sara Chodosh

THE POWER ISSUE

THE MANY AXES OF POWER

A READER NAMED JOHN just emailed me about *PopSci*'s November/December issue. He liked that it let him "match up the innovations and breakthroughs in science to what we know and use in our daily life." That got me thinking about the breadth of our next edition: the Power Issue. (Thanks, John! You just influenced a 146-year-old magazine.)

Power can come in many forms. It's strength, force, and energy—the ability to move machines as massive as aircraft carriers and as humble as our own bodies. It's in the wind turbines, Formula One engines, and nuclear plants you'll soon read about.

But power is also the ability to move minds. John, through the innovations of the internet and email, was able to guide my thinking on *Popular Science*, a publication that reaches millions. The physical particles required to store an email's data weigh just two ten-thousandths of a quadrillionth of an ounce, but these minuscule missives can sway editor's letters, influence elections, and inspire political movements.

As John wrote me that message, millions of survivors of sexual harassment and assault ignited a conversation about equality by writing and sharing social-media posts adorned with two suddenly powerful words: #metoo.

If feels absurd to compare a tweet to a jet engine. Yet I'd pit that digital chorus of voices against any rocket or bicep or thermonuclear reactor in its potential to radically shift the status quo.

As you read this issue, you'll find stories to love and stories to hate. Don't keep those thoughts to yourself; I read my mail, and I'd love to hear from you. We're a staff of just 21, but *Popular Science* is a community of millions. Maybe helping to shape *PopSci*'s next issue will give you a taste for inciting change—maybe the next email you send will have the power to change the world. Get to it.

illustration by Galya Gubchenko

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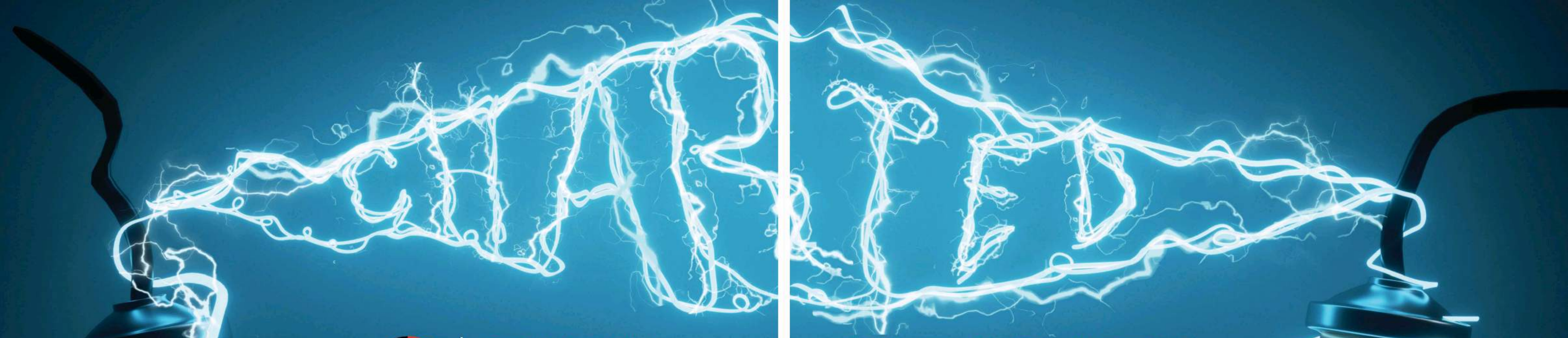


LIGHTS OUT

hack the grid

LAST SEPTEMBER, NEWS BROKE that hackers had laid siege to the U.S. power grid, probing deep into dozens of energy firms, looking for weaknesses to exploit. The Department of Homeland Security issued a threat warning about an ongoing stream of malware attacks that could one day lead to a Black Sky event, crippling cellphones, erasing bank accounts, devastating hospitals, and disrupting every sector of the economy. Girding our grid (some of which dates back to 1917) could cost $500 billion—too pricey for the more than 3,200 private companies that own its hardware. To shore up defenses, the feds are funding small and nimble teams of experts to develop security and detection patches that will (hopefully) protect the system and help it recover should the Black Hats succeed. Here are some of the grid's biggest vulnerabilities—and the efforts to fix them.

by Matt Hongoltz-Hetling / illustration by Sinelab

84 PERCENTAGE OF UTILITIES WHERE NONSPECIALISTS MAKE CYBERSECURITY DECISIONS

The grid's enemies rely on expert hackers to carry out their attacks. Most of the utilities they target lack that same expertise, defending themselves with pencil-pushers rather than professionals. That's because there aren't enough tech-savvy hired guns to go around. To combat this vulnerability, a federal task force is setting up mutual-assistance pacts, allowing one team of cybersaviors to help multiple companies.

215 ESTIMATED MASTER CONTROL CENTERS IN AMERICA

A hacker's ultimate goal is to own a master control center. Within these critical hubs, system operators rely on video-covered walls and button-filled consoles to keep the grid going. If a malignant program breaks through, it could corrupt the data that controllers rely on. So some power companies are creating duplicates. These twin nerve centers trade off grid-control duties and can also access pre-hack backups, allowing workers to replace a virus-infested system with a clean version.

72 hours from attack to society's total downfall

When a Black Sky hits, engineers have three days before food spoils, medicine and water run out, batteries die, and the public loses its collective marbles. Speedy fixes are vital, but that's difficult when the grid plugs thousands of power plants and even more customers into the same infrastructure. Companies like PJM Interconnection, which serves 13 eastern states, administer "organized markets" that help utilities obtain power from each other, making it easier to restore the grid.

21,500 NUMBER OF HIGH-POWER SUBSTATIONS IN THE U.S.

Like your home computer, the one at your local power substation needs regular virus scans and software patches. But it, and other devices embedded in the grid, lack the capacity to keep up with these frequent fixes. Instead of constant updates, Dartmouth College researchers developed a software patch called Autoscopy Jr. It lightly scans vital functions to identify signs, such as unexpected code lengths and timing hiccups, of a compromised system.

Utilities increasingly rely on smart meters: wireless devices that relay data about homes' power usage to companies for monitoring and billing. But like all networked devices, smart meters are vulnerable to cyberattacks. So BAE Systems is developing a way to keep hackers off the network. Protected with heavy encryption and multiple authentication checks, it can secure these devices while utilities shore up the rest of the grid.

1 IN 2 AMERICAN HOMES RELY ON SMART METERS

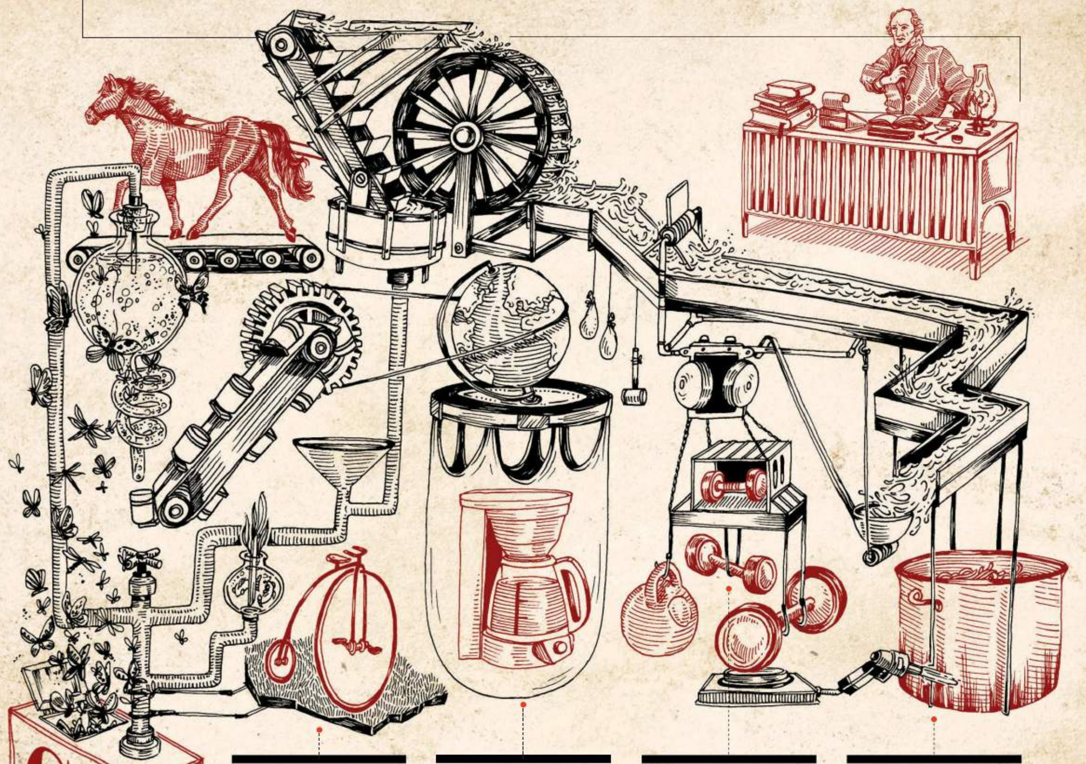
At each substation, older-model computers must continuously balance a three-phase current streaming through its transmission lines. Many of these outdated machines are susceptible to malicious junk code. Rather than replacing them with pricey upgrades, a second Dartmouth project is tapping linguistics theory to write programs in which only grammatically correct input is accepted, keeping hackers from interfering with the wires.

CIRCUIT-MILES OF TRANSMISSION LINES 697,000

NEIGH SAYER

what is a horsepower?

IN 1781, THE STORY GOES, JAMES WATT NEEDED TO CONVINCE skeptics to ditch their draft horses and buy his new steam engine. To prove his machine's superiority, he measured a horse walking in circles to turn a grindstone in a mill. He multiplied the distance it walked by its roughly 180 pounds of pulling force and came up with a new measure: horsepower. (His new engine did the work of 35 nags, about the same as today's riding mower.) We still use his math to sell F-150s, but it can feel kind of abstract. So we came up with a few new ways to visualize one horsepower.



One bicycle burst

In the momentary dash of a flat-out sprint, the average cyclist can eke out a single horsepower. Pro pedalers can generate twice that. Horses, however, have humans beat on staying power; even Tour de France elites can't sustain more than a few tenths of a horsepower over the full length of a race.

One coffee maker

In electrical work, we measure power in watts, a unit named for dear James. A lone watt is tiny—only enough to power an LED night light. That's why we almost always talk in terms of kilowatts, especially on electric bills. Still, 1 horsepower's worth, or 746 watts, is enough to power a standard drip coffee maker.

One enormous deadlift

A foot-pound is the work it takes to lift 1 pound a distance of 1 foot. To exert 33,000 of those, the equivalent of 1 horsepower, an eager equine could drag 10,000 pounds up 3.3 feet, 3.3 pounds up 10,000 feet, or (more realistically) 330 pounds up 100 feet, all in the space of an extremely sweaty minute.

One pasta party

Pull power and heat are two sides of the same coin (a coin made of energy). To convert, you'll have to work with British thermal units. One Btu provides roughly a kitchen match's worth of warmth. A single equine could pound out 2,545 Btu per hour, enough to boil 2.2 gallons of room-temp water, which would cook 14 servings of pasta.

DEFINITIONS

work (*n.*)
THE AMOUNT OF FORCE EXERTED OVER A DISTANCE. UNITS INCLUDE FOOT-POUND, KILOWATT-HOUR, AND BTU.

en·er·gy (*n.*)
THE CAPACITY TO DO WORK. HAS MULTIPLE FORMS, INCLUDING MECHANICAL, THERMAL, AND ELECTRICAL.

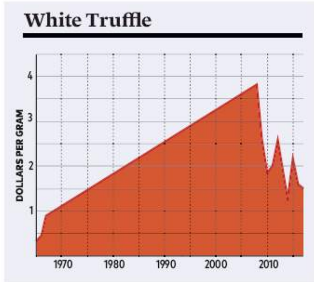
pow·er (*n.*)
THE RATE OF WORK, CALCULATED AS THE AMOUNT OF WORK DONE DIVIDED BY THE TIME IT TOOK TO DO IT.

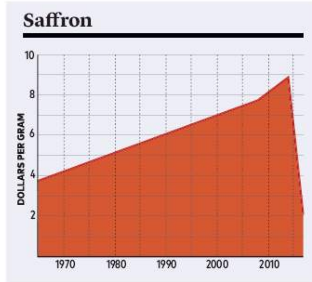
by Sara Chodosh / illustration by Lucy Engelman

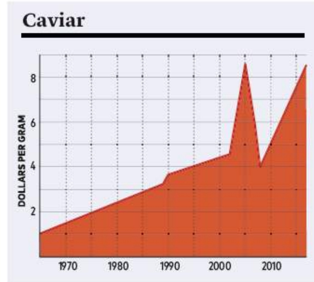
MY PRECIOUS

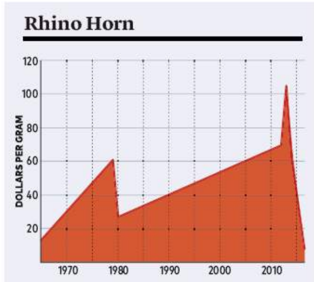
the price of luxury

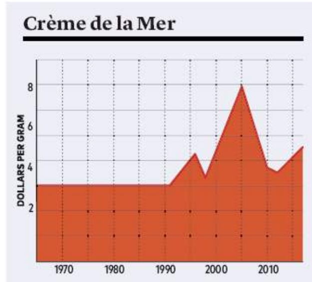
THE SAFFRON WAR OF 1374 LASTED 14 WEEKS, DRIVEN BY A NOTION THAT THE spice could cure plague. It can't. But people lost their heads over it. It's not just gold, diamonds, and oil we cherish and plunder. Seemingly benign commodities—whether it's medicinal tea or stinky fungus—have exerted power over us for centuries. Here's just a taste of their recent history.

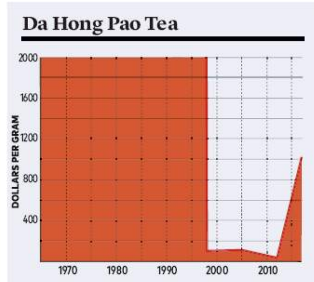








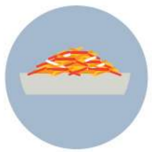




WHITE TRUFFLE

Italy's Tanaro river basin produces prized white truffles. In 2016, excess rains yielded bumper crops and sank wholesale prices 30 percent. New cultivation tactics involving careful irrigation and seed selection from known truffle-producing trees could further devalue the fungus. That is, if they can survive blight.

SAFFRON



The choice between Spanish and Iranian saffron is a matter of opinion. The complexly flavored pistils both come from the laborious harvest of the same tiny purple flowers. Some chefs prefer the Persian variety, but since the La Mancha spice can fetch twice the price, merchants relabel it, which forced the EU to crack down in 2014.

BELUGA CAVIAR

The more we clamor for wild beluga caviar from the Caspian Sea, the more local fishermen will kill sturgeon for their eggs, and the scarcer the fish become—driving up prices. In 1998, the Convention on International Trade in Endangered Species tried to halt this cycle by limiting kill quotas, to fairly limited success.

RHINO HORN

The market for rhino horn, prized in Asia for its mythical medicinal value, peaked around 2012. But widespread education about rhino horn's actual *lack* of medicinal value seems to be lowering prices. PSAs showing celebs like Richard Branson biting their fingernails—made of keratin, like horns—probably helped.

CRÈME DE LA MER

Astrophysicist Max Huber created the Crème in the '60s to heal his rocket burns. Its luxury status intensified in 2005, when Estée Lauder launched a limited-edition version at invitation-only soirées. Champagne and fresh berries, plus the exclusivity, convinced socialites to pay $2,100 for a three-week supply.

DA HONG PAO TEA

This tea is said to have healed a 14th-century Ming emperor's ailing mother. In gratitude, he placed a red robe around the trees, inspiring both the tea's name ("big red robe") and its cult status. The still-high price dropped in the 1980s after cultivators found a way to grow new trees from the Wuyi Mountain originals.

by Ellen Airhart / illustrations by L-Dopa

C / CHARTED

FUEL FOR THOUGHT

what's in your electricity?

LIKE ANY GOOD CONSUMER, YOU'VE FILLED YOUR HOME WITH POWER-THIRSTY screens and toasters. And they make your average American abode chug 30 kilowatt-hours of electricity every single day. (A kilowatt-hour, by the way, is 1,000 watts used over one hour. But you knew that.) Producing your daily juice requires various amounts of gas, coal, oil, wind, solar, water, or nuclear fuel, depending on your energy sources. But what if your home relied on just one of these? Here's how each of them would measure up.

SOLAR PANELS

450 SQ FT

One 300-watt, 18-square-foot solar panel can transform an average day of California sunshine into 1.2 kilowatt-hours. So you'd need to screw about 25 of them onto your Hollywood roof to cover one spin of the globe.

NATURAL GAS

234 CU FT

This stuff burns cleaner and cheaper than coal, and it's plentiful (thanks, fracking), which is why it recently topped all other electricity sources: 34 percent of what we consume. You would need about 41 bathtubs full each day.

WIND

54 SEC

Given a strong, steady wind, a typical turbine can spin out 2 megawatt hours of electricity per hour. Keeping the lights on and the Netflix streaming for a full 24 would take less than a minute. What a breeze.

WATER

24,000 GAL

Pouring a 640-square-foot swimming pool of water through the Hoover Dam's turbines would produce your daily electrical consumption in less than a second. That makes hydro our most productive renewable.

COAL

33 LB

As this dirtiest of fossil fuels loses ground to natural gas, it's used less and less often to generate electricity. To keep the typical home running round-the-clock on coal, you'd have to set two bowling balls' worth ablaze.

ENRICHED URANIUM

0.02 OZ

Nuclear fission packs an insane energy punch. It would take just a tiny amount of uranium—less than a paper clip weighs—to turn water into the steam that spins the turbine that ultimately produces the day's juice.

OIL

3 GAL

This energy-dense fuel drives most of our cars, trucks, and jets. In 2016, however, it accounted for the least portion—1 percent—of residential electricity. A house run on oil would slurp six two-liter soda bottles' worth daily.

POUND BY POUND AND GALLON BY GALLON: HOW MUCH IT TAKES TO POWER YOUR HOME

SOURCES: EIA, ENERGYSAGE, AWEA, USBR

by Rob Verger / illustration by Muti-Folio Art

SPIDEY SENSES

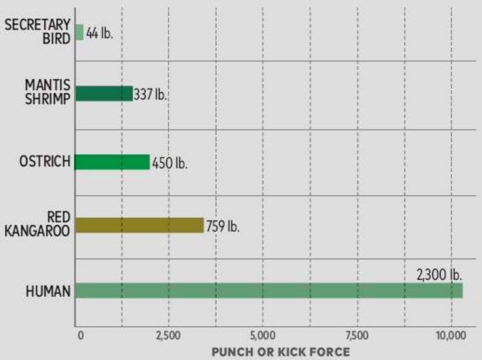
strength, in numbers

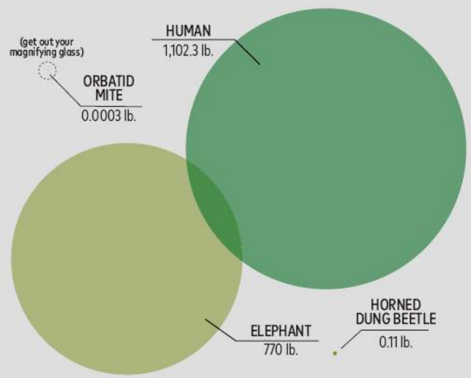
IN A BATTLE ROYALE FOR MOST POWERFUL ANIMAL, A RED KANGAROO MIGHT TAKE the martial-arts belt, thanks to a bone-shattering kick that delivers 759 pounds of force. Evolution has nudged wild creatures to hone their blows, bites, and brute strength for survival. For humans to even measure up, we must methodically shape our bodies with specialized practice and diet. But what if you pit all of us brutes against each other? That's just what we did, creating the following four competitions to find out who puts the "king" in animal kingdom.

80 Degrees a Tasmanian devil can open its jaws to chomp carrion snacks or rivals' faces. This gives its bite a force 3.6 times its weight.

150,000 Muscle units in an Asian elephant's trunk. Its nose has the strength and flexibility to store and spray a gallon of water—or uproot a tree.

15 Duration, in milliseconds, of an African secretary bird's cobra-killing kick. In sub-Saharan regions, these predators help control reptile populations.



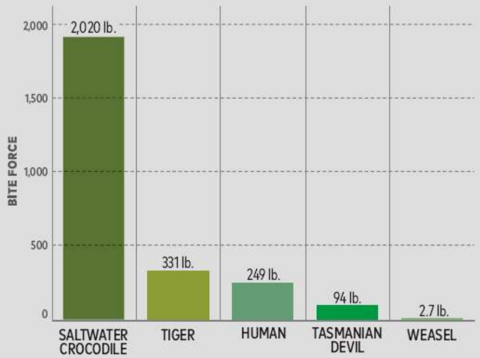


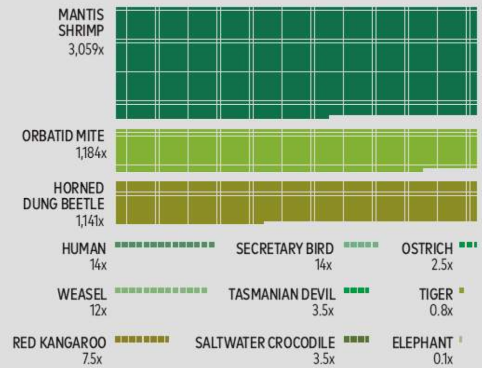
▸PUNCHES AND KICKS

In the ring, a taekwondo master with a black belt—and a 136-mile-per-hour kick that hits opponents with 2,300 pounds of force—could go toe to paw with a kangaroo. But the average human gym rat, who lacks the training to focus his kick, would be McGregored in round one.

▸LIFTING

In 2016, English strongman Eddie Hall set the current world record for a dead lift by hoisting 1,102.3 pounds, more than the weight of a concert grand piano. Asian elephants, by comparison, can shift 770 pounds with their trunks alone. Not bad, humans.





▸BITE

If the saltwater crocodile's horrific bite doesn't snap a wild boar's spinal cord, its underwater death spin will surely take it down. With a literal ton of brute force in its jaw, a croc easily out-crunches its closest competitor, the tiger, with a bite six times as strong.

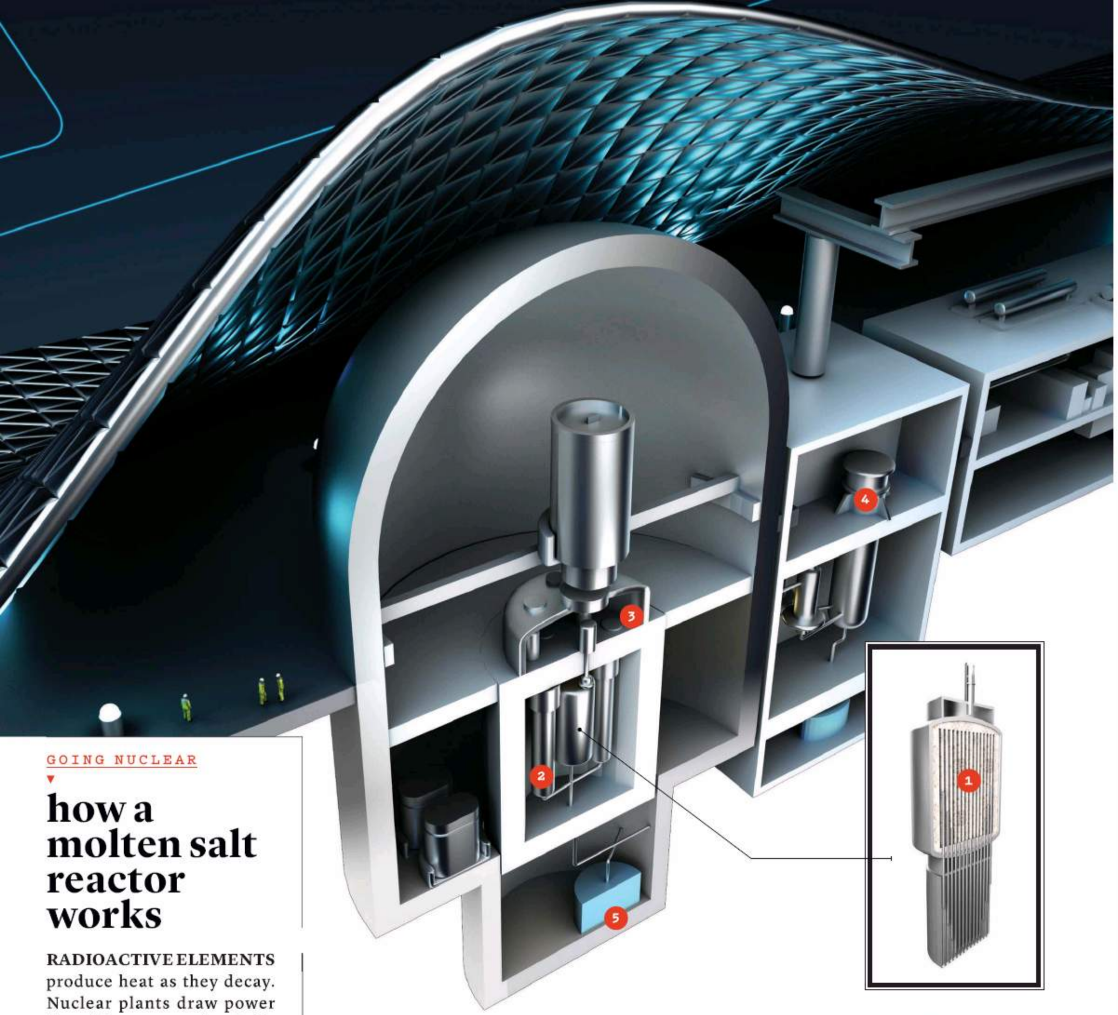
▸STRENGTH-TO-WEIGHT RATIO

Because big animals weigh more, they're relatively weak for their size. So tiny critters carry this category: A mantis shrimp's punch delivers more than 3,000 times its weight, and a mite shorter than a tenth of an inch can bench-press nearly 1,200 of its fellows.

by Sara Chodosh / illustration by Sean McCabe

GOING NUCLEAR

how a molten salt reactor works



RADIOACTIVE ELEMENTS produce heat as they decay. Nuclear plants draw power from this process, and typically stabilize the temperature with water. But during a power outage, H_2O—which needs pumps to flow—can't always prevent meltdowns. Molten salt reactors, which instead control heat with melted lithium and potassium fluorides, have a fail-safe: If the electricity dies, a plug will melt, causing the salts to seep down a safety drain and solidify around the uranium, preventing overheating. After a decades-long lull in development, countries from China to Denmark are building new molten salt reactors. Here's how they work.

