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P.70

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P.16

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P.36

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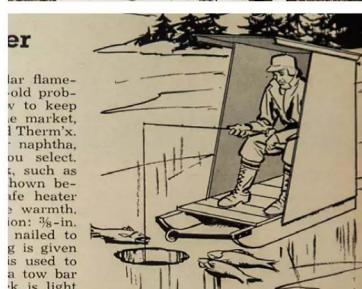
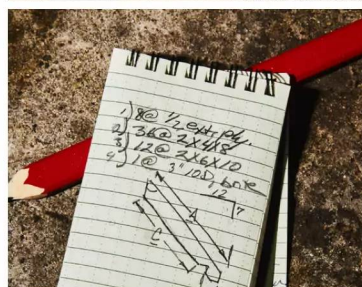
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2

Can't Stop Thinking About...

What happens to the human
body in the vacuum of space,
how to make tap water safer for
drinking, why air turbulence is
getting worse, and more. **p.5**

3

The Test

The versatile 8-inch chef's
knife is a kitchen must-have.
Here are three blades—plus a
sharpener—our editors love
right now. **p.70**

4

Made Right

A slippery and stubborn
pipe is no match for
the simplistic design of
Ridgid's straight pipe
wrench. **p.76**

5

Eds' Choice

Water-repellent pages and
smooth spiral binding make
Rite in the Rain's No. 935 the
ultimate DIYer's notebook.
p.78

6

60 Years Ago in PopMech

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and occasionally absurd
past. **p.80**

// ON THE COVER //

RIDGID STRAIGHT PIPE WRENCH PHOTOGRAPHED BY TREVOR RAAB

// FEATURES //

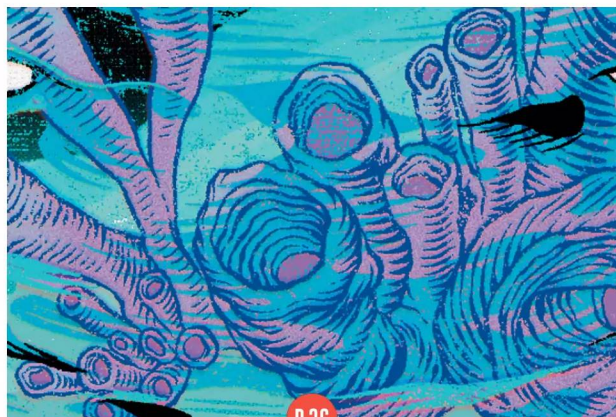


P.26

Build an Heirloom Cutting Board

Everything you need to craft an end-grain cutting board that stands the test of time. Plus, a DIY magnetic knife strip strong enough to hold all the blades in your kitchen.

By Bradley Ford

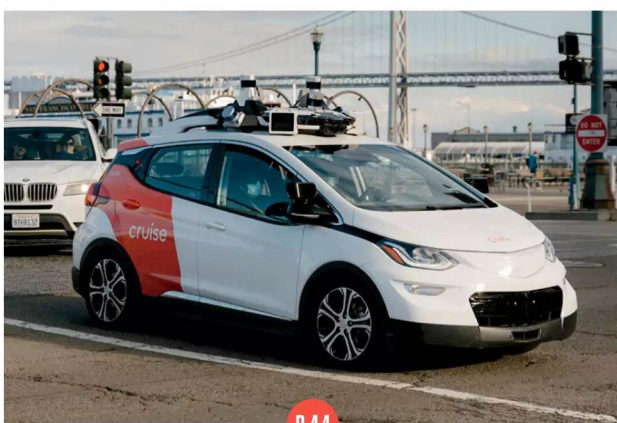


P.36

A Feast for the (Geologic) Ages

Three science-loving chefs build a prehistoric menu using ancient ingredients from some of the most important fossil sites in North America.

By Caroline Delbert, Riley Black, and Nala Rogers

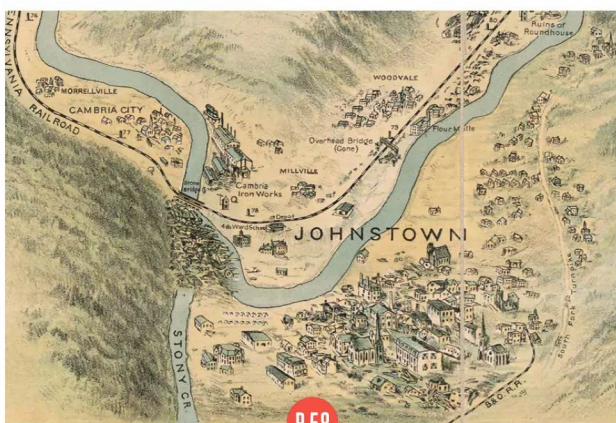


P.44

Autonomous Vehicles vs. the World

Companies like Cruise and Waymo have pitched the idea of self-driving cars as a smart, effective way to prevent accidents and make roads safer. What could go wrong?