1

Reactor vessel
Uranium floats in a stabilizing bath of melted fluoride salts inside this container. As the radioactive atoms split apart, their fission steadily heats the vessel to 1,300 degrees Fahrenheit, the approximate temperature of magma.

2

Primary heat exchangers
Tubes on either side of the reactor vessel transfer the heat to intermediate pipes, which are filled with clean molten salts. The uncontaminated substance can carry energy without producing any additional radioactive waste.

3

Coolant salt pumps
These pumps move the clean salts in the heat exchangers away from the radioactive reactor vessel and toward a steam generator housed in a separate building. This limits the hazardous material to a single, isolated location.

4

Steam generator
The searing salts heat water into steam, which spins a turbine to produce electricity. In one hour, a molten salt reactor may be able to crank out 500,000 kilowatts, enough to power 45 U.S. households for an entire year.

5

Drain tank
Contaminated reactor salts and radioactive gases filter into a waste-disposal system. These materials remain hazardous for only hundreds of years—compared with hundreds of thousands for traditional reactors' byproducts.

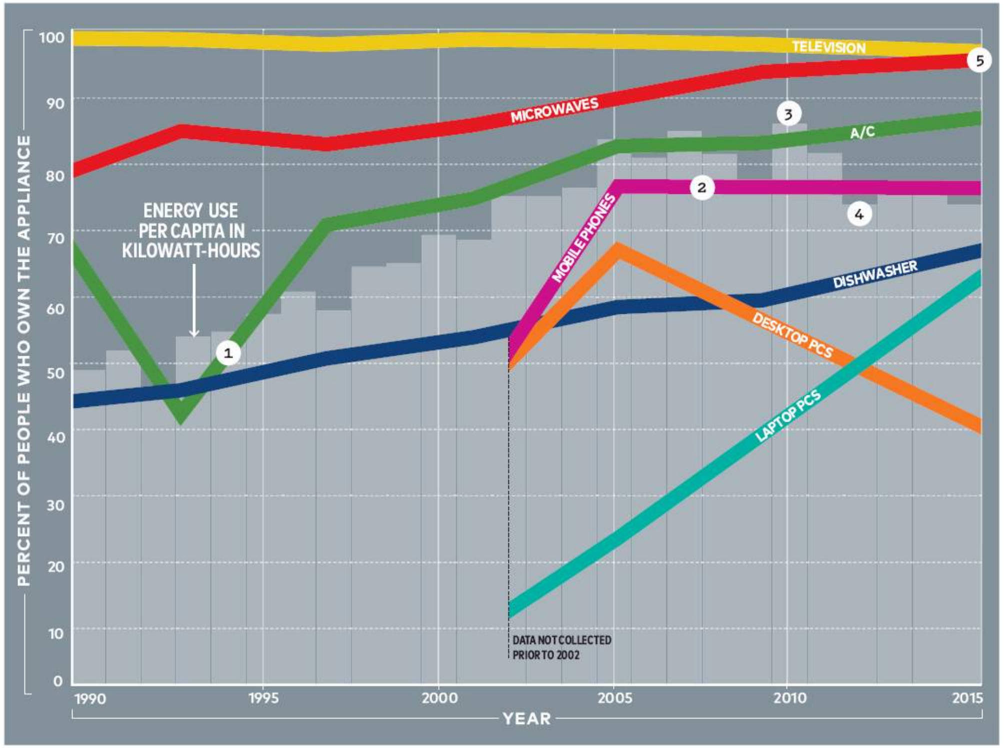
by Ellen Airhart / illustration by Sinelab

CHARTED

POWERING DOWN

more appliances, less energy

FROM BLARING ALARM CLOCKS TO LATE-NIGHT NETFLIX BINGES, THE average American uses 12 kilowatt-hours of energy around the house every day. That's a lot of wattage—enough to drive a Nissan Leaf across Rhode Island—but it's also our lowest personal-consumption rate since the start of the century. Although we're more addicted to gadgets than ever, these appliances are growing so efficient that per capita power hunger dropped 7 percent between 2010 and 2016, in spite of our growing doodad collections.



01

Intelligent HVAC
Indoor climate control is the largest energy suck, guzzling almost half a home's power. Federal standards, set between 1992 and 2015, spurred innovations like programmable thermostats and efficient AC units.

02

Phones for everything
Smartphones draw a mere 10-ish watt-hours of electricity per charge. Swapping them in can offset power-hungry desktops and televisions, which can guzzle 10 times as much juice per hour.

03

A need for heat
A cold winter in 2010 contributed to an all-time high in power demand in Southern states, where heating is largely electric. Folks used to 60-degree weather tried to stay warm as temps fell into the 20s.

04

Low-energy lighting
Starting in 2012, the Energy Independence and Security Act required that bulbs cut energy consumption by at least 25 percent. CFLs and LEDs slash usage by up to 80 percent for each of the 40 bulbs in a typical home.

05

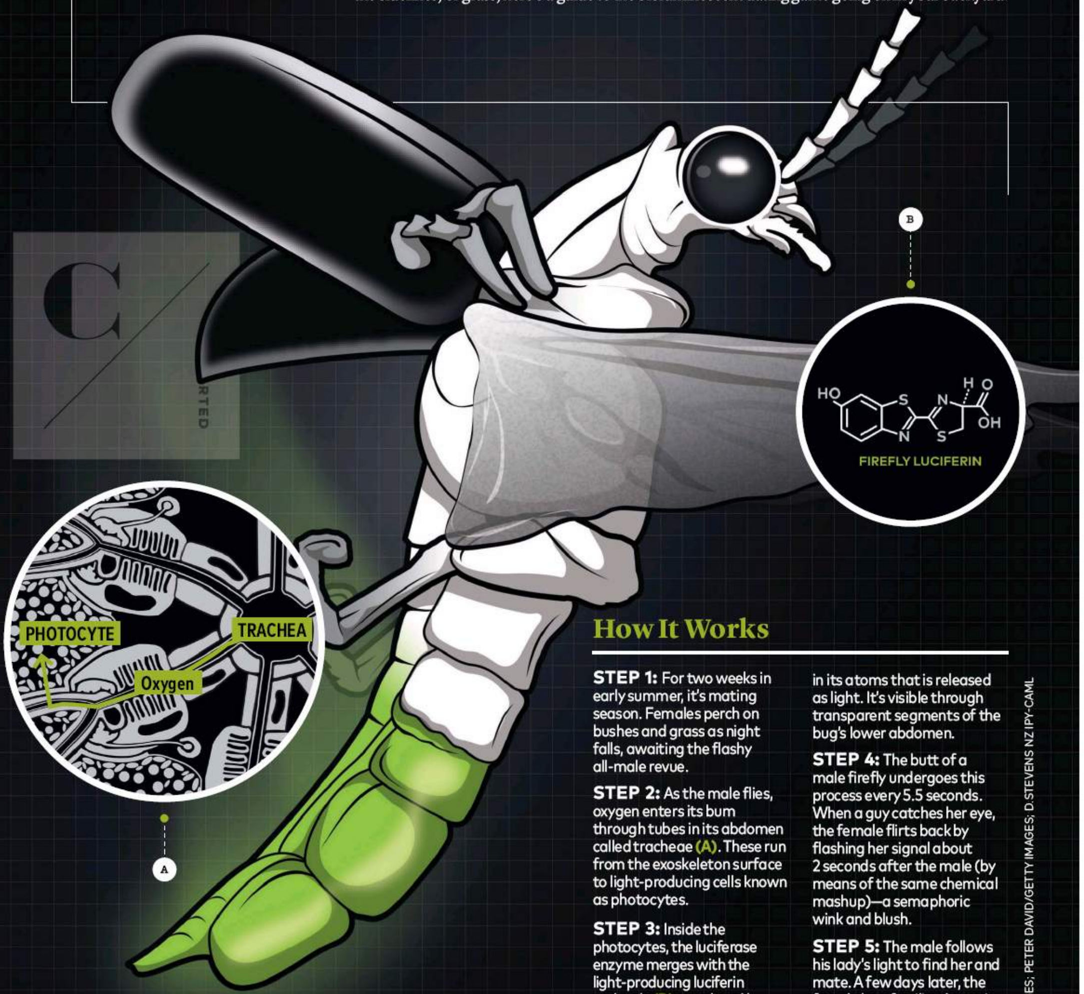
Nukin' it
Nearly 30 percent of all meals cooked in 2016 involved a microwave, which, in some cases, can save a lot of power: Reheating leftovers in the appliance uses 80 percent less energy than in an oven.

by Aparna Nathan / illustration by Sara Chodosh

ELECTRIC BOOGALOO

light a fire

FIREFLIES ARE BUTT GALS. SO ARE THEIR MALE *AMORI*. ON WARM SUMMER nights, both sexes home in on the blinking light of their crush's derrière. The rest is romance. Which makes it almost heartless for us to ask: What makes their bums blink? It's mostly a matter of chemistry, triggered by seasons, times of day, and those flashing signals. For *Photinus pyralis*, the common eastern firefly that populates North America, it is a choreographed dance. Next time you're sitting on the sidelines, or grass, here's a guide to the bioluminescent dating game going on in your backyard.



How It Works

STEP 1: For two weeks in early summer, it's mating season. Females perch on bushes and grass as night falls, awaiting the flashy all-male revue.

STEP 2: As the male flies, oxygen enters its bum through tubes in its abdomen called tracheae **(A)**. These run from the exoskeleton surface to light-producing cells known as photocytes.

STEP 3: Inside the photocytes, the luciferase enzyme merges with the light-producing luciferin molecule **(B)**, catalyzed by oxygen and energy-storing ATP. The result: oxyluciferin, a compound with excess energy in its atoms that is released as light. It's visible through transparent segments of the bug's lower abdomen.

STEP 4: The butt of a male firefly undergoes this process every 5.5 seconds. When a guy catches her eye, the female flirts back by flashing her signal about 2 seconds after the male (by means of the same chemical mashup)—a semaphoric wink and blush.

STEP 5: The male follows his lady's light to find her and mate. A few days later, the female lays fertilized eggs in the ground, which hatch two to four weeks later—all thanks to a magical light show.

FIREFLIES AREN'T THE ONLY MEMBERS OF THE ANIMAL KINGDOM THAT GLOW

GAUSSIA PRINCEPS These small crustaceans jet out bioluminescent liquid to confuse predators and make a hasty escape.

LOPHIIFORMES The anglerfish's fleshy-tipped "rod" full of bioluminescent bacteria lights up to lure smaller fish into its jaws.

GALITEUTHIS GLACIALIS Glowing patches below these squids' eyes cancel out its shadow so predators below can't detect them.

LEFT TO RIGHT: NIGEL CATLIN/GETTY IMAGES; PETER DAVID/GETTY IMAGES; D. STEVENS NZ IPY-CAML

by Nicole Wetsman / illustrations by Pete Sucheski and John Kuehn

DYNAMITE WITH A LASER BEAM

LASERS CAN MAP PLANETS, CUT METAL, PLAY YOUR old CDs, zap tattoos, and send cats into furry frenzies of clickbait. But Robert Afzal, who leads Lockheed Martin's advanced laser systems program, wants them to do more. He wants them to shoot stuff. Really big stuff. From the time scientists figured out in the 1960s that they could wield these intense beams of light as tools, the U.S. military has wanted one that can blast enemy missiles from the sky or fry a hole in a battle tank. "It's 2018, and everyone's wondering why we don't have this technology yet," Afzal says.

Thanks to him and his team, we now do. Early last year, they delivered the most powerful laser weapon on the planet to the U.S. Army. It is a 60-kilowatt-class blaster whose targeting dome, laser generator, and power and control hardware can be mounted on a truck and sent into battle.

So why did it take so long? Because it's really difficult. Ever since researchers began pondering the real-world potential of these science-fiction staples, three things have stymied them: the need for huge solid-state batteries or big tubs of chemicals to operate the lasers, assembly dimensions more comparable to 747s than nimble battlefield vehicles, and the thorny problem of light diffusion—the beam's ability to retain its intensity between source and target.

"Beam quality is a great challenge," Afzal says. "If you don't have good quality, it's like a Hollywood spotlight—very bright, but you don't blow anything up."

Before training his laser focus on blasting stuff, Afzal aimed it at a far more pacific pursuit: interplanetary exploration. He spent much of his career, from 1992 to 2001, at NASA's Goddard Space Flight Center, where he led the development and integration of lasers into space probes, such as the Mars Global Surveyor. In 2008, Lockheed acquired Afzal's then-employer, Aculight Corporation, and Afzal began applying his know-how toward Lockheed's weapons program.

"IF YOU DON'T HAVE GOOD BEAM QUALITY, IT'S LIKE A HOLLYWOOD SPOTLIGHT—VERY BRIGHT, BUT YOU DON'T BLOW ANYTHING UP."

From the start, the challenge in weaponizing light was jacking up the laser's horsepower to levels that could melt metal at a meaningful distance—going from, say, the 1,000 watts you'd find in an industrial cutting tool to between 30 kilowatts and 100 kilowatts or more for a weapons-grade model. Chemical lasers could achieve such performance, but they required unwieldy mixtures to generate the beam. While electrically powered solid-state lasers didn't have that drawback, they also didn't have the power—initially. Afzal found inspiration in the telecommunications industry.

Engineers there had realized that fiber-optic cables, which are great for transmitting data via lasers, could also boost the light beam's energy. Going further, Afzal found that by bundling multiple fiber-optic-enhanced lasers, he could generate enough juice—with high-enough beam quality—to toast enemy hardware from as far as a mile away. Thus was born the "beam combined fiber laser," a scalable system that laser engineers can dial in to produce a variety of powers.

Because the laser is electric, it's efficient. It has an unlimited magazine, and its capabilities will only improve as researchers are able to squeeze more from systems across the spectrum. So, in theory, it might someday lead to sci-fi's elusive Holy Grail: the handheld laser blaster. On that, Afzal is understandably cagey but still optimistic. "As systems get smaller and more efficient, and battery technology gets better, one would expect you could one day have a handheld system," he allows.

Yes, a phaser! It's coming!

by Eric Adams / photograph by Patrick Kehoe

GOODS

ATTACK SNACK

FEAR THE REAPER

PROP STYLING BY SARAH GUIDO LAAKSO FOR HALLEY RESOURCES

TEXAS TORTILLA-CHIP PURVEYOR Paqui has a decade-long reputation for making snacks that singe the tongues of even die-hard pepperheads. The devilish coating on the Carolina Reaper Madness tortilla chip combines the dust of three different chilies to make the world's hottest chip. Chipotle imparts a relatively pleasant smoky flavor but has only enough capsaicin—the compound that triggers our mouths' heat receptors—to reach 8,000 on the Scoville heat scale. That's about as hot as a jalapeño. Ghost pepper powder cranks the Scoville intensity to 1 million. The real pain comes from the Carolina Reaper, the current hot-pepper champ. At roughly 2 million Scovilles, it's about as scorching as the NYPD's pepper spray. That explains why Paqui sells the chips one at a time. A single crunch causes enough pain to leave your tongue and tummy tingling for hours—even after an ice cream chaser.

2.2 Million
SCOVILLE HEAT INDEX

The hottest Carolina Reaper tested currently holds the official world record.

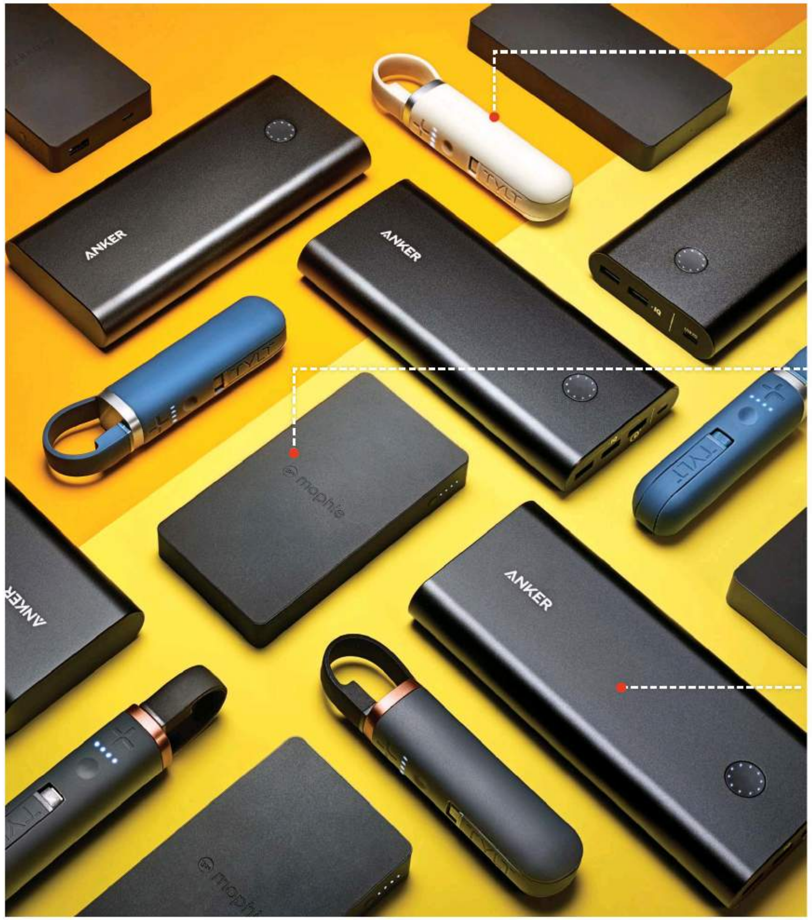
by Kendra Pierre-Louis / photographs by Sam Kaplan

GOODS

CALL FOR BACKUP

JUICE BOXES

PICTURE THIS: A YOUTUBE TUTORIAL ON CHANGING a flat tire suddenly goes black just before you get to the part about how to put on the spare. "No! No! No!" you silently shout to yourself, while cursing your utter lack of life skills. Your phone is dead; its 3,000 mAh battery—average for a smartphone—lasts only 12 hours of heavy use per charge on its own, but you can carry 100, 300, or 900 percent more time anywhere you go. Portable lithium-ion power packs will revive your handset in an emergency, or when you're just trying to watch *Wonder Woman* (yes, again) on a long flight.



1X battery power

The 5-inch **Tylt Flipstick** packs a 3,350 mAh battery that can completely refresh your smartphone via a 3-inch, integrated charging cable.

3X battery power

The half-pound **Mophie Charge Force Powerstation** sports a USB port and built-in wireless charging to dish out juice from its 10,000 mAh battery.

9X battery power

Three built-in USB slots and a USB-C port allow the 26,800 mAh **Anker PowerCore+** to charge up to three devices at once—including a laptop.

LAST HOPE

The **EcoXGear EcoBoost** draws power from a replaceable, 3-volt alkaline battery, so it can sit idle in an emergency kit for up to a decade before it dies. A built-in Lightning, micro USB, or USB-C connection transfers enough juice for up to four hours of smartphone usage. Call for help, then ponder life while watching *The Good Place.*

PROP STYLING BY SARAH GUIDO-LAAKSO FOR HALLEY RESOURCES; COURTESY ECOXGEAR

by Jason Lederman / photograph by Sam Kaplan

UNPOWERED TOOLS

MANUAL OVERRIDE

ON ITS OWN, THE HUMAN BODY STANDS ZERO CHANCE against concrete or lumber. Armed with a sturdy tool, though, we can smash foundations and tear down walls. But don't be hasty: Picking the wrong implement will supercharge your frustration. Wielding the right one, however, will amplify the power in your physique. These three are ideal choices for grunt-inducing jobs. Best of all, they don't need plugs or batteries—just muscles.

KNOCK DOWN A WALL
The claw at one end of the **Stanley FatMax FuBar Utility Bar** is sized to grasp the boards common in wall frames. And the beveled slot at the other makes pulling stubborn nails out of old planks easy, thanks to the leverage you can put on the 30-inch shaft.

CRUSH A FOUNDATION
The wedge-shaped side of the 8-pound **Fiskars IsoCore Sledgehammer** concentrates force onto a small area, ideal for breaking hard materials like asphalt. The rounded side of the steel head is perfect for busting up wood without sending shrapnel flying everywhere.

SPLIT WOOD
If Paul Bunyan were real, he'd want the 36-inch **Power Splitting Axe.** Gerber coated the stainless-steel head with a Teflon-like layer to help it slice through logs without getting stuck. The glass-filled nylon handle won't snap if you miss and knock it, but not the blade, into the wood.

by Stan Horaczek / photograph by Sam Kaplan

ELECTRIC DOPING

PEDAL PUSHERS

STANDING ON YOUR PEDALS AND HUFFING and puffing up a hill is totally unnecessary in the lithium-ion era. E-bikes—basically standard two-wheelers with motors and batteries squirreled away in their frames—put a little wind at your back. Torque sensors near the pedals signal the motors to kick in when you're pedaling, helping you boost your cruising speed up to 28 miles per hour. If the juice in the battery dries up, you can ride on using leg power, just like a regular bike. While e-bikes are a blast to ride, not every model is built for every terrain. Pedal-assisted mountain bikes are major overkill for commuting, and a casual beach cruiser isn't very useful on a rocky, rooty trail through the woods. This selection of souped-up whips can tackle any terrain—from urban jungle to actual jungle.

PROP STYLING BY SARAH GUIDO-LAAKSO FOR HALLEY RESOURCES

1 For cruising

Most e-bike motors mount near the pedals or rear wheel, but the **Faraday Cortland**'s is in the front, an arrangement that helps distribute weight. The sloped top tube stays out of the way when throwing your leg over, and the lithium-ion battery lasts about 25 miles per charge.

2 For going anywhere

The **Giant ToughRoad GX E+** hasn't met a street it can't handle. Its knobby tires grip dirt and gravel roads, while powerful hydraulic disc brakes stop you even in the rain. The frame allows for a comfortable, upright riding position, but the road-style drop handlebars let you duck down for sprints.

3 For the trail

Its 5.3 inches of suspension travel in the rear and 6 inches in front give the **Specialized Turbo Levo FSR Expert Carbon** a smooth ride over rocks and roots. The motor will save your legs while summiting hills, and then you can bomb back down. The carbon-fiber frame is stiff for responsive handling.

4 For commuting

The **Raleigh Electric Redux iE** will get you to work clean and dry. Its motor aids acceleration without soaking you in sweat, while fenders safeguard your duds from road splatter. Fat 27.5-inch wheels and mountain-bike-size tires make this steed stable and comfy on even on potholed pavement.

Power meter

E-bikes track how hard you pedal so they can know how much of an assist you need. Serious cyclists obsess over their power output for a different reason: tracking their training. The **Shimano Dura-Ace** crankset—the part of the bike that transfers your pedal power to the chain—has two sensors that measure the wattage your legs churn out as you push your feet round and round. The meter sends the info to your bike's computer or a smartphone, via Bluetooth.

GOODS

by Rob Verger / photograph by Sam Kaplan

FINE WINDS

WHAT MAKES THEM TICK?

THE APPLE WATCH IS THE MOST POPULAR TIMEPIECE IN the world, but not everybody wants to check email on their wrist or remember to plug in their chronometer every night to charge. For those folks, these elegant, accurate wearables use clever, time-proven energy sources to run their movements and keep ticking for years.

Sun power
The Seiko Prospex is a self-sufficient timepiece. A solar cell under the dial constantly tops off its built-in battery, which stores enough charge to last six months in the dark. The watch also sets itself to the correct time by receiving radio signals from cesium atomic clocks around the world that gain or lose roughly one second every hundred thousand years.

Motion power
Your wrist moves as you walk, type, or play Xbox. That jostling spins a circular rotor inside the Swatch Sistem51, winding a spring. As it uncoils, the coil whirls the movement inside the watch. Similar timepieces have more than 100 parts and prices beyond four figures, making this timepiece's 51-piece innards and $150 sticker a lovely rarity.

Finger power
Instead of twirling a fidget spinner, rotate the crown of the Hamilton Khaki Field Officer. Like an automatic watch, this mechanical timepiece has a spring as its engine; unlike one, it relies on you for winding. Roughly 30 seconds of twisting each day is more than enough to keep the hands continuously circling the 1.5-inch face.

GOODS

PROP STYLING BY SARAH GUIDO-LAAKSO FOR HALLEY RESOURCES

by Rob Verger / photograph by Sam Kaplan

POWERLIFTING 101

CARRY THAT WEIGHT

NO SPORT IS SO PURELY FOCUSED ON RAW HUMAN STRENGTH as powerlifting. But hoisting hundreds of pounds isn't something a body was naturally meant to do—at least not without the right training and equipment. Pros and amateurs alike rely on carefully tuned setups to ensure they don't pull any muscles. Here's the gear you need to get buff the right way.

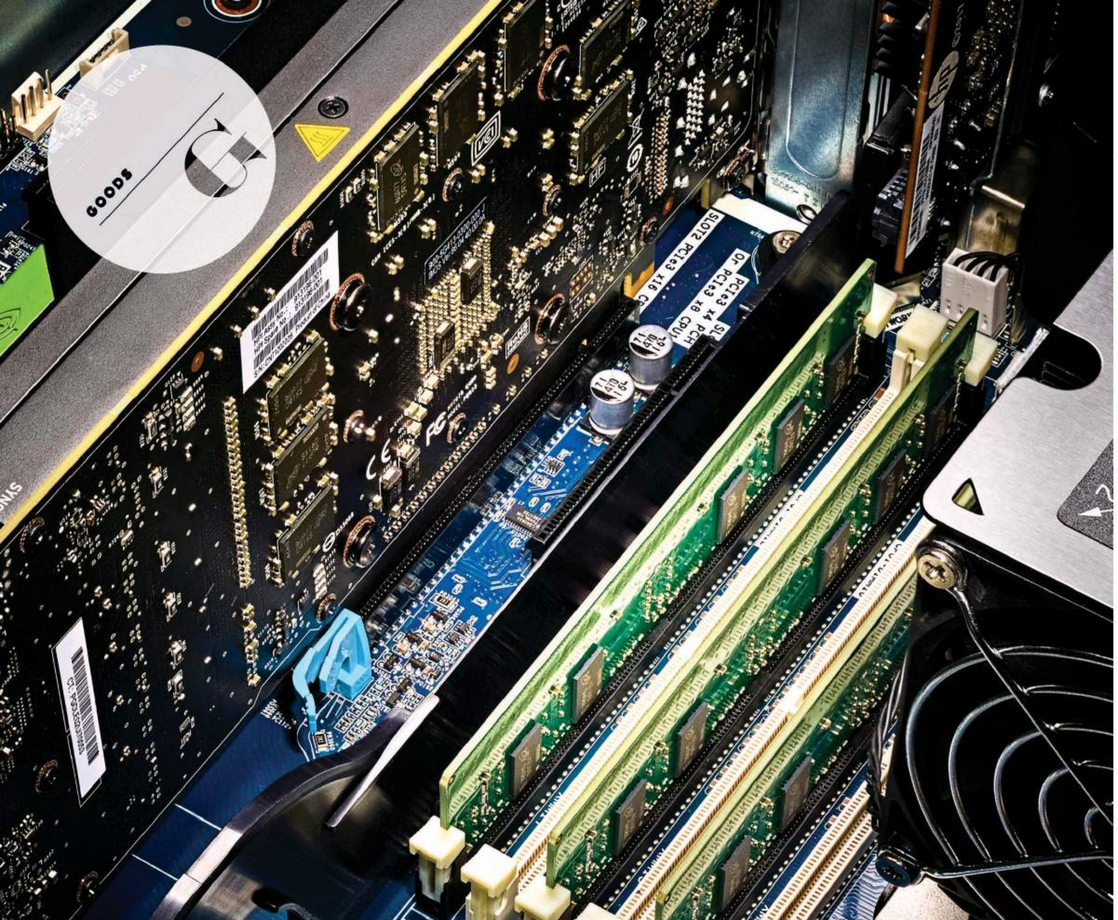
1
Grab a bar
On its own, the 44-pound steel **Ohio Bar** is the right weight for beginners to start pressing. But with a tensile strength of 190,000 pounds per square inch, it can hold enough heft to make the Hulk's pecs quiver. Diamond-shaped knurling—a texture common on weightlifting equipment—helps your hands keep their grip, as does a gritty polymer-ceramic coating.

2
Preserve your joints
Compared with your big bones and muscles, knees are fragile pockets of ligaments and cartilage that need protection during heavy lifts. Quarter-inch-thick synthetic rubber **Rehband RX 7mm Knee Sleeves** put pressure on the joints, increasing blood flow and stability. The curvy seams match the contour of your leg so the material won't bunch up and chafe when you bend.

3
Wear high heels
A squat starts from a standing position with the weight across your shoulders—then you drop your butt below your knees, and rise back up. But executing that move, with your ankles angled just so, is tough. The sturdy plastic in the rear of the **Reebok Legacy Lifter's** midsole jacks your heels three-quarters of an inch off the mat, the perfect amount to keep stable footing.

4
Protect your plates
Rusty weights give you cred with the Instagram pumping crowd, but it's better to provide the steel with some protection. The cast-iron **American Barbell Sport Bumper Plates** make for safer lifts because they come wrapped in rubber that both softens the crash if you drop 'em on the floor (even from overhead) and stops them from bouncing around the gym too.

by Stan Horaczek / photograph by Sam Kaplan



RENDERING PLANT

ALL THAT AND A BOX OF CHIPS

THE HP Z8 G4 IS ABOUT THE SIZE OF A CARRY-ON BAG, BUT FIVE years ago, a computer of its oomph would have been as large as a steamer trunk. Size isn't a big deal to Pixar animators, Formula One engineers, and others who use this kind of machine professionally, but it does make the desktop more reasonable for aspiring visual artists and die-hard PC gamers. The spec sheet alone can't quite convey just how much power is packed into this 18-inch-tall box. Here's how its maxed-out configuration compares to the machines we interact with every day.

14 15-inch MacBook Pro laptops' worth of processor cores

Like cars spreading out across lanes on an interstate, tasks must distribute among processor cores in order to progress simultaneously. More lanes means greater efficiency and faster performance. Two Intel processors have 28 lanes each, amounting to 56 total cores sharing the load.

250 Xbox One X consoles' worth of onboard memory

Slots for 24 memory boards create room for up to 3 terabytes of RAM, the short-term recall essential for keeping many tasks—like rendering a character's face and all the detailed background action—going at once.

4 full-size household refrigerators' worth of power supply

A 1,700-watt power supply, the largest ever in a desktop computer, is ample amperage to run a handful of large household appliances at the same time. Its true mission: keep up with demand from the processors and graphics cards, which guzzle up to 205 and 300 watts, respectively.

833 LTE connections' worth of transfer speeds

A pair of 10-gigabit-per-second Ethernet ports fling data between the cloud, external servers, and up to 48 terabytes of onboard hard drives. The hookups enable speedy synchronous access to both the Net and external storage.

by Corinne Iozzio / photograph by Sam Kaplan

POWER

photograph by The Voorhes

GOING ALL THE WAY (RENEWABLE)

IS IT SMART—OR CRAZY STUPID—TO RELY SOLELY ON WIND, SOLAR, AND HYDRO?

BY LESLIE KAUFMAN

illustration by Tim McDonagh

This past July,

as Dawn Lippert surfed the swells at her home beach in Honolulu, a rogue board sprang up and slammed her between the eyes. It could have been a knockout blow. But Lippert, a former high school soccer champ who had taken up surfing when she arrived here a decade ago—fresh from Yale and working as an energy consultant to the state as it began to wean itself from fossil fuels—possesses a resilient athleticism.

She managed to steady herself as the remorseful owner of the wayward board paddled her ashore. Once at the hospital, she received 12 stitches that snaked between her eyes and a parade of concerned nurses. Her fiancé, Brody, had explained that their wedding was a few weeks away. "Oh, honey," one nurse clucked, "this is not going to be pretty." As is her habit in the face of rough odds and bruising encounters, Lippert shrugged it off. "I was just grateful that it wasn't my eye," she recalls.

JULIE THURSTON PHOTOGRAPHY/GETTY IMAGES

Through the roof
Cheap panels and plenty of rays pushed home solar power to an unexpected 343 megawatts.

It's easy to draw conclusions about a person based on one anecdote. But Lippert is a true optimist. Which is a good thing, because as the world warms and humanity hurtles toward a catastrophe of its own making, she is part of an army of innovators who believe they can help the rest of us engineer our way out of global warming. Lippert is in Hawaii because the action is here. In 2015, the archipelago state became the first to legally require that its utilities generate 100 percent of their electricity from renewable sources. Deadline: 2045. Lippert is now backing dozens of companies to help the state achieve its radical goal.

A Seattle native, Lippert is CEO of Elemental Excelerator. It is a nonprofit accelerator that finds, funds, and nurtures the inchoate technologies that, she hopes, can extinguish our fossil-fuel habit. She looks for innovators who have had a "Eureka!" moment, who have seen something the rest of us have overlooked. "If these technologies are successful," she says, "they will affect a billion people. They will change the world."

But first, she has to help change Hawaii. The challenges are many. The state's utility consortium, Hawaiian Electric Companies, must corral the work of other utilities across the state's eight islands. With the help of private players like Lippert, it must develop things like battery-backed residential rooftop solar tech with voltage-smoothing inverters, wind farms, aggregated demand-response software, and peak-shifting electric-car charging. So far, it has achieved 27 percent renewable electricity.

Lippert and her team have assembled an impressive portfolio of firms—in fields like energy storage, microgrid hardware, machine learning software for energy efficiency—to get the rest of the way there. In its five years, Elemental has awarded $22 million to 63 startups from around the world, resulting in 35 demonstration projects in Hawaii. It has also attracted powerful allies to contribute to its war chest, including the U.S. Navy (which gives $6 million a year), the U.S. Department of Energy, international electric utilities, and the Emerson Collective, an investment and philanthropic platform run by the late Steve Jobs' wife, Laurene Powell Jobs.

The mainland is closely monitoring the state's experiment, and thus some of Lippert's novel solutions, because going full green tech has captured the imagination of energy experts, planners, and policymakers. "Everyone is watching Hawaii," says Stanford University's Mark Z. Jacobson, an atmospheric scientist and the academic godfather of the movement. "Everyone wants to see who will be the first to run on 100 percent renewable power and keep the grid stable at low cost."

Until 10 years ago, the United States got less than 10 percent of its electric-generation capacity from renewables—and most of that came from the great dams of the West and Northwest. But increasing alarm over our future, and the plunging costs of wind and solar power, is reshaping the utility landscape. More than half of new electric generation in 2016 came from the sky and wind. That holds true even in red states, where many don't believe in the science of climate change. To some, it's looking a lot like we can actually wean ourselves from oil and gas in one generation. What was a nerdy dream a decade ago has grown into a movement. Politicians have jumped aboard, pledging their localities to an all-in green future. As of last year, 47 American cities have joined the fight, including major population centers like Atlanta, Salt Lake City, and San Diego.

> **"The market is ready for these solutions. Our role is to invest now so they can scale."**
>
> — DAWN LIPPERT

Of course, not everyone is cheering. Fossil-fuel advocates warn of an all-too-serious challenge. "Hospitals, sewage treatment, clean water, industrial production, communications networks, iPads, etcetera, all require copious amounts of energy," says Mike Krancer, an energy lawyer and consultant in Pennsylvania and prominent supporter of fracking and natural gas. "That is not going to come from renewables at a 100 percent level—not now, not ever." Even some of the people who favor wind, solar, and hydro think total reliance on it is a bad idea—even for a tiny island state. "It is an absolutely unachievable target if you want to have affordable energy and reliability," says Charles McConnell, the executive director of the Energy and Environment Initiative at Rice University and President Obama's former assistant secretary of fossil energy.

But the not-ever argument is one Lippert likes to have. Sitting in a Honolulu park, where she takes new entrepreneurs for training, she says the technologies Elemental is backing today will help create a green-powered future that is not only possible, but inevitable. "The market is ready for these solutions," Lippert says, perched beneath a monkeypod tree. "Our role is to invest now so they can scale further and faster."

FOR MOST OF ITS HISTORY, THE HAWAIIAN Islands, lying 2,500 miles from the nearest landmass, grew energy. For centuries locals lit their way with oil from the kukui nut, the fruit of the state tree. In 1887, they managed to electrify the royal Iolani Palace—four years before Washington, D.C., managed to electrify the White House.

American-style modernism changed that. As the population grew, so did the demand for power-hungry conveniences. Just 15 years ago, Hawaii imported 90 percent of its annual fuel—$5 billion worth. The average household electricity bill stood at roughly four times the mainland's, even though locals use less energy than most of the nation.

The situation became so crushing that in 2008, the state set a goal to move to 70 percent clean power by 2030 through renewables and energy-efficiency savings like tougher building codes. Lippert, then working as a consultant with Booz Allen Hamilton in Washington, D.C., was among the specialists who flew in to devise a game plan. While it called for solar and biofuels, it also envisioned huge wind farms on smaller, less-populated islands like Moloka'i and Lanai, connected via deep-sea cable to Oahu, with its nearly 1 million residents and 9 million annual visitors.

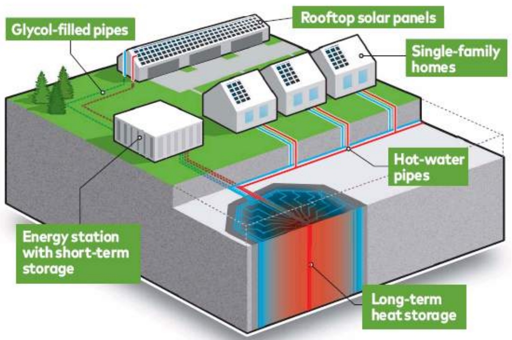
The timing was perfect. Cheap Chinese solar panels, and Hawaii's sunshine, propelled residential rooftop solar from a projected 23 megawatts of capacity by 2015 to 343 megawatts. During the run-up,

THE EARTH IS A BATTERY

Forget warehouses packed with lithium-ion cells: We'll soon store renewable energy in the dirt and grab it when we need it.

Solar panels generate plenty of energy on summer days. Not so much in winter, especially in northern climes. If we intend to go all in on renewable power, storing the stuff for use when we need it later is key. Underground thermal energy storage allows engineers to take excess energy, shunt it below ground, and save it there indefinitely. Existing caverns, subterranean rocks, or even man-made holes are ideal spots to stash juice. The process is fairly simple:

Solar panels on rooftops—say, garages—heat **pipes filled with glycol**, a conductive organic compound used in antifreeze. The hot glycol travels to an **energy station** where it transfers its heat to water. Some of the warmed H_2O flows into **pipes** to nearby homes, providing hot showers. Excess heat directs into **long-term storage**, hundreds of pipes in bored holes up to 120 feet deep. Hot water moves through these tubes, warms the earth to about 175 degrees, cools off, then travels back to the energy station where the process repeats. Because the earth holds the heat, it can return it to the water pipes in winter.



LEFT TO RIGHT: ILLUSTRATION BY PETE SUCHESKI; DOUGLAS PEEBLES/CORBIS VIA GETTY IMAGES

What a breeze
The world would have to build 800,000 of these to produce half of its daily power needs.

Governor Neil Abercrombie pushed for a new liquid gas plant. The converts to green energy pushed back. They demanded a law that would prevent backsliding by requiring the entire state to run on nothing but renewables.

By then, the idea had already taken academic hold on the mainland. Just a few years earlier, in 2009, Mark Z. Jacobson helped author a groundbreaking paper in *Scientific American*. It mathematically challenged classic arguments of the fossil-fuel crowd: that renewables are too expensive and unreliable; that they are not powerful enough for industrial processes; that to get enough energy from wind and solar, we would have to cover an obscene amount of land with wind turbines or solar panels.

Last year, Jacobson laid out a road map for the U.S. and 138 other countries to go 100 percent renewable by 2050. His computer modeling demonstrates that fully green generation could be more affordable and reliable than today's grid—assuming we prioritize storage. In addition to lithium-ion batteries, he calls for using pumped hydro (in which you use midday solar power to pump water uphill and then release it in times of need to power turbines downhill), existing hydroelectric reservoirs, and underground thermal energy storage (UTES), in which

DAWN LIPPERT

The CEO of Energy Excelerator, her nonprofit funds and nurtures technology companies. It has assembled a portfolio of businesses in energy storage, microgrid hardware and machine learning software for energy efficiencies.

COURTESY DAWN LIPPERT

you pump hot water into caverns, excavated pits or bored holes in the ground. The heat is then stored in the surrounding earth, or sometimes in stones, daily, weekly or even seasonally, and can warm buildings when needed.

This past June, 21 academics and energy researchers, many of whom favor renewables, refuted Jacobson's earliest assumptions as delusional. His theory, they argued, would require us to build enough energy storage to put out two and a half times the power capacity of the entire national grid: 4 trillion kilowatt-hours. Nearly all of that would consist of UTES technologies that don't yet exist at commercial scale. But the authors' underlying concern was equally political. They worry that opponents could use Jacobson's all-or-nothing approach to diminish the role of any green tech on the grid. Despite the fact that solar power has grown annually 68 percent during the past decade, it still accounts for only around 1 percent of our power. Jacobson has sued the study's lead author for libel.

As mainland academics, partisans, and politicians debate the go-green movement, the voyage is already underway in the central Pacific. "Clearly in our island community, we are much more aware of the effects of climate change, global warming, and sea-level rise," Governor David Ige said last June. "What we do impacts our environment because we know that leadership can start at home." He concluded, "We here in Hawaii can make a statement and can lead the world if it's important enough to us."

The giving tree
The pongamia's seeds are oily and can be made into a renewable fuel as energy-dense as diesel.

COURTESY TERVIVA INC.

ELEMENTAL'S OPEN-PLAN WORKSPACE—IN A downtown Honolulu high-rise—is a feel-good place, decorated with smiling pictures of young entrepreneurs from all over the world. The atmosphere is laid-back. It is unusual among accelerators for several reasons, but most obvious is that all but five of its of 19 staffers are women—and mostly women in their 20s and 30s. At kickoff meetings, Lippert gathers her company leaders for updates and support, but also for fun, like picnics at the beach, where everybody takes part in the traditional art of pounding taro root into poi, a local food. Frequently she organizes her intense newbies in a circle, asks them to put their hands in, and conducts a cheer.

Her organization is unique for another reason. It is a nonprofit investing in commercial technologies. As such, it typically takes just enough of a stake in a company so if it succeeds, Elemental can share in the proceeds to fund even more tech dreamers. Of the dozen companies Lippert and her selection team fund each year—out of 450 or so applicants—all must address a specific energy roadblock in Hawaii with a solution that could someday work on a larger scale. In addition to up to $1 million in funding, Elemental gives companies a chance to create an in-state pilot project that will test their tech and whether they can make money.

> **"Hospitals, industry, and iPads all require tons of energy. That is not going to come from renewables at 100 percent—not ever."**
> — MIKE KRANCER, ENERGY LAWYER

At first glance, energy generation here would seem easy. The state's eight islands are resource rich: sun, trade winds, and an active volcano, which provides about 30 percent of the Big Island's electricity from geothermal. But Colton Ching, a utility official overseeing the transition, says that even if the state used every piece of appropriate land for utility-scale wind and solar, it will still get Oahu, with just over two-thirds of the state's population, "to just a little over 70 percent of its energy needs."

So one of the things Lippert's entrepreneurs want to provide is the other 30 percent. She directs me to a hillside off Oahu's North Shore, where a company called TerViva has planted 50 stunning acres of pongamia trees. A Southeast Asian and Indian species, the tree has wide green leaves that produce thick clusters of flowers. These become pods with very oily seeds that can be processed into a renewable fuel.

The word "biofuel" leaves a bad taste in some mouths, due to the debacle that was corn ethanol: land-intensive, tough on soil, relatively expensive. But pongamia are inexpensive and soil friendly. Burning a gallon of fuel made from its seeds produces nearly as much energy as a gallon of diesel. It is a rare leguminous tree; it puts more nitrates into the soil than it takes out. And of course, the trees continuously take carbon dioxide out of the air. Since their crop is seeds, the plants don't have to be cut down, and the soil never needs to be tilled. Some of Oahu's power plants can burn raw pongamia oil. TerViva has turned the oil into biodiesel and even jet fuel that meets airplane-engine specifications.

Turning tree pods into jet fuel is a nice trick. The real challenge is imposing consistency on renewables that come and go with the wind and clouds. Homeowners who rely on wind power don't want flickering lights, which represent a few seconds when the grid loses power from one source and rushes to replace it from another. Future networks must deliver power from these intermittent sources without missing an electron.

Lisa Laughner, a former Rolls-Royce executive, and her company, Go Electric, is trying to solve this. Her team, backed by Elemental, has installed hardware and software at Camp H.M. Smith, home to the U.S. Pacific Command, on Oahu. The gear monitors power-flow patterns to the millisecond and helps control the camp's high-security 5-megawatt microgrid, which integrates diesel generators and solar.

But any renewable future must include (CONTINUED ON P.81)

ROAR

HOW WILL F1—THE WORLD'S FASTEST AND MOST POPULAR MOTORSPORT—RECKON WITH A (QUIETLY) SURGING ELECTRIC TIDE?

BY JOE BROWN

◀ **Steer clear**
A Mercedes F1 racer takes turn 5 at Circuit of the Americas.

DRIVERS TAKE TURN 11 AT CIRCUIT OF THE AMERICAS pretty slowly. It's tight, and they'll only hit about 60 miles per hour, depending on the car. Then they'll charge down the main straight, a three-quarters-of-a-mile descent that lets the right machine clear 200.

As I stand in the grandstands before turn 12, a black-and-gold racecar quickly fills my field of view. It's Texas-hot in Austin today, close to 90 and humid, but the car brings a wind with it. The wind is made of noise.

Fans come to Formula One races for this kind of sensory experience. When the series spun up in 1946, following the exhaustive end of World War II, fantastic machines replaced the terrifying cacophony of bombs with the joyful chorus of speed-linked sound. Over the years, millions of fans have swarmed the edges of racetracks to hear F1's roar.

But you don't just hear an F1 engine. You feel it. As the car flies by the grandstand, the concussive wave emanating from its eight pounding cylinders hits me in my chest, the back of my neck, and behind my eyes. Is it fair to call this a noise? It feels more like an emotion.

Too bad I'm not technically witnessing Formula One. I'm watching the Masters Historic series, an undercard to the next day's U.S. Grand Prix. This full-throated racer is an F1 car, yes, but it's one that hasn't competed for the championship in nearly 40 years.

The modern cars, whose complex hybrid powerplants are more than twice as powerful as the old-school V-8 that just streaked past me, don't sound as awesome. You can stand trackside at a present-day Formula One race without even wearing earplugs. This development has fans and teams making a ruckus of their own.

The decibel-depleting transition came four years ago with new league regulations that put hybrid gas-and-electric engines into F1 machines in an effort to appease the increasingly eco-conscious public. And while you might not equate a hybrid—you know, like a Prius—with the planet's pre-eminent racing series, the new cars are faster and more advanced than anything that's come before. This is important for competition, but also for the technological trickle-down that's so key to F1's place atop the motorsport pantheon. Many Formula One innovations find their way into our personal rides: Disc brakes, carbon fiber, and traction control are just a few examples that have made our own automobiles safer, more efficient, and, yeah, faster.

Formula One's hybrid engines definitely bring the innovation, but they're a bit short on sensory thrill.

"That's the slightly embarrassing thing," Ross Brawn, Formula One's managing director of motorsports, tells me later that day from a hermetically white hospitality room two buildings and a road removed from the circuit. "Everyone remembers how great the cars used to sound." Another V-8 screams down the track, its wail piercing our air-conditioned sanctum, and he fights a smile. Brawn, who has been working with F1 cars since the late 1970s, recalls a louder time. "We used to have engines that were ear-piercing," he says. Then hybrids arrived, and, "suddenly you could have a conversation next to a running car," he says.

This hints at an existential questions for Formula One: In our environmentally friendly future, will the most advanced racing series in the world still drive the innovations that power our road cars, or will it instead become pure sport, with entertainment as its singular goal? Or could an all-electric championship overtake F1 as the fastest R&D lab on planet Earth?

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FORMULA ONE IS AMONG THE MOST CASH-infused sports in the world. Race weekends take place on five continents from March through November and draw in excess of 100,000 paying spectators apiece. Team budgets stretch into the hundreds of millions of dollars. Much of that money goes toward developing parts, materials, and systems for their thoroughbred machines. Some of those innovations end up in our driveways.

But as the consumer world trends toward electric vehicles, Formula One shows no sign of putting the brakes on its gas-burning engines. To keep from losing fans and their yawning wallets, F1 heavies look to the petrol-fueled sensory assault of a modern Grand Prix to maintain interest. In parallel, to maintain the interest of eco-conscious race fans, the Federation Internationale de l'Automobile (FIA), which governs most of professional racing, recently bankrolled a new electric racing series called Formula E.

You'd think an all-amps competition would be the most sophisticated racing around, but Formula E is not as technologically cutthroat as F1. To attract smaller outfits, the FIA made entering Formula E, which is only three years old, relatively unintimidating: Many major parts are standard, so you don't need the kind of R&D operation required to develop, for example, a battery from scratch. And to keep the titans of motorsport from trampling newcomers, constructors (teams) can't spend more than $25 million per year on their rigs. That's a tenth of an F1 budget.

In both Formula One and Formula E, the FIA has a lot of say in how racing squads spend their money. Recently, the FIA has been directing teams to put their cash behind green tech, even in performance-obsessed F1.

Every year, the FIA and Formula One's management crew hand down technical regulations to F1 teams; every seven years or so, they create a thoroughly rethought set of these specs. The regulations direct every aspect of a car: engine configuration, angle of the driver's seat, number of joules the car's battery can discharge in a lap, and so on. The interpretation of these specs, even more than jockeying on the track, is F1's real field of play.

"The teams are fighting a technological war," says Brawn, a former tech boss with a reputation for ruthless

OPENING SPREAD: PAUL CROCK/AFP/GETTY IMAGES & RONALDO SCHEMIDT/AFP/GETTY IMAGES

MARK THOMPSON/GETTY IMAGES

▲ Clockwise from left: Formula E driver Nelson Piquet Jr. hops into a new ride. Mercedes-Benz Project One supercar. Mercedes driver Lewis Hamilton and team boss Toto Wolff.

CLOCKWISE FROM LEFT: CHARLES COATES/GETTY IMAGES; COURTESY MERCEDES-BENZ; MARK THOMPSON/GETTY IMAGES

> **"The teams are fighting a technological war."**
> —ROSS BRAWN, FORMULA ONE MANAGING DIRECTOR OF MOTORSPORTS

competition. As soon as a squad receives the 100-plus-page document, engineers embark on an epic nerd-out, searching for technological edges and loopholes to exploit.

In 2014, the spec mandated new hybrid engines that thrust Formula One into the future—or at least the present day. The regs called for small gasoline-electric setups and resulted in a 35 percent reduction in fuel use. These power units, as they're called, are highly advanced. The gas-powered component displaces just 1.6 liters—that's smaller-than-a-Toyota-Corolla territory—but its diminutive six cylinders achieve phenomenal efficiency. In concert with an electric motor, they put more than 1,000 horsepower onto the track. These cars and their tiny engines are scary fast, breaking speed records at almost every race.

Fans, however, were not impressed by the hybrids' debut. "This yr F1 is kinda dull…I miss the…deafening sound of the V8," wrote one Twitter user. "#F1 in 2014 sucks. Hybrid v6 sound like my jetta," another tweeted. The media was brutal too. *F1's* "new sound gets thumbs down," read one Associated Press report.

The cars' noise level improved over the past three years, but not enough for some. Brawn, who now works for F1 leading the team that writes the all-controlling regulations, had a choice: Steer F1 toward electric power, or push it toward gas. Focusing on electric power would, without a doubt, hugely benefit electric-car R&D; gas would sound amazing. Brawn's bringing back the roar.

"The show has to be the number-one priority," Brawn says, and then starts slapping the table to punctuate the list of factors that, to him, define Formula One: "The racing [*slap*], the drivers [*slap*], the history [*slap*], the noise [*slap*], the smell [*slap*], the atmosphere [*slap*]."

The FIA's next set of regulations, currently being drafted by Brawn and his crew, could pump up the atmosphere. They go into effect in 2021 and will likely allow higher fuel flow so the V-6 power units—still hybrids—can rev higher and scream louder. They also might do away with a device that makes the power units more efficient—and quieter—by harvesting energy from the engine.

The decision to not go greener is all business. F1 is expensive, and Brawn knows companies won't rush to drop a quarter-billion bucks to fund a team in a sport without fans. "You create the show because you've got substantial investment from manufacturers or technological partners who create this magic of Formula One," he says.

Toto Wolff, team principal of the magic-creating, four-time world-champion Mercedes-AMG Petronas F1 squad agrees. "Formula One is an audio-visual spectacle," he says. "We need to be shocked by the sheer speed of the cars, looking at them, and by the sound of the engines."

As a corporate officer at Mercedes-Benz (official title: Executive Director and Head of Mercedes-Benz Motorsport), Wolff answers to a publicly traded company that sells upwards of 2 million cars a year. His job is not just to win on the track; he also has to make sure the technological gains he achieves there have practical applications.

He can cross that off his to-do list. Sort of. Late in 2017, Mercedes introduced the Project One, which is essentially a street-legal F1 car. "The rear axle has got exactly the same power unit attached to it," says Andy Cowell, Mercedes' managing director of high performance powertrains, who oversaw development of that power unit. "The only differences are that it's got an aftertreatment on the exhaust system to meet emissions regulations, and the tuning is adjusted so it can cope with regular gasoline." That's some direct tech transfer! Too bad most of us won't see a Project One at our local dealers. They run $2.8 million, and Mercedes sold all 275 of them the day they went on sale.

The high-performance hybrid is, at least, the near future of go-fast cars. But hybrids burn gas, and they've been on public roads for 20 years. It's hard to look at something with a tank full of hydrocarbons and see our motive destiny. By most accounts, Formula E and the wave of electric vehicles rushing toward dealerships will dominate our driveways in the years to come.

•••

"EVERYBODY JUMPS ON THE HYPE OF ELECTRIC cars because Tesla is doing it, but no auto manufacturer who is going pure electric has ever earned one dollar of profit," says Wolff, his German-accented English just *ein bisschen* louder than normal.

Maybe he's just nervous. The next day, his lead driver, Lewis Hamilton, will climb into his 1,000-horsepower hybrid and try to win the U.S. Grand Prix, the race that brought Wolff to Austin this weekend. There's more than just high-fives at stake: A win could secure the World Championship—and its roughly $150 million purse—for Mercedes. Kind of a high-pressure day.

Still, Wolff continues musing about EVs. "My personal view—and I'm not a road-car expert—is that hybrid is the future," he says. "I can see full electrification in cities as a first step, and hybrid everywhere else. But I doubt that we will have more than 25 percent electric by 2030."

Even so, Mercedes has committed to entering Formula E in 2019. "The reason for us joining is that our road cars are gonna go electric—that's a fact," says Wolff. This sounds like a contradiction, but it's not. Mercedes recently announced plans to produce a line of urban-aimed electric vehicles called EQ, and the racing series is a way for the company to promote it. "The marketing aspect interests us," he confirms. When I ask him if Formula E tech will have a meaningful impact on Mercedes' innovation in electric vehicles, Wolff is clear: "Not yet."

That's because Formula E's regulations are pretty locked-down. Engineers can play with the powertrain, the stuff that physically turns the wheels. And that would seem like a big deal, but every team uses the same chassis—the parts that determine how a car handles—and the same battery. Unlike in internal combustion engines, the battery is the most important component of an electric car. It's what lured Mercedes to the starting line.

Current Formula E battery packs can't last a 50-minute race, and, at about 440 pounds, it's impractical to swap one out midcompetition. That's why, about halfway through an ePrix, this happens: The car dips into the pit. The driver unbuckles his five-point harness, removes his steering wheel, climbs out of his car, hops a few steps over to a fully charged car, climbs in, lets the team buckle his safety harness and attach his steering wheel, and zooms off, motor whirring like an angry vacuum cleaner.

TRICKLE DOWN TECH

Innovations meant to make drivers faster on the Formula One track have made their way into our everyday wheels more than you might expect.

Carbon Fiber

This rigid weave of carbon and resin first made its way into F1 in a 1981 McLaren. During that year's Italian Grand Prix, driver John Watson crashed at high speed, and survived largely because of the aerospace material. Today you'll find the strong-yet-light stuff in nearly every performance car—from wheels to roofs.

Disc Brakes

Old-school drum brakes press metallic shoes into the sides of bowl-like housing. This builds up heat, which can reduce stopping power. The 1951 British Racing Motors Type 15 was the first F1 car with disc brakes, which pinch large plates between small calipers. Now most production cars use this setup.

Tire Tech

Racing punishes tires. Pirelli currently makes all F1 rubber, and its latest P Zero road skids wear features pulled straight from the track. Hardened material where the tire meets the rim increases stability in turns, while extra silica reduces rolling resistance to boost fuel efficiency.

Fuel Injection

Mercedes-Benz needed to get more fuel into its 1954 F1 engine. It found its flow by ditching the carburetor for a fuel-injection system adapted from WWII fighter planes. The next year, the first fuel-injected production car, the 300SL, rolled off the lot. You'll find this setup in most modern cars, even base models.

Sequential Manual Transmission

F1 cars haven't used stick shifts since the '90s. The now-standard, semiautomatic system shifts gears via a paddle—no clutch-stomp required. The scheme first showed up in 1989's Ferrari 640 racer, and hit roads thanks to street racers like the early 2000s' Toyota MR2.

illustrations by John Kuehn

A pit stop spans about 40 seconds—40 seconds of seat belts and skipping between cars. It's boring and kind of embarrassing. What company wants racecars that can't finish a race? "It doesn't appeal to us to change cars because the batteries don't make it," says Wolff.

He's not alone in that sentiment. "The current configuration encourages people to have range anxiety," says Dick Glover, CTO of McLaren Applied Technologies (MAT). McLaren, a key player in F1 since the 1960s, doesn't just race: The company's Applied Technologies division supplies parts to every team in F1.

MAT is developing a battery that will treat Formula E's anxiety problem. Guess when that new battery will be ready. Yup—2019, which is when Mercedes plans to join Formula E. Porsche recently announced plans to race that year too. And Nissan, which makes the electric Leaf, will start running in 2018. These new teams could change Formula E into the kind of technological warfare that today makes F1 so compelling. And maybe even unseat it as the premiere R&D venue for a new generation.

Maybe.

Formula E's big challenge, if you ask Brawn, is that of a very fast chicken and its expensive egg: Without the public awareness and ticket sales, teams won't pour serious money into the sport, even if you let them. But absent those big spenders' crazy tech, the all-electric series won't draw the crowds... that attract the serious money. And on and on.

One solution would seem glaringly obvious: Formula One could go electric. Generations of history make it unthinkable for constructors like Ferrari to step away. And legions of fans will buy tickets and TV packages that support the multiple billions of dollars required to create the spectacular machines. Just as those same fans gave up their DVDs for Netflix and landlines for cellphones, they'll come to appreciate aspects of racing other than the noise. Right?

"I don't see it in the next five to 10 years," says Brawn. "I can't see that." And he's just referring to the tech required to run 186 miles at F1's hammering pace. "We have some tough questions to ask ourselves," he says.

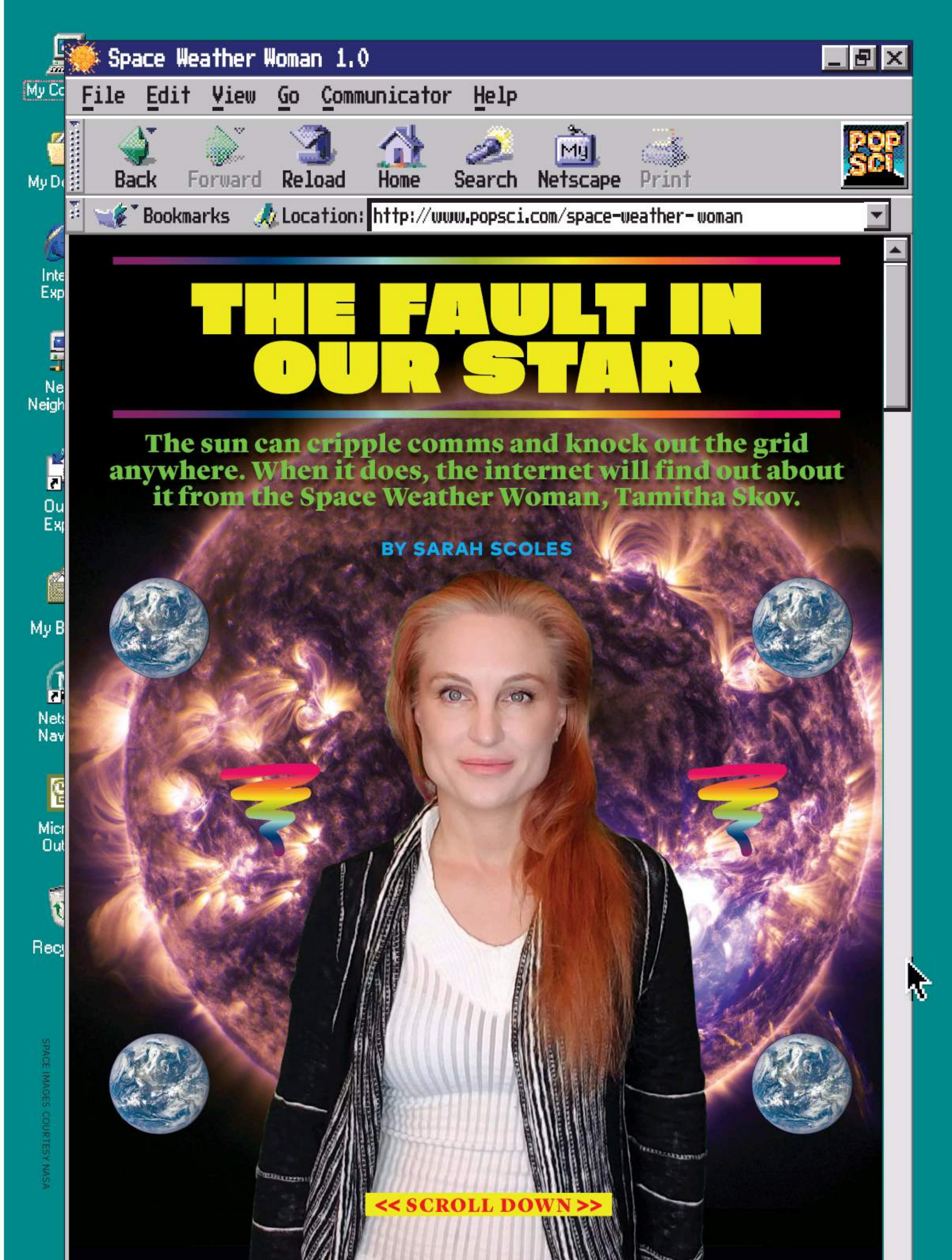
Here's one: What if F1 were just a sport, with no real-world analog. Armies don't fight with spears anymore, and yet Olympians still win medals for throwing javelins. Why couldn't 24 petrol-powered cars racing around a track be part of our all-electric (or nuclear or hydrogen or whatever) future? "Transportation can become a commodity; it doesn't need to trigger any emotions within you," says Wolff. "Motor racing—the danger and the technology—that triggers emotions. I can definitely see the two not being aligned all the time."

Or maybe it depends on where you live. "We're used to a fairly homogeneous world," says McLaren's Glover. "In the future, it will be anything but that. Some countries will be very heavy on electrification. In others, it won't be much different from what you have now." So the tech on an F1 track might have applications in areas that won't be suited to electrification until decades after cities and infrastructure-heavy markets adopt it. For a sport that prides itself on its global reach, this makes a lot of sense.

That Sunday in Austin, at the race weekend's main event, Mercedes' Lewis Hamilton doesn't make a great start and finds himself in second place behind his Ferrari rival. Five laps later, though, Hamilton charges down that three-quarters-of-a-mile main straight at more than 200 miles per hour, and, right in front of the turn 12 grandstands, passes the Ferrari. He takes the lead. He clinches the championship. The roar of the crowd is all you can hear.

And they're off Drivers race toward the first turn at the U.S. Grand Prix.

MARK THOMPSON/GETTY IMAGES



THE FAULT IN OUR STAR

The sun can cripple comms and knock out the grid anywhere. When it does, the internet will find out about it from the Space Weather Woman, Tamitha Skov.

BY SARAH SCOLES

SPACE IMAGES COURTESY NASA

SHORTLY AFTER SUNSET ON JUNE 18, 2013, a woman drove her minivan onto Brighton Street in Belmont, Massachusetts. Her GPS told her to turn right. But the metallic voice, guided by satellite data, steered her wrong: onto a railroad track. She tried to drive off, but the van got stuck. No sooner had she unbuckled herself and her two kids and ushered them out than a train crumpled her car into a ball of foil. Not long after, someone sent a news story about the incident to space physicist Tamitha Skov. She didn't just see a GPS acting up. She saw the sun acting up. While our star looks calm and contained, its surface roils: Spots form and darken it like scabs; loops of plasma link its regions; its atmosphere streams farther outward than the star is wide. Solar flares, which are bursts of radiation, and coronal mass ejections, which are bombs of stellar material, disturb both Earth's magnetic field and upper atmosphere. There, they disrupt devices—like GPS receivers—that rely on electricity or radio communication. This interplay between the sun and Earth is called space weather, and it is Skov's specialty.

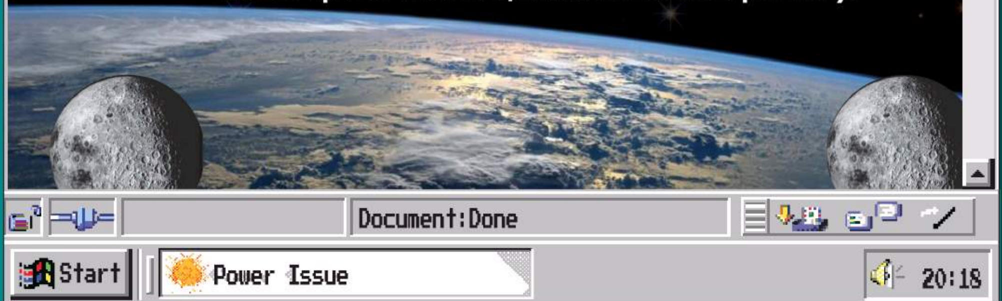


illustration by John Kuehn

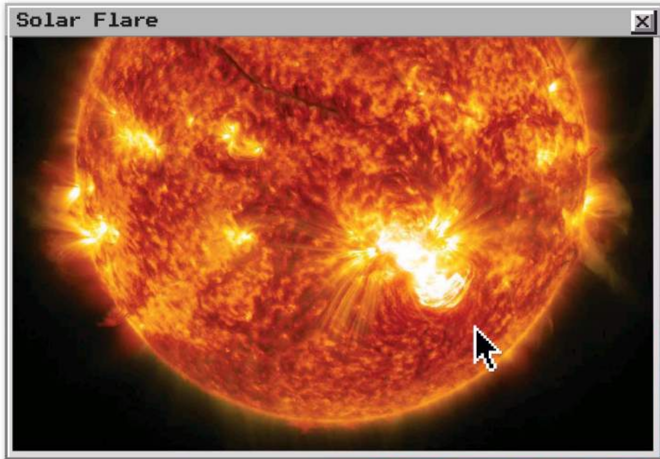
At the time, Skov had just begun a Web video series that gave space-weather forecasts, much like the predictions Al Roker makes on TV for clouds and sunshine. In it, she explained how our nearest star affects Earth. She had a modest but engaged following. Motorists were already starting to tip her off whenever their SiriusXM service cut out, airline and small-craft pilots would tell her when navigation went awry, and taxi drivers would describe routing errors.

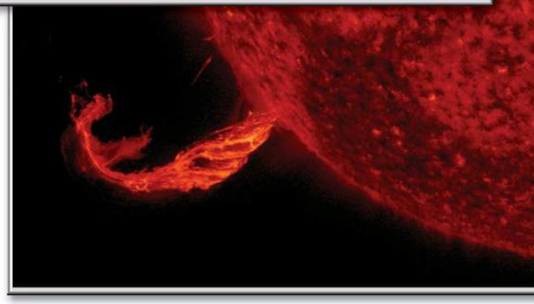
A number of these accounts involved drivers rolling, at the behest of their GPS, onto train tracks, or other not-roads, especially near dawn and dusk. At first, Skov blew off these anecdotes.

When the reports kept coming, she consulted an atmospheric expert at the Aerospace Corporation, a federally funded R&D center where Skov works as a research scientist. "What's up with this?" Skov asked her colleague. "Is it something?" Yes, the woman replied, the atmosphere is always unstable at sunset and sunrise. Add solar flares to that? "It could definitely make a difference," the expert said. Skov checked the website of the Lockheed Martin Solar and Astrophysics Laboratory to see if there had, in fact, been a solar flare around the time of the woman's fateful drive. And there it was: a C-class outburst, medium strength.

No single small solar event—like this C-class flare—can yet be definitively linked to a specific problem, like a GPS device in a minivan leading its driver onto railroad tracks. Skov nonetheless calls incidents like this one smoking guns, even if scientists can't conclusively prove the cause. She strives to make people aware that this kind of thing *can* happen. "I was trying to impress upon people that GPS is extremely susceptible," she says of the van accident, "and just blindly trusting it is nuts."

Space weather's effects can be small or significant. The C-class solar flare was hardly noticeable, even if it did total the woman's car. But there is also plenty of evidence that humans need to watch out for the sun—big-time. So Skov dedicated herself to explaining the increasing terrestrial problems that will come from the star that lets us live on Earth in the first place. She became the Space Weather Woman, connecting her viewers to the cosmos and bringing all levels of space weather to all kinds of people.





Stormy weather
New space probes may help us learn more about the timing of solar flares (above) and coronal mass ejections (right).

THE LAST TIME THE SUN *really* made people go *uh-oh* was on March 10, 1989. Astronomers watched as the star set loose a billion tons of gas at a million miles an hour—a coronal mass ejection—and blasted a solar flare along with it. The radiation, traveling at light-speed, struck Earth eight and a half minutes later. As it collided with the upper atmosphere, it charged up molecules, blocking radio communications at Earth's upper latitudes, including from Europe into Russia, which at the time, listeners took as Cold War interference. The radio-frequency problems mostly affected ground-to-air and ship-to-shore communications, as well as shortwave-radio and amateur radio users.

The real problems came two days later, when a slower-moving swarm of magnetically charged material arrived. It pummeled Earth's magnetic shield, which protects the globe from everyday radiation. Charged particles whizzed down magnetic-field lines and smashed into atoms in the air, producing Northern Lights. Usually those stay, you know, up north. But this time, the show played as far south as Texas. Satellites lost their bearings and tottered as particles bombarded their electronics. The storm stripped the *GOES-7* weather satellite of half its solar cells, shortening its lifetime by 50 percent.

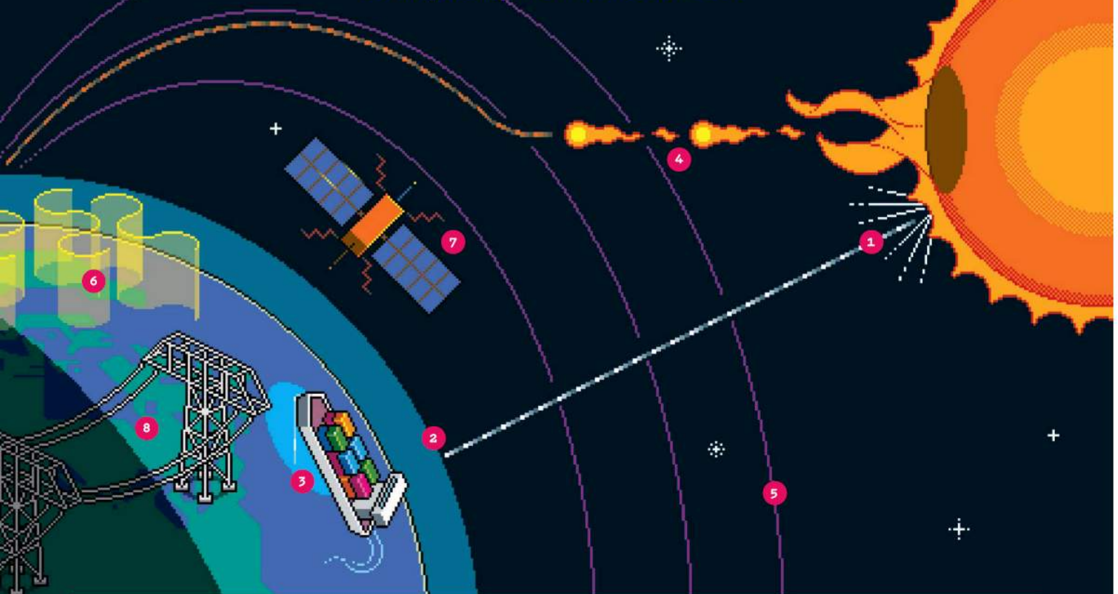
Earth's shivering magnetic field also created ground currents. Coursing along, they encountered a flaw in Quebec's power grid. It was easier for the current to flow through the power lines than across the rocky ground, and the extra load caused circuit breakers to trip. Around 3 a.m. on March 13, the whole province went dark.

It's Quebec: It was cold—5 degrees Fahrenheit in some places. There was no heat. Schools and companies closed; public transit and the airport went still. The outage affected 6 million people for up to nine hours.

Today, modern society relies on exactly the devices that such a storm disrupts. A 2017 study in the American Geophysical Union's

MASTER BLASTER

Disruptions from a distant star



>> Light and heat from the sun nurture life on our planet. But our star can also cause harm, and not just by scorching our skin. Changes in its surface generate flares and coronal mass ejections. Astrophysicists aren't sure what triggers these events but associate them with shifts in the sun's magnetic field. They are most common during times of high solar activity, when cool, dark sunspots appear on the star's surface. Both have the potential to cause disasters on Earth. Here's a breakdown. —Mary Beth Griggs

SOLAR FLARE
These bursts of radiation travel at light-speed, taking only eight and a half minutes to zap our planet. When a flare (1) hits the ionosphere (2), it can obliterate radio communications—ship-to-shore, for example (3)—which normally bounces off this layer of the atmosphere as it travels across the globe.

CORONAL MASS EJECTION
This explosion of stellar material contains plasma (4)—hot, magnetically charged gas—that sprints toward Earth at up to 6.7 million miles per hour. When it smashes into our magnetic field (5), it causes auroras (6). But supersize ejections can throw off GPS satellites (7) and disable electrical grids (8), bringing society to a standstill.

Space Weather journal estimated the effect if a solar storm as great as the largest on record—an 1859 shakeup called the Carrington Event—were to strike again. It would cost the United States $42 billion per day. The repercussions could last years, perhaps decades. The power grid could fail. You wouldn't be able to get money out of a bank. Businesses couldn't operate. Water pumps wouldn't work; phones either. Food would go bad. Governments would have a hard time governing. "We have created an incredible vulnerability, unlike any other," says Bill Murtagh, program coordinator for the Space Weather Prediction Center, the celestial arm of the National Oceanic and Atmospheric Administration, headquartered in Boulder, Colorado.

Solar disturbances were largely the concern of academics until 1994, when the federal government created the National Space Weather Program to support research into the storms. In 1996, scientists held the first space-weather workshop in Boulder. Since 2007, they have been meeting annually to discuss the latest research. Their reports, as well as ones from private industry, eventually alarmed the Obama White House, which in 2014 established a task force to devise a defensive strategy, coordinate government agencies and the private sector, and increase the quality of space-weather predictions.

There is a greater than 10 percent chance that a Carrington-scale event will happen within the next decade, according to a paper by Pete Riley of Predictive Science, a space-weather research company. That might sound like a small number, but it's higher than the chance of a major earthquake hitting California.

Scientists like Murtagh and Skov follow the sun's activity daily, so they see how it fiddles with tech in ways most of us fail to register. It is precisely because of that familiarity that they understand how serious even another Quebec-size event would be. Skov wants regular citizens to gain the same perspective. That's why, under the alter ego of the Space Weather Woman, she details for them the ups and downs of the sun's violent outbursts.

illustration by eBoy

"GPS is extremely susceptible, and just blindly trusting it is nuts," Skov says.

SKOV HAS OUTFITTED A DIY recording studio in her home in the San Fernando Valley, just far enough north of Los Angeles that you begin to think that maybe you're somewhere else. At the end of a road steep enough to require using a parking brake, she's a little closer to the sky than her neighbors. This fall morning, she's been working on a new video about why people should care about how the sun's behavior affects humans.

Skov stands in front of a big monitor paused on a frame showing Twitter statistics. We live, she says, in a brave new(ish) world. A solo space physicist can start her own branch of meteorology from a room right off her driveway. And she can also gather information—about aurorae, radio-communication problems, and GPS errors—from a global community.

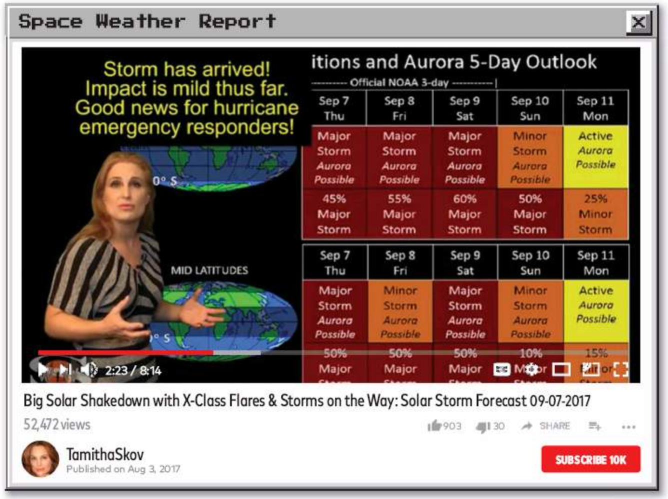
She moves away from the monitor and toward her camera. A green screen hangs from the wall to her right. The room shines with synthetic illumination: A ring light—like a luminous Life Savers candy—encircles the camera; across the room, a warmer bulb beams against a drugstore umbrella spray-painted silver.

The studio dates to her grad-school days, when Skov studied space physics at UCLA, was part of a pop alternative rock band, and ran a production company recording other musicians. After she graduated, she kept the studio going as she started work at the Aerospace Corporation, which gives guidance to the military, space agencies, and the private sector on research and development and technology transfer. There, Skov studied space weather's interactions with satellites. "I was beginning to get this big picture," she says. "This isn't 'space weather' as a cool term. This is space *weather*." Outside her professional life, she pivoted from audio to video production.

All of it spun together in 2012, as she grew concerned about the sun's threats. She took to Twitter, where people had questions—lots of them. And Skov had answers, sans jargon. "You put three words that are from the space-science field on Twitter, and you already walked all over your character limit," she says. Soon, she began producing short videos and putting them on YouTube. Then came the nickname and her likeness superimposed on the sun: the Space Weather Woman. The style reads as intense: close-cropped shots of the sun's flares that make the viewer feel less like it's a mysterious object 93 million miles away and more like it's right there with her—and so with them.

Initially, Skov kept her two identities separate. She used her married name in her forecasts and her maiden name on scientific papers. She thought the slimmed-down science might slam into the research community at the wrong angle. But peers found her anyway after a space physicist discovered her videos and sent them to a researcher listserv. Some scientists pointed out small inaccuracies. Others simply didn't like her "loosey-goosey" language, which didn't use their jargon, with its specific but impenetrable meanings. She took the legit criticism—it kept her honest, she says—and left the rest. "I think I'd rather be pelted with olives from scientists than pelted with olives from the public," she says. Now, researchers too watch her forecasts, along with 27,000 Twitter followers and 11,000 YouTube subscribers. "There is really nothing like it around," says Christian Moestl, a space-weather scientist at the Austrian Academy of Sciences. "Her YouTube videos and Twitter feed are watched by both researchers and interested public to see what's going on."

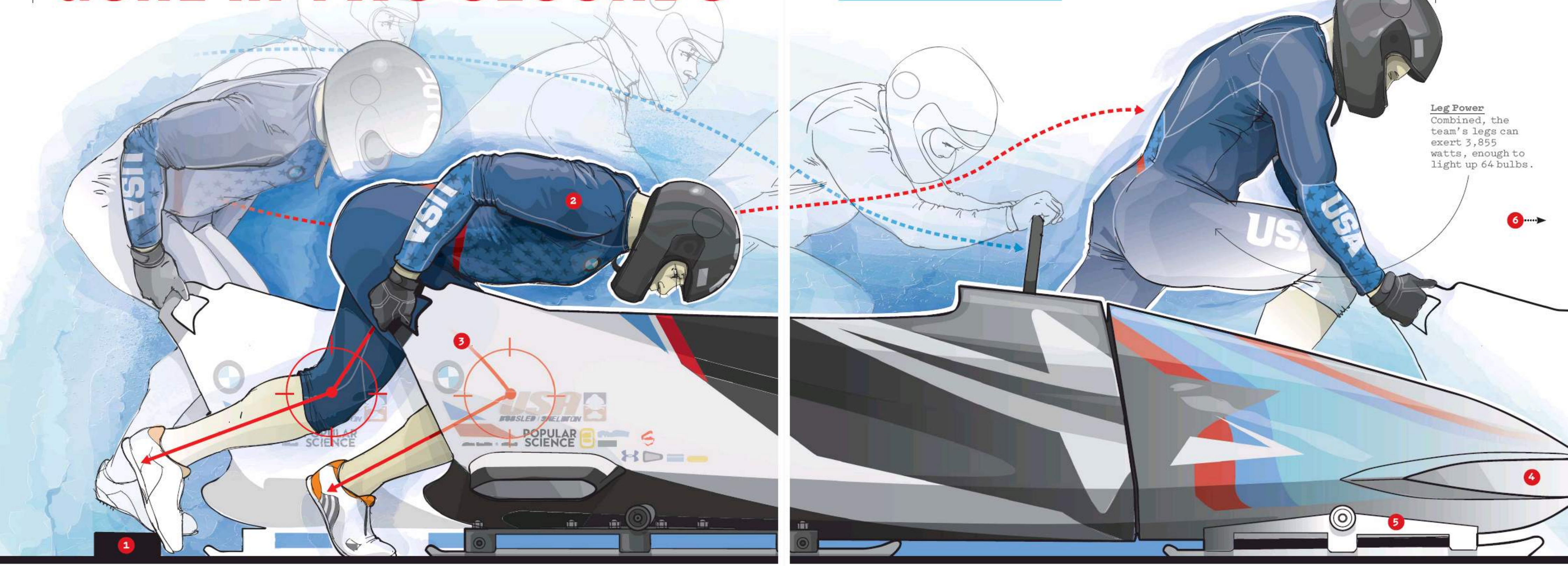
Skov's biggest fans are in the amateur-radio community: people with handsets and ham licenses. Radio operators see space weather scrape across Earth in real time when their broadcasts get blocked or enhanced. Amateur radio operator Tom Crow first found her forecasts on a program called *Ham Nation*. (CONTINUED ON P.84)



Threat level
Skov, a space physicist, films her reports in her home studio.

GONE IN TWO SECONDS

THE PUSH THAT KICK-STARTS A BOBSLED RUN IS ARGUABLY THE MOST POWERFUL MOMENT IN ANY OLYMPIC SPORT. WE DOVE INTO THE IDEAL FORM, EQUIPMENT, AND CONDITIONS THAT CONTRIBUTE TO THESE PIVOTAL SECONDS. **BY CLAIRE MALDARELLI**



ON TRACK

1 Picture a bobsled course as three sections: a 49-foot segment where athletes get their sleigh moving ahead of the starting line; a 65-to 100-foot portion they use to build up speed after the clock starts; and the remaining 4,000 or so feet down which they ride, twisting and turning, to the finish line. The first few runs of the day are always faster: Each one creates more friction-increasing ruts, upping times.

MUSCLEMAN

2 A two-person bobsled team includes a pilot, who steers the sleigh, and a brakeman (foreground), who does most of the pushing. This athlete must generate enough force to break the inertia of a 375-pound sled. He needs preconditioned fast-twitch muscles: larger tissue fibers capable of short, sudden exertions. That's why bobsled scouts often recruit sprinters from track and field or wide receivers from football.

THE BIG PUSH

3 When the buzzer rings, the brakeman steps onto the ice, gripping two handles on the sled's rear. He bends his knees, leans forward, and might lock his arms straight: This directs the force for the initial push horizontally, directly from the athlete's legs—not his relatively weak arms. Exerting a combined 5 horsepower, the team can bring the sled from zero to up to 15 miles per hour in just two seconds.

AERODYNAMIC OUTFITTERS

4 Air drags on a fast-moving sleigh, slowing it down. And the faster it moves, the greater that backward pressure grows. So designers give a bobsled a rounded, conical nose. As it moves, this pointy prow splits the air, decreasing wind resistance. The humans also make their bodies more aerodynamic by wearing skintight compression-fabric suits that help further reduce drag.

SLIP AND SLIDE

5 In ideal race conditions—a freezing, sunny day—a thin, unnoticeable film of water forms on the ice, making the surface extra slippery. Steel-alloy runners, sanded and shined, further decrease friction to allow the sled to slide. To improve traction, competitors wear shoes covered in 350 to 400 spiky steel needles, which cut into the ice with each step, allowing their feet to get a grip on the slick stuff.

CLOSING TIME

6 After that initial push, the athletes cross the starting line and continue pushing for another 65 to 100 feet. Then the pilot hops in, bringing the total weight on the brakeman up to about 575 pounds. He runs a few more steps, until his legs can't crank any faster, and jumps in just before the sleigh reaches 25 miles per hour. If perfectly executed, the push can shave enough time to put a team on the podium.

illustration by Mike Sudal

BUILD THEM UP? OR TEAR THEM DOWN?

WHY CAN'T WE DECIDE WHAT TO DO ABOUT NUCLEAR ENERGY?

BY MARY BETH GRIGGS
PHOTOGRAPH BY THE VOORHES

Beach bums
The shuttered hulks of San Onofre's twin reactors

LUIS SINCO/LOS ANGELES TIMES VIA GETTY IMAGES

WITHIN SIGHT OF THE SUNBATHERS AT Old Man's surf spot, 55 miles north of San Diego, California, loom a pair of 176-foot-tall orbs. They're a strange backdrop, home of the San Onofre Nuclear Generating Station. Since its first reactor fired up in 1968, the plant has powered millions of lives. But now these concrete and steel domes house a problem. Inside their frames sit millions of pounds of radioactive fuel no longer of use to anyone.

In 2012, a small radiation leak forced the shutdown of one reactor. Rather than go through the regulatory red-tape of restarting the remaining reactor at reduced power, Southern California Edison, the operator, decided to shutter the whole plant. This year, workers will begin dismantling it as part of the costliest and biggest nuclear decommissioning project ever attempted in the U.S. The initial deactivation should take 10 years, with 700,000 metric tons of infrastructure crushed and freighted off to burial plots in Utah, Texas, and Arizona. The most radioactive stuff—3.2 million pounds of spent uranium-235—will be interred on-site in steel-and-concrete casks that will dot the landscape like tombstones.

It's a fitting metaphor for what seems like the beginning of the end of America's nuclear-energy ambitions. San Onofre is one of 19 nuclear power plants in the U.S. undergoing decommissioning. Of the 99 remaining reactors in the U.S. fleet, as much as one-third might be taken offline within a decade or two. Some might apply for an extension. But many could close for good thanks to three things that are killing off nuclear energy worldwide: competition from cheap natural gas, the rising affordability of wind and solar generation, and fear of radiation-spewing accidents.

"The nuclear industry is pretty broken in the United States," says Armond Cohen, executive director of the nonprofit Clean Air Task Force, which advocates for low-carbon energies to combat climate change. Cost overruns and delays have hamstrung the few nuclear power plants that were under construction, in South Carolina and Georgia. Even if that weren't the case, nuclear today makes no economic sense, Cohen says. "You could build the most cost-effective reactor in the world, and it wouldn't beat the cost of a compressed-gas plant."

It's not just the U.S. industry. A number of other nations are dimming the lights on their nuclear plants. Germany, where eight reactors supply 13 percent of the country's power, has vowed to shut them all by 2022. Switzerland pledged to phase out its five reactors, which provide 40 percent of its energy. And France, which gets 75 percent of its energy from nuclear, vowed to slash consumption to 50 percent by 2025, only to back off that promise in November, worried that a shift from carbon-zero nuclear would prevent it from meeting its climate-change goals and lead to an electricity shortfall.

And yet a handful of other nations are accelerating toward a nuclear future. China, in trying to reduce its expanding reliance on coal, is aggressively pushing for more alternative fuels, with plans to increase its nuclear capacity to as much as 150 gigawatts by 2030, up from about 38 gigawatts in 2017. It is adding 20 new reactors to its current fleet of 37. Russia is building seven, India six, and South Korea three.

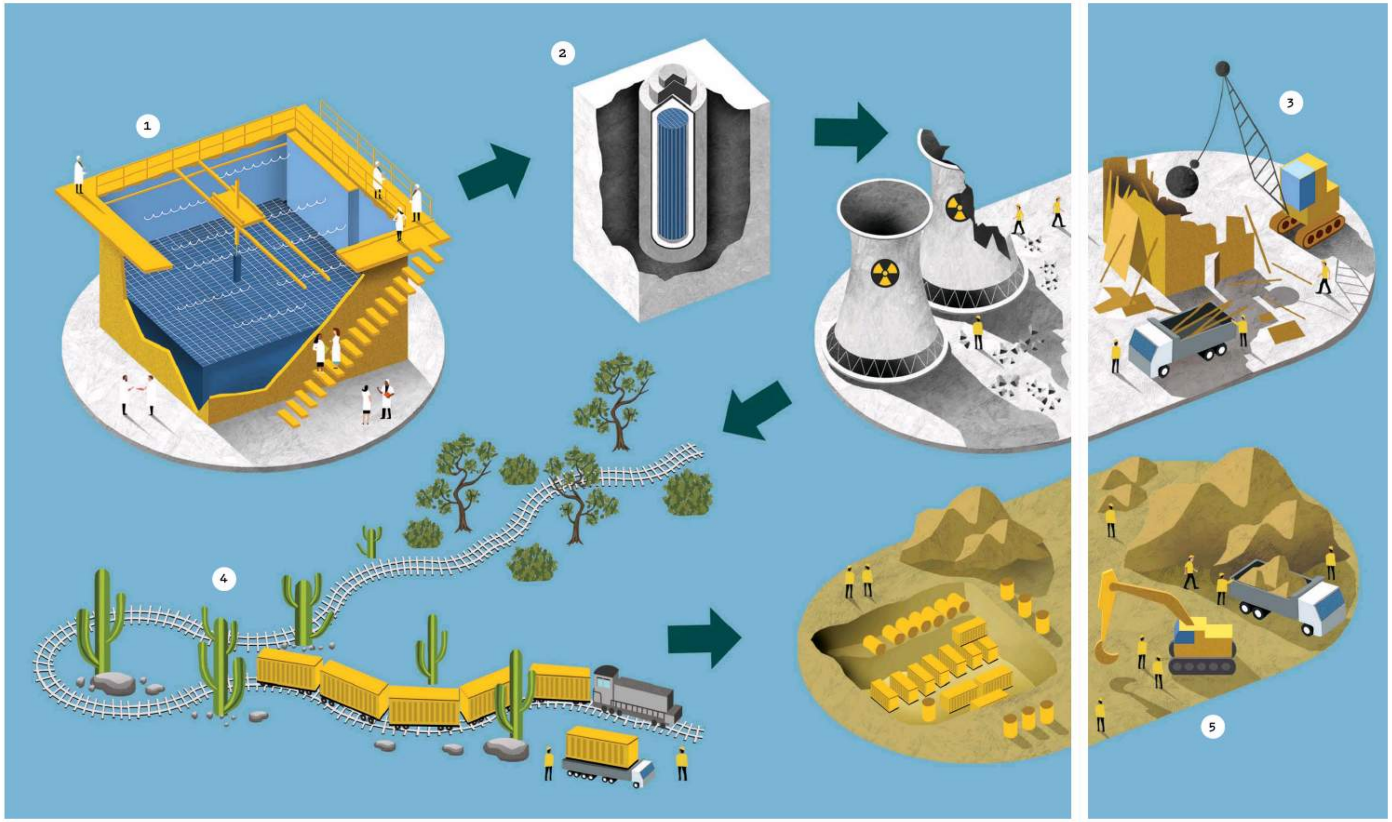
China, in particular, is pursuing novel reactor designs expected to run more cheaply, efficiently, and safely than those the world has used for decades. The most common today is the light water reactor, in which water cools solid nuclear fuel and generates turbine-spinning steam. Alternatives include a variation on the light water reactor called a small modular reactor that, in theory, could be built quickly and inexpensively, though its design will put out less energy. Another is a molten salt reactor that employs melted salts to cool fuel and produces less waste than the current fleet.

As the U.S. retreats from nuclear power, critics warn it is giving up on a source of electricity that is reliable and emits zero carbon, a boon to any nation looking to trade some of its fossil-fuel habit for clean power. Former Obama energy secretary and nuclear physicist Ernest Moniz cautioned as much this past July. At a summit on energy and security, he said abandoning nuclear would leave the nation vulnerable to environmental and strategic threats, by sidelining a greenhouse-emissions-free power and by weakening national-security interests:

Critics warn that the U.S. is giving up on a reliable energy source and leaving itself vulnerable to strategic threats.

UNBUILDING AN ATOMIC GIANT

INSIDE THE BIGGEST NUCLEAR POWER PLANT TEAR-DOWN IN THE U.S.



1 COOL IT
At the San Onofre nuclear power plant, workers transfer 2,668 fuel assemblies—holding 1,109 metric tons of radioactive uranium-235—to 17-foot-tall stainless-steel containers. These sit inside a deep, steel-lined cooling pool for several years, chilling at temperatures around 68 degrees Fahrenheit, until workers can move them to storage.

2 ENTOMB IT
After the fuel cools, workers fit the canisters into 20-foot-deep concrete casks embedded in the ground. The concrete helps trap the fuel's radiation inside, while vents circulate air to keep it cool. These casks, which will be monitored and guarded around the clock, are strong enough to withstand earthquakes, tsunamis, even the impact of a jet crash.

3 RIP IT
Remotely controlled tools cut up the highly contaminated equipment (less than .04 percent of the debris). Other robotic machines will remove the most tainted waste. Then workers—using hydraulic hammers, saws, and bulldozers—rip apart the buildings. Mundane office materials like shelving, furniture, and insulation fill out the junk pile.

4 SHIP IT
Demolition produces more than 25 million cubic feet of debris—rebar, concrete, and piping—enough to fill a decent-size college-football stadium. The San Onofre site hosts up to 60 rail cars at a time, waiting to cart off the low-level radiation debris. Trucks haul the nontainted stuff—75 percent of the total—to landfills in Texas and Arizona.

5 BURY IT
Freight cars carry the low-level radioactive debris—now packed in drums, bags, and large containers—to a nuclear-waste landfill in the Utah desert. Workers there check and document radiation levels, then bury the stuff in "embankments," from 8 feet below grade to 38 feet above grade, in sedimentary rock and covered in clay and rock. —*MBG*

COURTESY SCE&G

Suspended
South Carolina utilities have halted work on this reactor.

A brain drain of nuclear engineers and technicians to nuclear-hungry countries is sure to follow.

The historic irony is not subtle. The U.S. ignited the nuclear age, aided by scientists originally from nations such as Germany, Hungary, and Italy. After it demonstrated the horrific power of nuclear energy on Japan in World War II, the U.S. military and commercial researchers looked for ways to exploit the technology. An early success: nuclear powered submarines that could travel underwater almost indefinitely. The sub's reactor design quickly became the basis for the light water reactors we use today. The problem is the uranium in a number of those reactor designs operate at high temperature, requiring a massive amount of water to keep from overheating. If anything—for instance, a natural disaster—disrupts the plant's safety system, the reactor core can melt down, releasing radiation into the environment.

A Cold War nuclear boom saw hundreds of light water reactors spread across the U.S. and Europe. As they proliferated, public fears grew alongside them, and by the 1970s, movies like *The China Syndrome* evoked the horrors of what might happen if something went wrong. Weeks after that movie's release in 1979, it did. A partial meltdown on March 28 at Three Mile Island, near Harrisburg, Pennsylvania, rattled the nation. In 1986, an explosion at a plant in Chernobyl, Russia, and its subsequent radiation contamination of 90,000 square miles galvanized public opinion. Finally, in 2011, a 9.0 magnitude earthquake and tsunami triggered a series of events that led to a core meltdown in three reactors at Fukushima, Japan.

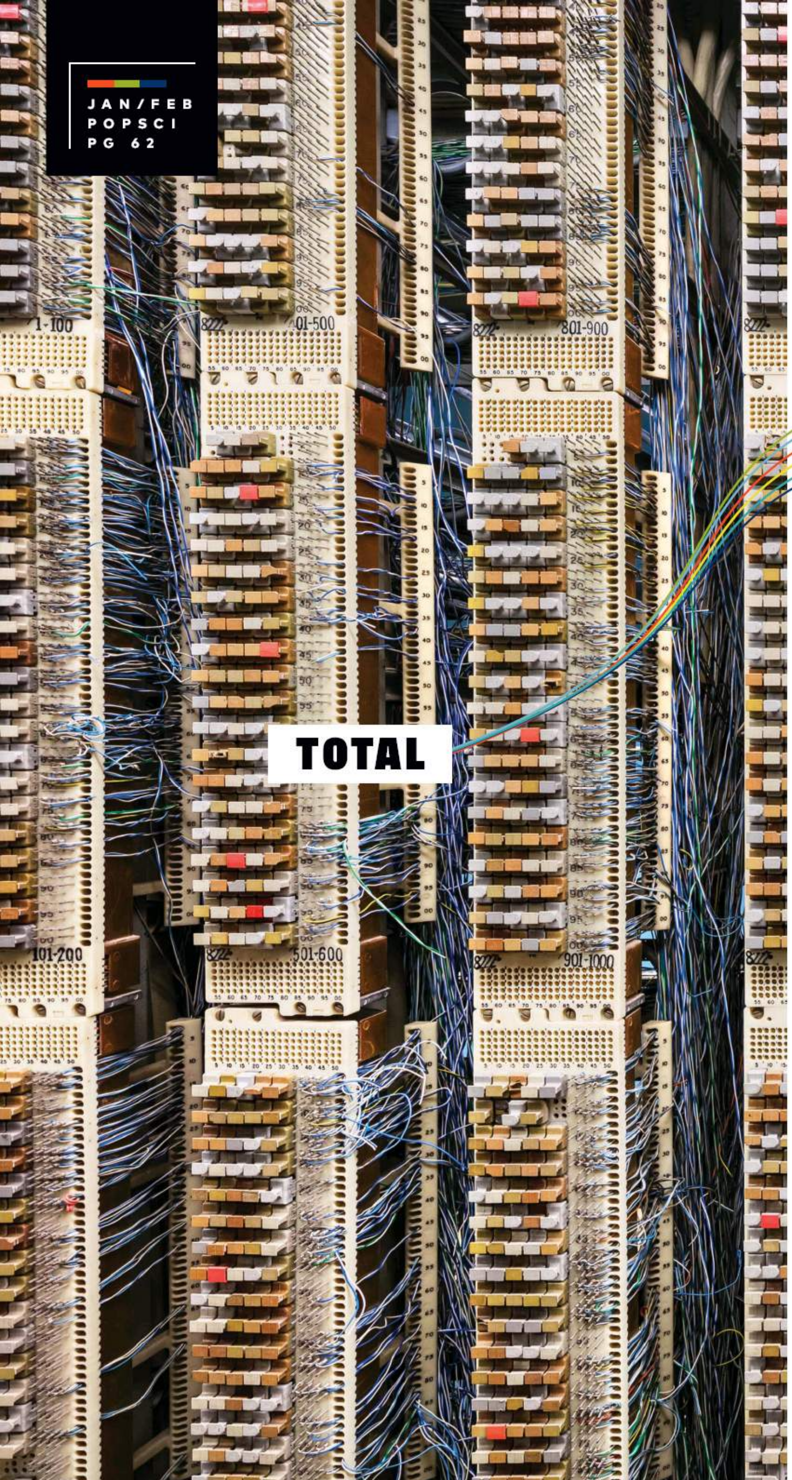
This history of rare yet dramatic accidents was enough to sway public sentiment, but the availability of cheap natural gas made the choice easy. Much of the world that once embraced nuclear is now dealing with hundreds of silenced reactors and with cleaning up thousands of acres dotted with steel and concrete hulks and spent fuel. A $222 billion industry has sprung up to decommission these behemoths.

THE CHOREOGRAPHY OF UNBUILDING a nuclear power plant is complicated and requires hiring companies and workers that specialize in the process. In the case of San Onofre, it's the Los Angeles-based AECOM and EnergySolutions, headquartered in Utah.

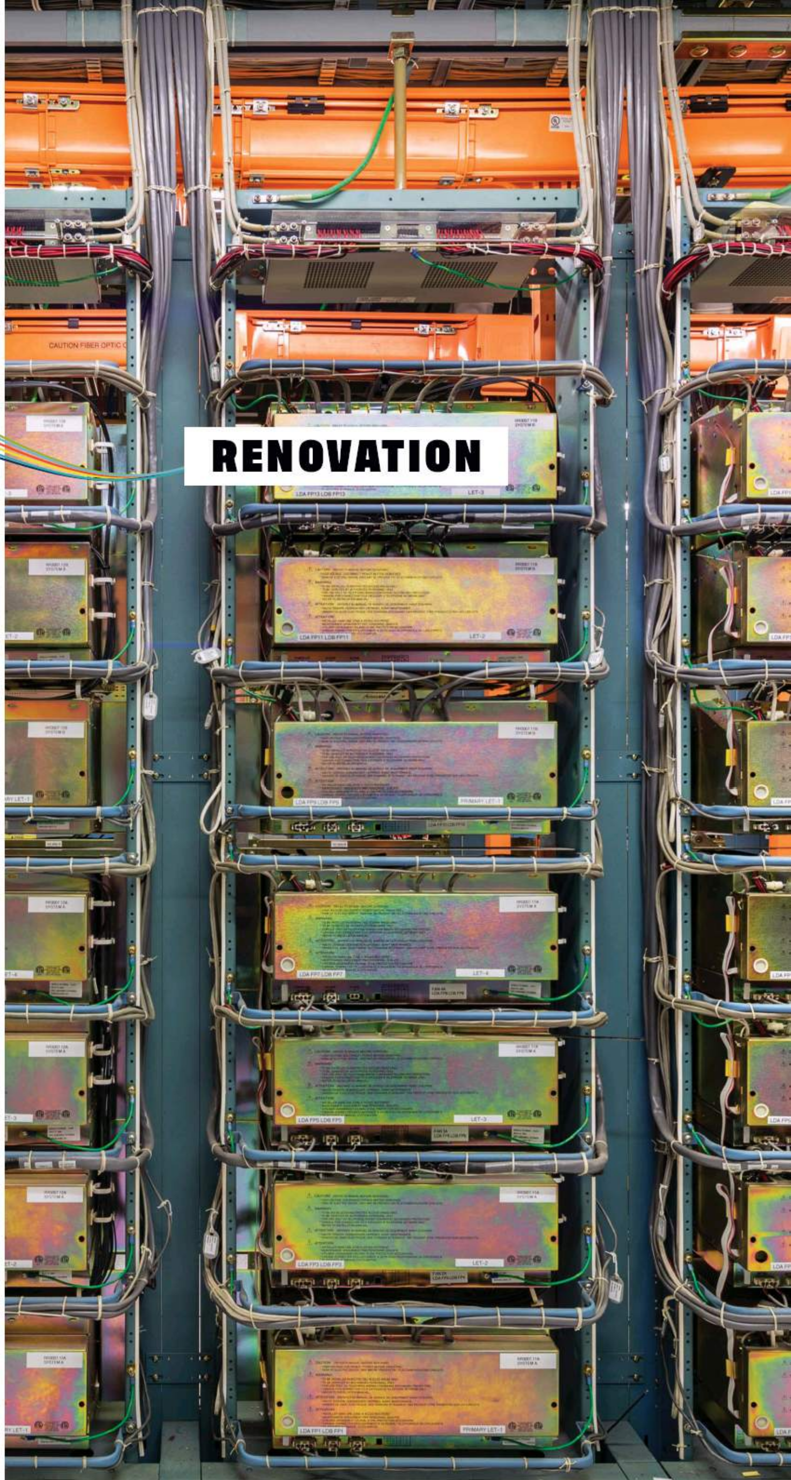
The $4.4 billion project aims to sweep clear most of the narrow 85-acre beachfront site. Workers have already moved the plant's spent fuel into steel-lined cooling pools. After it has sat there for several years, workers will transfer it to 73 steel canisters and then tuck these inside 25-foot-tall monoliths next to the domes.

This repository will sit just 125 feet from the Pacific, behind a seawall that rises 28 to 30 feet above sea level. Its proximity to the coast—and to the 8 million people who live within 50 miles—means many of them want the waste gone. Last April, protesters dressed in hazmat suits and carrying surfboards marched through San Diego demanding the waste's removal. The utility wants it gone too, but it has to keep it safely on-site for now. Tom Palmisano, vice president and chief nuclear officer at San Onofre, says that the storage system, known as dry cask, is designed to withstand an airplane crash, tsunami, even ground acceleration from a nearly magnitude 7.4 earthquake. (CONTINUED ON P.86)

illustration by Adam Simpson

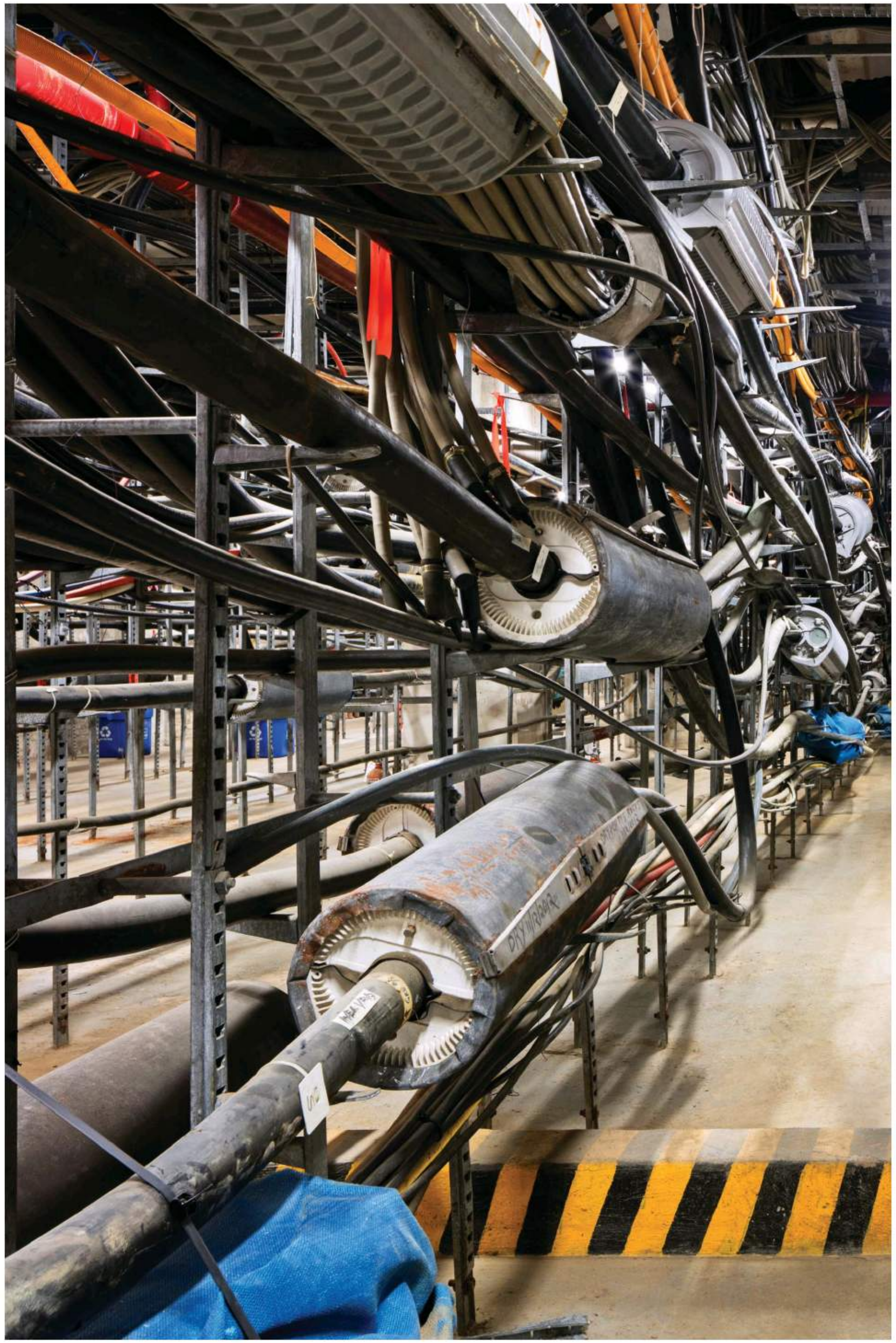


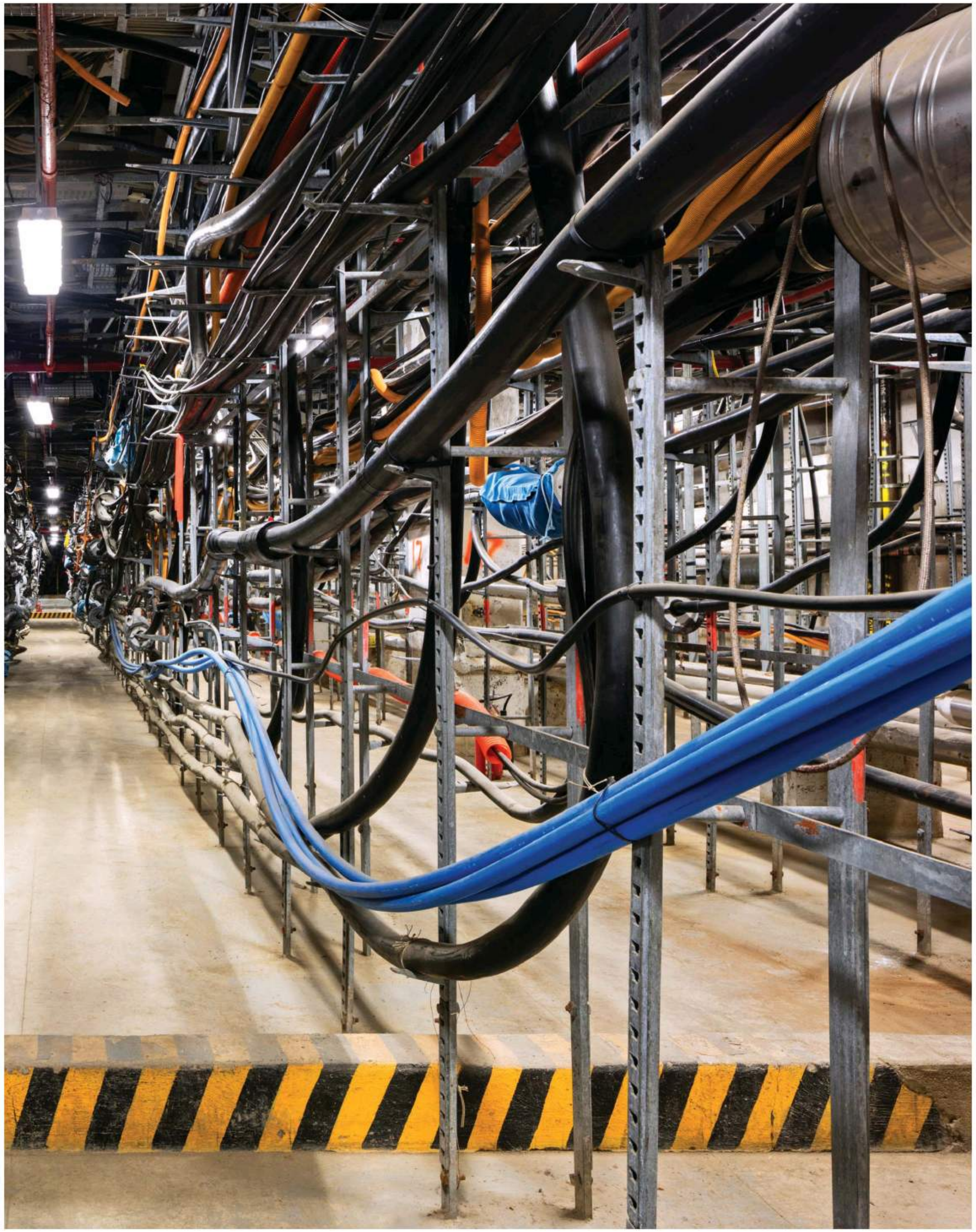
TOTAL GUT RENOVATION



THE CABLES THAT KEEP INFORMATION FLOWING THROUGH THE BIG APPLE ARE UNDERGOING A TRANSFORMATION, FROM AGING COPPER TO STRONG AND FAST FIBER. IN TELECOM BUILDINGS AROUND THE CITY, LINES THAT ONCE SNAKED ACROSS HUGE FRAMES (LEFT) NOW FEED INTO COMPACT FIBER- OPTIC HUBS (RIGHT).

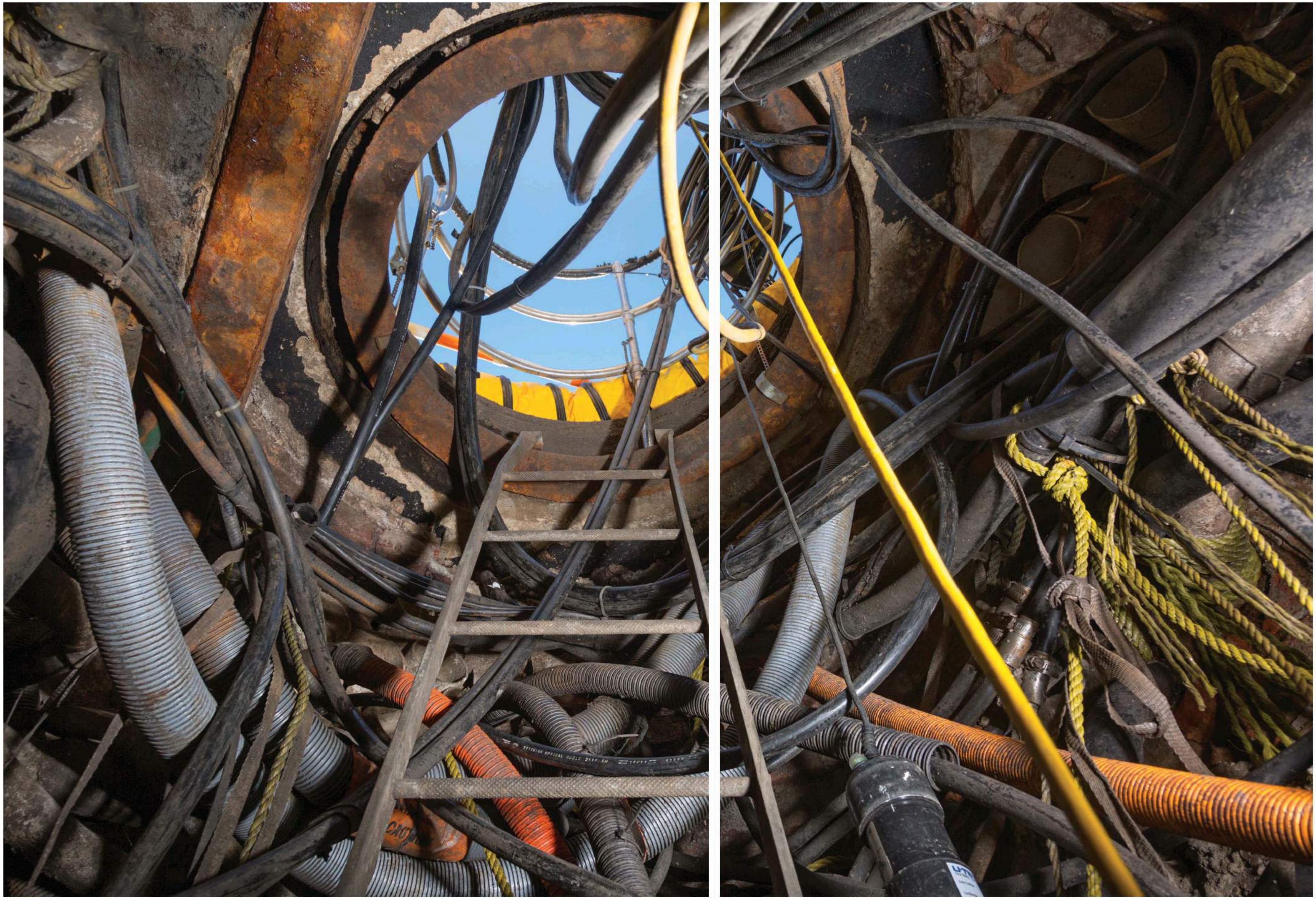
PHOTOGRAPHS BY CHRISTOPHER PAYNE
TEXT BY CORINNE IOZZIO





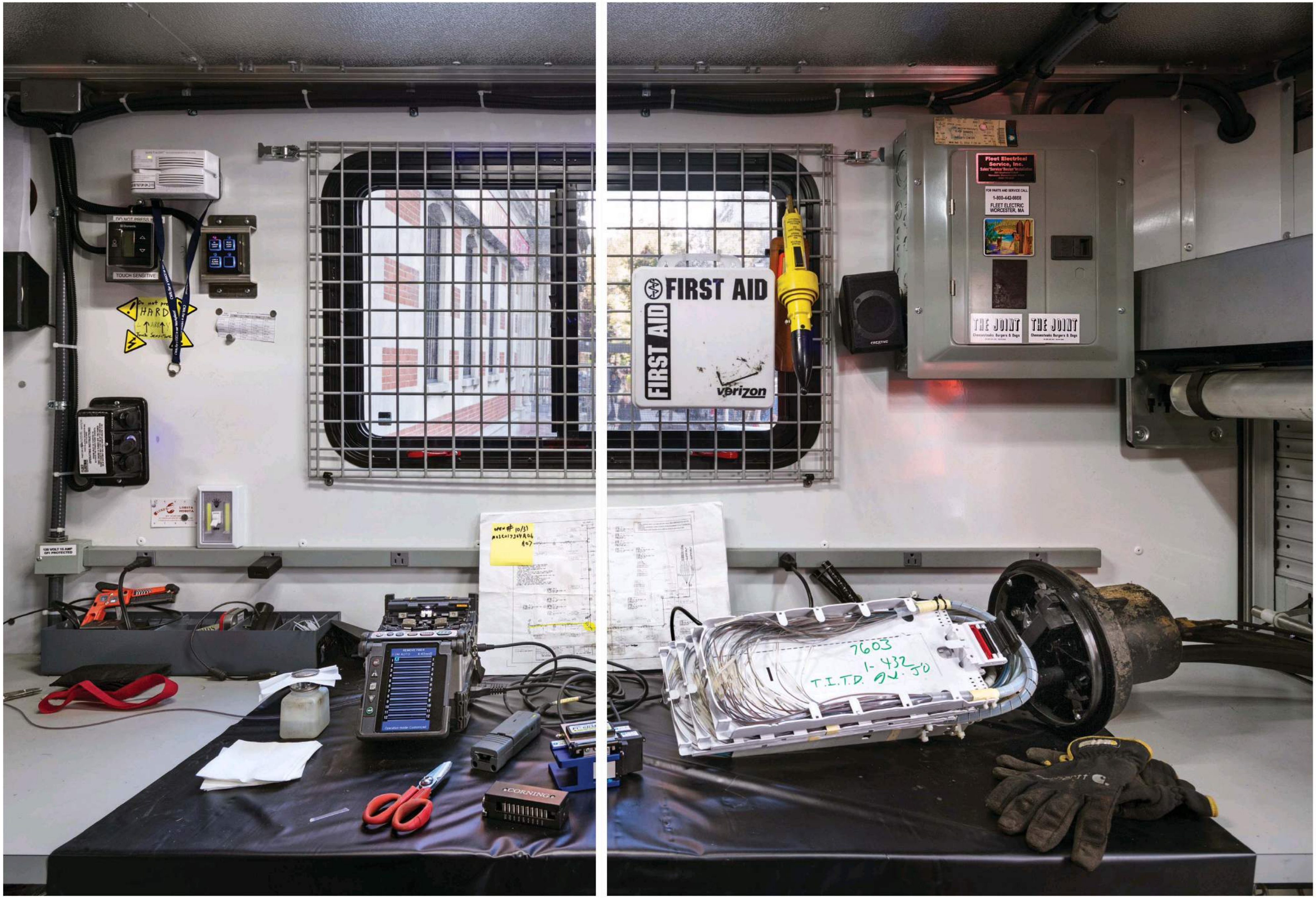
The Vault

In the topmost of five subbasements at 140 West Street in Lower Manhattan, Verizon phone and data lines wind in from the surrounding neighborhood to connect customers with switches and network hubs upstairs. The thick, black sheaths house copper cabling, which the telco giant is working to phase out. The yellow tubes tucked up close to the ceiling hold the new fiber-optic lines. These conduits manage the same data haul as copper, but in far less space.



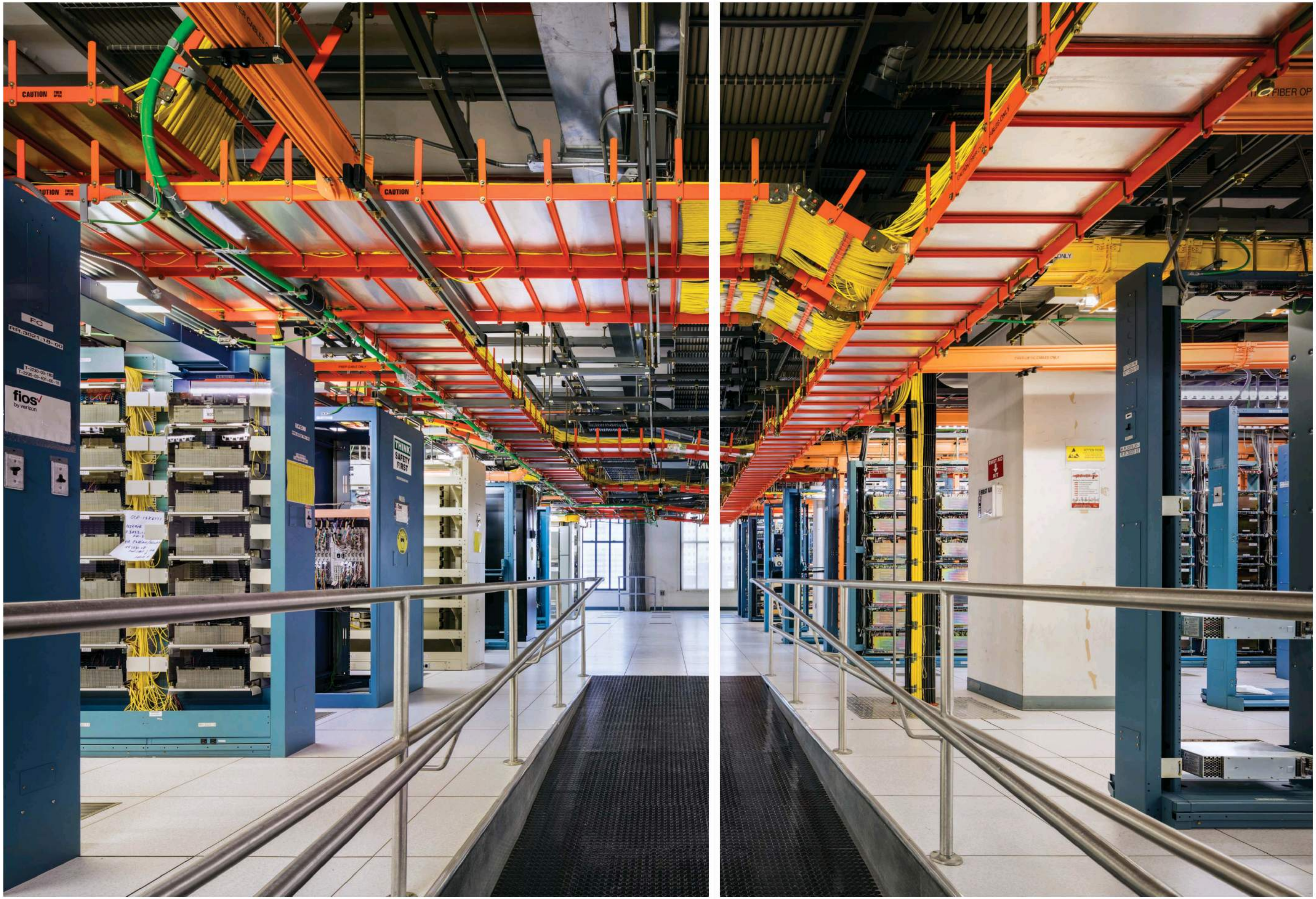
Intestinal Fortitude

Telecom workers pop open manholes throughout the city to extend the five-times-faster fiber network into more buildings and neighborhoods. The existing lines snake through orange and gray tubes below the street, so workers must pull them above ground to connect new stretches of the glass-based cable. The fragile copper it's replacing (seen encased in black) corrodes when wet and, if broken, requires laborious manual mending.



Splice of Life

In a clean truck above the open manhole, workers fuse the surfaced fiber to fresh cable (seen wrapped around a frame on the right of the workbench) in a process called splicing. A purpose-built machine (at left) hits 3,632 degrees to melt and join the lines. The screen shows the fiber's internal glass strands (there can be 24 per cord) and indicates when each new link is working. The process takes seconds, but the two-man teams need anywhere from 30 minutes to a few hours to repeat it for each cable of fiber at a given job site.



Light Show

Back at 140 West Street, networking equipment shuffles the fiber-optic demands of customers: packets of Netflix streams, Facebook updates, or business dealings from One World Trade Center across the street. These light-based signals can travel farther and faster than the electrical pulses in copper-based DSL lines, and use only a fraction of the energy.

TALES FROM THE FIELD

ROCK AND ROLL

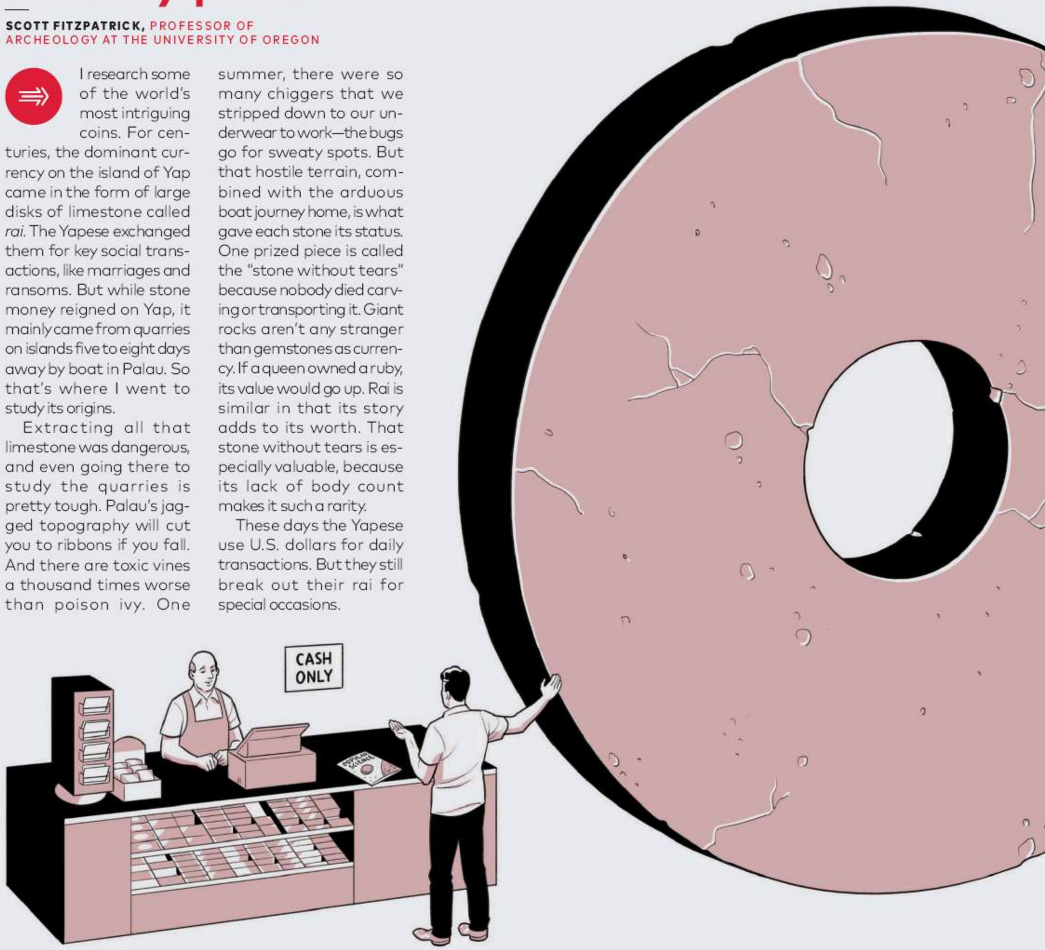
a heavy price

SCOTT FITZPATRICK, PROFESSOR OF ARCHEOLOGY AT THE UNIVERSITY OF OREGON

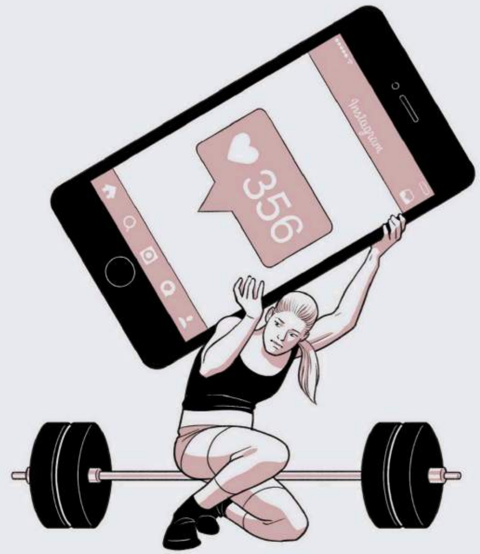
I research some of the world's most intriguing coins. For centuries, the dominant currency on the island of Yap came in the form of large disks of limestone called *rai*. The Yapese exchanged them for key social transactions, like marriages and ransoms. But while stone money reigned on Yap, it mainly came from quarries on islands five to eight days away by boat in Palau. So that's where I went to study its origins.

Extracting all that limestone was dangerous, and even going there to study the quarries is pretty tough. Palau's jagged topography will cut you to ribbons if you fall. And there are toxic vines a thousand times worse than poison ivy. One summer, there were so many chiggers that we stripped down to our underwear to work—the bugs go for sweaty spots. But that hostile terrain, combined with the arduous boat journey home, is what gave each stone its status. One prized piece is called the "stone without tears" because nobody died carving or transporting it. Giant rocks aren't any stranger than gemstones as currency. If a queen owned a ruby, its value would go up. Rai is similar in that its story adds to its worth. That stone without tears is especially valuable, because its lack of body count makes it such a rarity.

These days the Yapese use U.S. dollars for daily transactions. But they still break out their rai for special occasions.



as told to Kendra Pierre-Louis / illustration by Anuj Shrethra



GAINS

my powerlifting pulpit

CASEY JOHNSTON, WRITER OF THE HAIRPIN'S ASK A SWOLE WOMAN COLUMN

When I'm telling the story of how I became a lifting evangelist, the aesthetic changes I had hoped for—and achieved—come up a lot. Lots of women get into lifting just to lose body fat, and others are afraid to try it because they think it will make them look bulky. But the more important narrative isn't how my looks have changed, it's about becoming stronger.

Powerlifting changed my most basic interactions with the world. Picking up groceries, reaching to grab something, or even going up stairs—it's all effortless. You just feel powerful, even as someone who's not that coordinated or athletically skilled. The mechanics of a dead lift or a squat are designed to use your body's strongest muscles in the most effective possible motion—the motions you need to navigate everyday life. Your body wants to work like this. You're building and growing in places where it's natural for you to get stronger, and you feel it quickly. That was three and a half years ago. I hate to say I've "fallen in love" with lifting, but it did take the pressure off everything I used to worry about concerning my body and food.

That's why I started my column. I built this constructive relationship with my body where I fed it properly and gave it the optimal type of work, and that afforded it an opportunity to get stronger by building muscle. It's philosophical for me, and I don't think I'm alone in that. People write to me out of the blue saying: "I found your column, I read it, I took up lifting, and it changed my life. I'm so grateful."

as told to Sara Chodosh

GIRL POWER

hyperloop high

ELIZABETH AWAD, SENIOR AT ST. JOHN'S SCHOOL IN HOUSTON, TEXAS

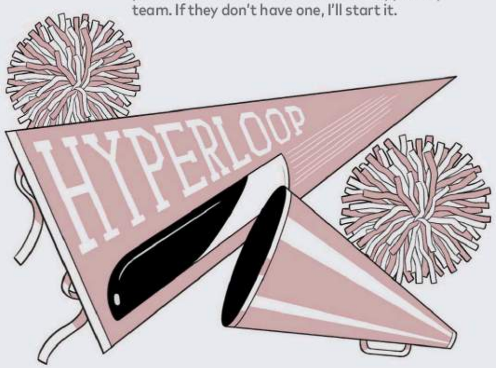
When my older brother found out about the SpaceX-sponsored hyperloop competition in 2015, he immediately started a team at our high school—and I wanted in. We needed to design a pod that could carry passengers on the kind of high-speed-rail system Elon Musk proposed.

We wound up with the most detailed, intricate blueprint we could think of. It took a year of early mornings and late nights in our workspace at school to figure out how to turn those plans into something six students could actually build. It was always design, redesign, build, rebuild. Persistence was the most important part of the process.

At the big event at SpaceX HQ in California in January 2017, we were the only high school team left in the competition. Then, three days before we had to prove our pod could levitate, the air-compression system blew. Even though it was a contest, everyone was super collaborative; we asked other teams what they thought was wrong, and called air-compressor companies for advice. Having all that input paid off: We rebuilt in time to be the first vessel to levitate in the test vacuum. Seeing our pod finally hover in place was the most amazing feeling.

We came in ninth place overall, and I am determined to keep participating. I'd heard that women have a harder time in STEM, but I didn't really get it—my mom is a doctor and my grandma is a chemist. When I got to SpaceX, I looked around and saw that there were 25 girls in a room of 400 competitors. It shocked me. Since then, I've been working with elementary schools to inspire young girls to get into these fields. Underrepresentation is unacceptable.

I believe this is our future. I'm planning to study engineering when I go to college next year. Wherever that is, I'll be on the hyperloop team. If they don't have one, I'll start it.



as told to Rachel Feltman / illustrations by Anuj Shrethra

SHOCKING SCIENCE

don't fry this at home

KEN CATANIA, PROFESSOR OF NEUROBIOLOGY AT VANDERBILT UNIVERSITY

In 2014, I set out to write a book about predator nervous systems. I got some electric eels to observe and photograph for a chapter about electrogenic fish. I could have just read existing studies on the animals and their behavior, but I wanted to get to know them for myself.

Soon I noticed something interesting. A fish would speed by the eel, and 3 milliseconds later, the zippy swimmer would freeze like a statue. It was like a superpower. That's how I got hooked. Eventually, we found that eels use high-voltage pulses to remotely control nerve fibers in nearby animals.

And here's another twist: Imagine that you duck behind your bed to hide from a monster. Then suddenly you jump up off the ground, and you didn't even try to do it. That movement would give you away. If you're hiding from an electric eel, all it has to do is fire off a blip of current to make you twitch. That tells it exactly where dinner is hiding.

But defensive moves take a little more muscle. Eels don't always have enough power to take down predators while they're swimming underwater. It's best if they break the surface and deliver the shock directly, skin to skin. To see how efficiently an eel passes current in the open air, I actually let a small one jump up and zap my arm. It felt like the shock from an electric fence, but the pain was worth it to get the data.

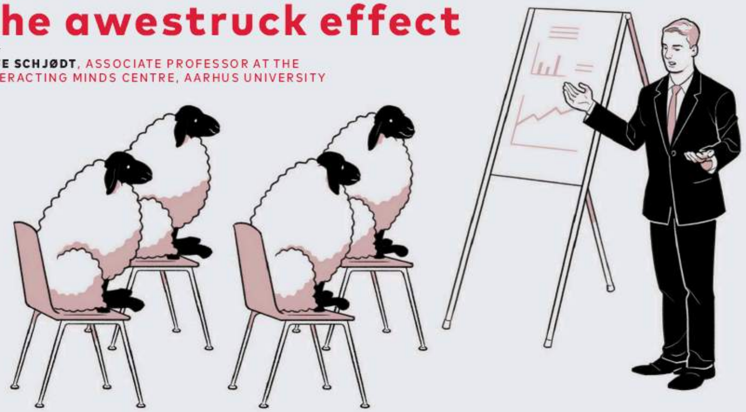
I never did finish writing that book. These discoveries are a great way to procrastinate.

as told to Ellen Airhart / illustration by Anuj Shrethra

SHEEPLE

the awestruck effect

UFFE SCHJØDT, ASSOCIATE PROFESSOR AT THE INTERACTING MINDS CENTRE, AARHUS UNIVERSITY



I study social psychology, especially the effect that charismatic religious leaders can have on their followers. In one of my group's studies, we brought in Christians who believe in the healing powers of the divinity. Using an fMRI machine, which highlights active areas of the brain, we saw that when they listened to prayers from healers, areas associated with reasoning and skepticism were immediately suppressed. Nonbelievers didn't have the same apparent loss of rational thought.

We all experience versions of that. Many bosses exert this kind of charisma, and it likely causes the same brain behavior.

My colleagues and I think this could be a survival mechanism. Spending all your time on critical thinking keeps you from getting everything else done, so you build trust in other people. You're allowing others to think for you. But the power of charisma doesn't come from any particular skill in the person influencing you. It's all about the faith you put in them.

Understanding how this all plays out neurologically has completely changed the way I interact with the world, but that's not necessarily a positive thing in every scenario. It's ruined my relationship with doctors. Sometimes I wish I could just blindly trust that my physician is prescribing me the right medication.

But I've come to appreciate that trust needs to be earned—whether it's in a doctor, a news source, or a person of authority.

as told to Claire Maldarelli

GENTLY 'CROSS THE ARCTIC

In 2017, Alex Gregory led the Polar Row expedition on a path through the Arctic Ocean.

2
Olympic gold medals in rowing Gregory has won for England.

600
Miles his crew rowed in the Arctic Ocean over the course of 13 days.

11
World records set, including northern-most latitude for a rowing crew.

UNLUCKY BREAKS

struck down in his prime

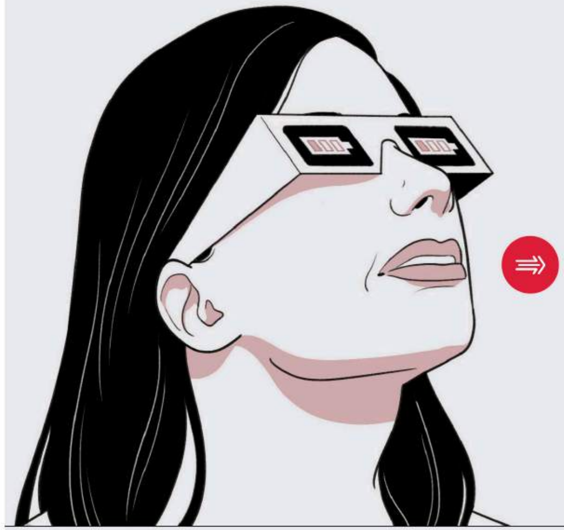
MARTHA ROBBINS, RESEARCH SCIENTIST AT THE MAX PLANCK INSTITUTE FOR EVOLUTIONARY ANTHROPOLOGY

Big fights between gorillas don't happen that often in Uganda's Bwindi Impenetrable National Park, but when they do, it's all about what we call dominance turnovers—changes in power. One of the most memorable involved an ape called Rukina. In 2001, the young male challenged his leader, Zeus, for control. Leaders decide where the group forages and get to mate with the females, so there's a lot of competition.

The struggle between them lasted for three years—until Rukina grew strong enough to beat Zeus in a fight. Rukina ruled for 11 years, attracting new members, and we all thought he would lead the band for several more. Then one day I got word from my team that Rukina was dead, but not at the hand of another silverback. He was struck by lightning while lying in his nest. To me, accidents like these seem even more shocking in the animal world.

It was a good reminder of how quickly things can change when you're on top—literally in a flash.

as told to Mary Beth Griggs / illustrations by Anuj Shresthra



ON THE BRIGHT SIDE

total eclipse of the power grid

SAMMY ROBERTS, DIRECTOR, SYSTEM OPERATIONS, DUKE ENERGY

On your average August day, about 6 percent of the power generation we oversee in the Carolinas comes from solar. So we knew we'd see some kind of impact as the 2017 total eclipse darkened our sky.

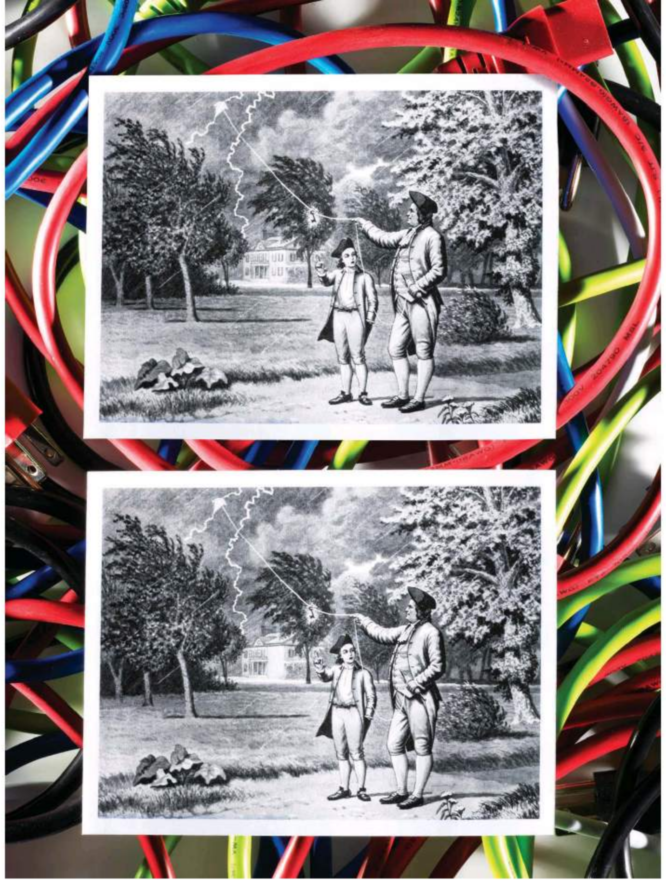
We worried that people flocking in to see it would clog up the roads and keep us from responding to problems, or that all the livestreaming would bog down the cellular channels we use to acquire data from the field.

What we actually saw was a big *drop* in power usage, probably due to the no-sun decline in temperature—less AC use—and the fact that everyone shut down whatever they were doing to go outside. Gas-fired generators had no problem making up for the missing solar.

So, it all went pretty smoothly. But it's still a once-in-a-lifetime event. Who else can say they've had to figure out how an eclipse would affect our electricity?

as told to Rob Verger / illustration by Anuj Shresthra

HEAD TRIP



THE HOUSE IN THE TOP IMAGE HAS FOUR RIGHTMOST WINDOWS. THE ONE BELOW HAS NONE; TWO TREES ON THE LEFT HAVE NO SHADOW IN THE BOTTOM IMAGE; A PLANT IS MISSING FROM THE SHRUBS TO THE LEFT OF BEN'S FEET.

KEY INFORMATION

why it's so hard to spot the difference

trip meter: real world — westworld

GAZE AT THE TOP IMAGE OF BEN Franklin's famous kite study. Now, the one below it. See the changes? *(Answers to the right)*

You probably can't, and you're not alone. In fact, what psychologists call change blindness is really a power struggle raging in our brains.

When we view something, we notice big details—the people, the forest they are in, perhaps the house in the back—and fail to zero in on less important features like the number of shrubs in the forest or the house's finer details (hint, hint). Dan Simons, a psychologist at the University of Illinois at Urbana-Champaign, says that's because if we spotted everything, we'd be unable to focus our attention. So our brain fails to log details it deems unimportant. When we flip back and forth trying to find them, we can't because we never noticed them in the first place. However, once we do see the disparity, it gets stored as one of the obvious elements, and then we can't seem to unsee it.

Simons says he's not surprised we don't encode everything we see. What shocks him is that people think they do. Some of his study participants claim to always notice Hollywood continuity errors—like when the number on John Connor's escaping Cessna 172 Skyhawk changes in the third *Terminator* movie. When, in fact, they often miss them, he says. "We're not aware of all of the changes we never saw."

by Ellen Airhart / photographs by Brian Klutch

ILLUMINATING

batteries not required

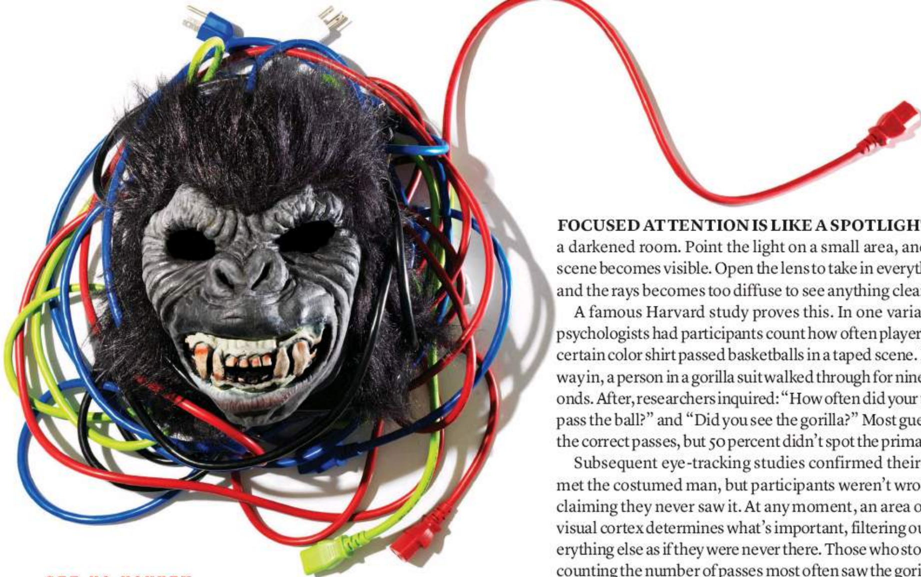
ROLL THIS MAGAZINE INTO A TUBE. NOW, keeping both eyes open, look through it with one eye. Compared with the plain view, the tube-filtered scene will seem brighter, as if lit by a flashlight. This makeshift torch will even make textures and patterns pop.

No one has a definitive explanation for this false illumination. Neuroscientists' best guess is that it has something to do with the way our brain interprets contrast. Within a tubular sight, the circular border appears darker than the environment within it. This triggers something called the brightness enhancement effect, in which your perception of an object's luminosity changes when you view it alongside something else. In fact, researchers found that the interior view appears nearly twice as bright as what's outside it.

This trick isn't just a fun thing to do with *Popular Science* after you've read it cover to cover; it has practical applications too. Radiologists sometimes use the illusion's power to make out faint yet potentially important details on scans, like a slight bone fracture or a tiny tumor. Even if the light is all in our head, in a pinch, it still works.

trip meter: real world — westworld

by Nicole Wetsman



SEE NO MONKEY

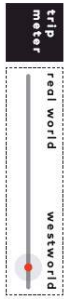
I'm looking through you

FOCUSED ATTENTION IS LIKE A SPOTLIGHT IN a darkened room. Point the light on a small area, and the scene becomes visible. Open the lens to take in everything, and the rays becomes too diffuse to see anything clearly.

A famous Harvard study proves this. In one variation, psychologists had participants count how often players in a certain color shirt passed basketballs in a taped scene. Halfway in, a person in a gorilla suit walked through for nine seconds. After, researchers inquired: "How often did your team pass the ball?" and "Did you see the gorilla?" Most guessed the correct passes, but 50 percent didn't spot the primate.

Subsequent eye-tracking studies confirmed their eyes met the costumed man, but participants weren't wrong in claiming they never saw it. At any moment, an area of our visual cortex determines what's important, filtering out everything else as if they were never there. Those who stopped counting the number of passes most often saw the gorilla.

Study author Chris Chabris says we should embrace this visual hiccup when tempted to multitask: We gain so much by focusing, why lose it to notice everything?



by Claire Maldarelli

(CONTINUED FROM P.41) reliable storage that can bank surplus power from wind and solar, and then release it on command. So far grid operators have found two solutions. One is the type of storage found in batteries. Another relies on de facto storage: smart devices that control power demand on appliances, mediating between peak-production and peak-demand times. Lippert and her team are looking at both solutions. In the second bucket, they've backed a company called Shifted Energy.

Shifted has retrofitted its grid-interactive devices onto water heaters at Kapolei Lofts, an affordable-housing complex. During the day, when there is excess solar on the grid, the devices can turn on the heaters (when few are at home and using them) to preheat H_2O for evening showers. By equipping 1,000 water heaters with these devices, Shifted estimates it is creating up to 3 megawatt hours of storage from the excess solar.

Landlords love this project because it saves money on electricity bills. Governments love it because it brings the less affluent into the renewables revolution. And utilities love it because those are 3 megawatts—enough to power up to 1,000 homes—that it doesn't have to produce and deliver during peak evening demand.

Water heaters are not the only tool in Lippert's arsenal of storage alternatives. Since the start of the Industrial Revolution, companies have used metal flywheels as crude storage devices. Heavy spinning discs, they hold kinetic energy in their rotation. But because of their weight (100 pounds or more) and friction on bearings, they traditionally allow for a few minutes of emergency supply. That could change with a company Elemental is backing called Amber Kinetics.

In 2009, Edward Chiao, a UCLA engineering grad, teamed up with Seth Sanders, a UC Berkeley professor who had been researching flywheels since the 1990s, to found Amber. Together, they built a vacuum-sealed container and placed a 5,000-pound steel disc on a spindle inside and under a magnet. The magnet keeps the wheel from exerting too much downward force on the ball bearings and slowing down. Daytime solar power can spin the wheel, and after sunset, it can release up to 32 kilowatt hours of electricity (enough to power an average U.S. house for a day). In theory, flywheels could be scaled up to release hundreds of megawatts for up to four hours, enough for peak evening demand. Amber is testing its flywheel at Hawaiian Electric to evaluate its reliability and cost effectiveness at relieving Oahu's daytime oversaturation of solar. Peter Rosegg, a spokesman for Hawaiian Electric, says the utility is open to this and all forms of storage. It plans for the batteries from electric cars to someday play a huge role in demand shifting.

IT'S LATE SUMMER, AND LIPPERT and I are walking through downtown Honolulu. The sun is out, and the natural optimism of the climate is almost oppressive. Lippert is preparing for a three-week stint training a new set of entrepreneurs, in which she'll stay up one night until 2 a.m. singing karaoke with them. Right now, she's refreshed and enthusiastic. I ask the point of pushing to 100 percent. Wouldn't getting to 70 be good enough, and let natural gas handle the rest? She admits the last 30 percent is "exponentially" harder than the first 30, but argues the effort is worth it anyway. "What is the danger of not doing this?" she says. "The risk of not doing this is greater than the risk of doing it."

And, she points out, Hawaii is already proving the skeptics wrong. Renewable use jumped from 8 percent in 2008 to 27 percent in 2017. Moreover, the state has an aggressive schedule to roll out another 400 megawatts of wind and solar in the near future. Based on this pace, Hawaiian Electric recently put out a report estimating that it would reach the goal of 100 percent five years earlier than mandated by law, or by 2040.

That outlook is based on a few unproven assumptions. Looking out 20 years, for example, the state's power plan says it will get hundreds of megawatts of offshore wind by using floating turbines, anchored to the sea floor. This hasn't been done anywhere at an affordable scale, but Hawaii has enough faith in the emerging technology to include it.

And the state, like every place going 100 percent renewable, bets big on electric cars as its future transportation mode. Car batteries will play a crucial role in taking excess energy off the grid during peak solar hours and returning it at night if needed. Hawaii has the second-highest penetration of electric cars in the U.S., but it's still under 1 percent.

After five years, Lippert can claim that a handful of (CONTINUED ON P.87)

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Just as food supplies energy, this is the only water that supplies the extra energy you may need to live longer!

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We have **13 International Patents, 332 FDA Tests.** You've seen the ads: "I've fallen, and I can't get up!" Why can't they get up? Because they lack the needed arm strength. On the contrary, I am now in my 88th year and I warm up curling 50-lb. dumb bells in each hand, though strength usually starts to wane at 81. I could still reverse curl over 200 pounds at 68. Witnesses said it's a World Record.

HYDROGEN BOND ANGLE CAN BE CHANGED

With an **Engineering Degree** that includes Steam Plant Design, in college I was taught that distilled water with a **Hydrogen Bond Angle (HBA)** of only 101° was worse than tap water with an HBA of 104.5°. **My water property change to HBA 114° was confirmed to *The Washington Times* by the Los Alamos Nuclear Lab:** "He did change the Hydrogen Bond Angle in water and we wish we owned his patents!" (Video at JohnEllis.com created after a 1/27/92 *Washington Post* investigative article: "10,000 people a day said it cures anything, even cancer and diabetes.")

SOMETHING YOU CAN MEASURE

That article also included an International Patent Description: "The **curative power** results from movements of water between two metal tanks," producing **results confirmed** in another investigation by Guy Abraham, M.D., who taught at the UCLA Medical School doing Independent Blood Flow Studies on how to prevent heart attack and/or stroke and **flush out the blood stream** at the same time. He said, "You can't argue with something you can measure…the ability of blood (94% water) to go through a membrane into the cells to the extremities. Nothing is even close to your water. Your HBA is 114°!" **(See two videos** at JohnEllis.com **proving** you are drinking the wrong water. The results have been duplicated **thousands** of times, proving this water provides **"Body Electric"** energy that powers your heart—defibrillators and pacemakers—because it takes less energy for the body to split water into Hydrogen and Oxygen.)

To stem the naysayers I offer this: **My college engineering professor, Dr. John Weishampel, gave me the only grade of 100% in 30 years of teaching!**

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Gilbert Daunant (Prince Rainier's cousin): "I just walked 40 blocks and I am 95! Send another E5 to Monaco!"

CONTROVERSY IS HEALTHY

Like **Thomas Paine,** the author of *Common Sense,* **anyone not generating controversy isn't doing much of anything…**as true as God's accuracy revealed in the Power of a Perfect circle (360° divided by Pi = 114° almost exactly!). Can atheists explain this? **Think about this:** Eggs of any species always hatch at the same exact time divided by seven; Watermelons always have an even number of stripes; Oranges have an even number of segments; Corn has an even number of rows; Waves of the sea roll 26 per minute in all kinds of weather; All grains have even numbers on the stalks. **The Lord specified: 30, 60 and 100-fold—all even numbers!**

SOMETIMES CONTROVERSY CAN BE DANGEROUS

We lived at the top of **Paine Avenue in New Rochelle,** N.Y. for 70 years and **a musket ball hole in the wall of the Thomas Paine Cottage reminded visitors he was embroiled in major controversy.** Fortunately they missed.

My grandmother's sister (Google: Nursing Sisters Port Dover), in spite of being repeatedly mentioned in wartime dispatches for heroism and "valor in the face of the enemy," was presented only a certificate by King George V because a woman could not receive the Victoria Cross!

As a result, my grandmother moved to Rochester, N.Y. and befriended **Susan B. Anthony** and Red Cross founder **Clara Barton.** There are hundreds of letters and pictures, including one of the ambulances my grandmother donated, encouraged by her friend **Carrie Chapman Catt,** who lived around the corner in New Rochelle. As a youngster, I remember all the sewing machines and their many friends at my grandmother's house sewing clothes to be sent to keep children warm during the brutal English winters. Carrie is most famous for her speech before Congress that resulted in the 19th Amendment that gave women the right to vote in 1920!

In most cases, there shouldn't be any controversy. Like the government scientists at Brookhaven Labs, who bought hundreds of our machines after a nuclear mishap in the 1980s: **"You have the only product that recycles water to get rid of radiation!"**

CONTROVERSIAL IDEAS NOT ALWAYS WELCOME

The rear room on the first floor of Thomas Paine's house (left) in New Rochelle, N.Y. is known as the "Paine Room." On Christmas Eve 1805, a gun was fired into this room in an attempt on Paine's life. The musket ball "passed through about three or four inches below the window making a hole large enough [for] a finger to go through…"

INSET: The bust of Paine on top of the Paine Memorial.

THE POWER OF POSITIVE THINKING

As I listened to **Dr. Norman Vincent Peale** eulogize my father upon his death, I thought hard about making people's lives better. In my case, I wanted to increase the human lifespan. My Godfather, **Dr. James E. West,** Chief Boy Scout Executive from 1907-37, helped thousands of youngsters take a positive direction in life. So, too, did Norman Rockwell, who we all knew and loved. He was hired by Dr. West for *Boy's Life Magazine.* **These men had a dedication to their fellow men and had an impact rarely seen today.** Dr. Peale came to our family gatherings with his "Power of Positive Thinking." That had a huge impact on millions of lives, including Joel Osteen and President Trump. And, like the Catholic Priest who saw the Cross at ground Zero 9/11, *forget controversy and dwell on a positive outcome* like the Olympic athletes I have known that imagined themselves winning using Dr. Peale's powerful message!

I AM NOT NEW TO CONTROVERSY

I am not new to controversy: In 1957, I had the best discus throw in the World (*T&F News,* Vol. 10, No. 12) but gave it up because I knew Anabolic Steroids would cause users heart damage. All the top athletes were told they were safe by doctors. However, their inventor, John Ziegler M.D., said before he died: **"I wish I had listened to [John Ellis]. I damaged my own heart!"**

There is a long list of Olympic friends who are dead because steroids were "FDA Approved." **I was right then about anabolic steroids and I am right now about viruses and disease!** *Like steroids…they thought more is better* including "energy shots." **More isn't better! Only 20 drops is needed for "Soaring Energy" with my water! (See photo below.)**

Get your bottle of SOARING ENERGY SHOT®: Only 20 DROPS produces **30 TIMES MORE ENERGY…** using our FREE water: Call 570-296-0214.

AMAZING POWER PROPERTIES

A company that produces **hydrogen generators** for trucks found the *power required slowly went down over 24 hours from 31 amps to less than 1 amp.* **By adding ONLY 20 DROPS of our water to their ordinary water, they were making the same amount of hydrogen in their hydrogen generator!** (www.johnellis.com) Using this technology, you can power your car, heat your home and produce electricity for pennies. **Watch the video** that shows examples **proving that you are drinking the wrong water.** Just as food supplies energy, this water provides the **"Body Electric"** energy that powers your heart!

OUR HUMANITARIAN EFFORTS

I am the inventor of the **E5 Water Machine.** I have decided, along with my loved ones (it's a family effort), to **donate** our 418-acre estate on top of Crystal Mountain in Pennsylvania to any large foundation or university for humanitarian purposes. **My dream is to create a Memorial Medical Center to further my water discoveries.** You'll realize after seeing all that we have done (www.johnellis.com), it's fitting this property be used to further these water discoveries! Details of our 501c (3) Living Water Environmental Foundation can be sent to you. **A portion of every sale of our Water Machines currently goes to maintaining the property, which is even now being used by Boy Scouts, Girl Scouts and other youth groups *free of charge.***

TAKE A TAX DEDUCTION!

With our 501(c)(3) non-profit foundation, you can buy a Water Machine and take a tax deduction! There are thousands of families in the U.S. who need our water machines—kids in Flint, families in poverty, etc. When you buy a machine, a portion of the proceeds go to this humanitarian aid project. **Contact us at P.O. Box 553, Westbrookville, NY 12785 or call 845-754-8696.**

(CONTINUED FROM P.53) "Dr. Skov has a knack for explaining terms in detail without the feeling that it's been dumbed down."

Then there are the aurora tourists. Skov's forecasts tell them where to go when. But that charge flows in both directions: Field reporters also tell Skov where the aurora is showing up. "People started informing each other, and the community began to build," she says.

Skov believes that understanding how life on Earth is looped inextricably with our star can help people grok the import of the really, really big one. She draws a comparison to more-familiar weather forecasting. Humans grow up hearing about meteorological phenomena great *and* small. But that doesn't happen with space weather. "It's like trying to tell someone who's never seen rain how dangerous a hurricane is," she says.

Once people understand, they can prepare for extreme space weather as they do for any natural disaster: Have water supplies, extra gasoline, and nonperishable food, and make a plan for meeting up even if you can't communicate. And have some board games, because this might take a while.

AS THE SPACE WEATHER Woman, Skov is at the vanguard of interpreting data from NASA satellites and observatories for regular folks. But when big entities like satellite operators, energy companies, and airlines need to know how the sun's shine will affect them, they turn to the Space Weather Prediction Center, whose scientists scrutinize the data, looking for activity strong enough to cause friction with earthly objects.

Any time that happens, they send out alerts—categorized from one to five, with five being the highest—to utilities, satellite companies, and others. Toward the end of 2017 they did that around 100 times a month. With a warning, technicians can reroute electricity, reschedule communication, and delay satellite operations.

When the sun carries on in a big way, a subset of the scientists relocates to the High-Activity Room, a sealed-off spot where they talk with major players. There, the Federal Emergency Management Agency has its own internet-enabled video-conferencing monitor, labeled like leftovers in an office refrigerator. FEMA needs to know what's coming so it can prepare for the disruption a major power outage would cause, and to coordinate with operatives before a communications blackout occurs. "Communication is life or death," Murtagh says.

In September, rescue workers got a taste of what it is like when the sun and Earth *both* create hurricanes. Just as Irma battered land, the sun sent out a series of flares and coronal mass ejections. High-frequency radio comms ceased in the storm-battered Caribbean. Hurricane Watch Net, made up of amateur radio operators, reported disruptions.

While this confluence didn't add to the destruction, it could next time, especially as earthly storms come with more frequency and force, and are thus more likely to line up with a starburst. Just like with a Category 5 hurricane, there'd be no getting around a major solar event. All we could do is see it coming, get a sense of how bad and big it would be, and prepare to hunker down for a while.

Soon the Space Weather Prediction Center will gather the data to make more-precise predictions, with the launch this year of observatories like NASA's Parker Solar Probe, which will fly closer to the sun than anything so far, and two additions to the sun-and-Earth-watching GOES satellite series in 2018 and 2020. Its scientists have also created a model that will make local space-weather reports possible. "The AccuWeathers of the world can take the information and make a tailored product," Murtagh says.

Those space AccuWeathers are only in their infancy, but Skov can't wait for them—and for the broadcasters and predictors and translators who will bring our star down to Earth for people. She's working with the American Meteorological Society to create a space-weather-broadcast certification. She might be her discipline's version of Al Roker, but even Al Roker needs local forecasters, standing in front of their own green screens, giving that quotidian space-weather report to a curious audience. "You say, 'Imagine 10 to 100 times worse than this,'" she says. "And they go, 'My god.' It hits them. And they go: 'I get it. I really get it.'"

Contributing editor Sarah Scoles is the author of Making Contact: Jill Tarter and the Search for Extraterrestrial Intelligence.

(CONTINUED FROM P.61) Though workers could, in theory, move the casks to a permanent resting place, none currently exist in the United States. The Department of Energy is legally bound to take spent commercial nuclear fuel and house it in a permanent spot. But the government never developed a permanent storage place after President Obama scuttled a plan to store commercial and military nuclear waste at Yucca Mountain, Nevada. This past August, the Nuclear Regulatory Commission said it would resume the work needed to eventually open that site. In the meantime, some 70,000 metric tons of nuclear waste is stored across the country.

At San Onofre, workers will place spent fuel in dry-cask storage and then demolish the buildings and offices. First, remotely controlled underwater tools will saw through radioactive steel from inside the empty reactors. Workers will store some of this material on-site for later disposal with the used fuel. They will pack the non-tainted portions—some 75 percent of a total 25 million cubic feet of rebar, concrete, and piping—in steel containers to dispose in the Southwest.

Rail cars will haul low-level radiation debris to specialized landfills. EnergySolutions will cart some of it to its desert facility in Clive, Utah, where workers will bury it beneath thick layers of clay, gravel, and rock.

More of these nuclear graves will cover the landscape as utilities take reactors offline around the globe. And unless renewable energy takes the place of nuclear, more carbon from fossil-fuel-fired plants will fill the air. When San Onofre shut down in 2012, natural-gas-fired electricity plants stepped in—adding 9 million tons of CO_2 into the atmosphere in the following 12 months.

Despite the financial pressures from natural gas and the growth in wind- and solar-energy production, Cohen holds fast in his belief that the U.S. should give nuclear energy another chance. "There are new technologies in the works," he says. "This isn't going to be your father's nuclear industry. It might fail, and it ultimately might be unnecessary, but it's worth trying."

For now, though, the nays have it.

Mary Beth Griggs is an assistant editor at Popular Science. *She covers space, geology, archaeology, and the environment.*

(CONTINUED FROM P.81) companies are becoming commercially viable. Go Electric's contract for smart microgrids at Camp Smith has proved so successful that it's won similar work at the Army's Fort Custer training base in Michigan and the Tooele Army Depot in Utah. Another, Stem, which uses learning software to automate energy-storage savings for schools and businesses, as well as provide grid services to utilities, has 29 customers on Oahu and is gaining them in California.

Of course, not all of the state's technologies will or should be portable. Renewable electricity very much needs to be tailored to local natural resources. Places beyond these tiny volcanic islands have already figured that out. Iceland, which has exceptional geothermal, and Norway, which has abundant hydro, have maintained nearly 100 percent for years. In Denton, Texas, where the wind blows strong, officials expect the city to be fully wind-and solar-powered by the end of this decade. Burlington, Vermont, the first U.S. city to boast 100 percent, burns local wood chips for fuel and has plenty of hydro from its rivers and dams. Many other cities have made significant progress; Las Vegas says that all of its municipal buildings now run on solar.

Why, all these efforts seem to be asking, must we be destined to dig dinosaurs from the ground and burn them to make our cars go and our toasters pop? Roughly 150 years ago, no one thought we could convert sunlight into electricity; then in 1876, someone discovered that selenium, when exposed to light, could do just that. Solar hovered at the edges of society for a century before humans found the will to make it affordable and efficient. But once that happened, solar's rise has been akin to the overnight rock star—from YouTube poseur to stadium attraction in one short decade.

Lippert believes that other superstars are out there. For her, the fact that a simple flywheel, with a few smart tweaks, might turn out to be a force of energy is thrilling beyond what anyone had imagined. "People had no idea that a flywheel is a solution," Lippert tells me. "It was that unknown. That is what excites me."

Leslie Kaufman, a regular contributor to PopSci, writes on climate change and renewable energy.

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I WISH SOMEONE WOULD INVENT...

A Phone Battery that Lasts a Week

GEORGE BENADE VIA FACEBOOK

A WEEK OF PLAYING *MINECRAFT* AND STREAMING Netflix? Not likely. The electrodes in your current cellphone battery contain limited places (known as ports) to store electrons, those subatomic particles that create charge. That might change soon, but not by a lot. In 2011, Yury Gogotsi and his materials science team at Drexel University crafted a concoction of elements including carbides, a combo of carbon and other metals, to create a new material named MXenes. It has more ports and routes to them, so the batteries can charge in seconds. Gogotsi is working on putting them in phones, so you might be able to add a room to that cube palace without recharging.

Paint that Stores Energy

PHILIP JAMES JAROSZ VIA FACEBOOK

Done, almost. Torben Daeneke, an engineer at the Royal Melbourne Institute of Technology University, developed a paint that creates energy. A mixture of molybdenum-sulfide and titanium oxide absorbs sunlight and air's moisture to generate hydrogen fuel. Right now the concoction works only under lab conditions and is inefficient: A sealed vessel captures just 1 percent of the generated hydrogen. Daeneke's team still needs to figure a way to convert that fuel into electricity. Still, if you painted your house with it (a house in a lab, of course), you could toast 160 slices of bread hourly.

Artificial Red Blood Cells

MATTHEW TALBOT-GADSBY VIA FACEBOOK

Bioengineers have theoreticized synthetic, microscopic blobs to give our muscles more oxygen, but current nanotechnology can't make them. Instead, maybe we can maximize what's already inside us. Microbes in our gut influence many bodily functions, including how much energy we generate from food. Elite athletes, researchers found, have higher quantities of certain bacteria, such as *Prevotella* and *Methanobrevibacter smithii*—both involved in this energy metabolism. Now some researchers are studying how nonathletes can foster more athletic intestinal bacteria.

WANT TO KNOW IF YOUR IDEA COULD BECOME REALITY? TWEET @POPSCI, EMAIL LETTERS@POPSCI.COM, OR TELL US ON FACEBOOK.

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