By Joe Lindsey



P.58

Was America's Deadliest Manmade Disaster Preventable?

An 1889 dam collapse sent a wall of water surging toward a Pennsylvania town. Today's dams are just as vulnerable.

By Dylan Taylor-Lehman

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TREVOR RAAB (BOARD); YIRAN JIA (FEAST); JASON HENRY (AUTONOMOUS); ALAMY (DISASTER)

For the Man Who Gives Everything and Expects Nothing

If you're anything like my dad, you give your family everything. Your name, your time, your values — the people in your life know they can depend on you for practically anything. In exchange for imparting all of this energy and experience, you expect nothing in return.

The point? You deserve to treat yourself once in a while. You do so much for the people you care about. Now it's time to focus on you for just a few minutes. That's where the Men's Due Volta Watch comes in. This astonishing innovation provides a digital readout that's powered by a precise quartz engine, combining both analog and digital timekeeping.

Outfitted with a stopwatch, alarm, a.m./p.m. settings, and day, date and month complications, this timepiece stands out from the crowd. With its large face and handsome, masculine design, this watch is perfect for the back nine and the happy hour afterwards. Water-resistant up to 3 ATM, this timepiece won't wimp out if you have a run-in with a water hazard.

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Can't Stop Thinking About

2



HOW YOU DIE IN THE VACUUM OF SPACE



YOU DID IT. YOU ANNOYED

your crewmates enough that they shoved you out of the space station. No suit. No air. Just you and the vacuum of space. Here's a brief timeline of what you can expect.

First, It's Going to Be Really Cold //

The human body will take a while to cool down, but it will be serious. There are three ways to transfer heat from a warm body to its surroundings: Convection is the movement of a fluid or gas, like warm air rising to higher altitudes. Conduction is the transfer of heat through physical contact (or air), like when you touch a hot stove. Radiation means emitting electromagnetic radiation.

Without any air or water to surround your body, convection or conduction can't transport heat and cool you off. There's just radiation. A typical human body emits only as much energy as an old-school incandescent lightbulb, so it will take time before your body is cold enough to cease functioning.

But the coldness and the vacuum are going to affect you in faster ways. For starters, any oils or moisture on your skin will evaporate in the vacuum, leaving a nasty frostbite. And you will suffer a rare vacuum-induced malady known as ebullism. The lower pressure on the outside of your body causes the liquids just inside your skin to expand, causing you to swell, possibly to twice your size.

Don't Hold Your Breath // The moment the atmosphere escapes the airlock, you might be tempted to hold your breath. The problem is that your squishy bits (lips, throat, and upper respiratory system) are not designed to hold in a lungful of air against a vacuum. All that air in your lungs will come out, despite your best efforts, and if you try to hold it back, it will escape in an especially violent way, causing irreversible damage on its way out.

Here's the fundamental problem. In space, there's no air to breathe (a vacuum is completely empty). But your brain doesn't know that—your

heart keeps pumping. Your circulatory system keeps running. But your lungs are empty.

Very quickly, the oxygen saturation of your blood throughout your body drops. To preserve its most vital functions and conserve oxygen as much as possible, your body shuts down the most oxygen-hungry part of itself, your conscious brain.

You have somewhere between six and 12 seconds before you lose consciousness and completely black out.

That's all the time you have to stay in control and get yourself to safety. After that, you can still be rescued and revived to relative normalcy.

But eventually, the lack of oxygen will take its toll. One by one, your major organs will shut down. After only a handful of minutes, you will suffer complete organ failure, otherwise known in the medical community as death.

What comes after? A postmortem space odyssey that will likely end with your body's organic molecules scattering into a wide, diffuse debris field over billions of years. With luck, those molecules will be swept up in the formation of a new solar system, perhaps becoming recycled into the emergence of a new life form on some distant, alien world.—*Paul M. Sutter*

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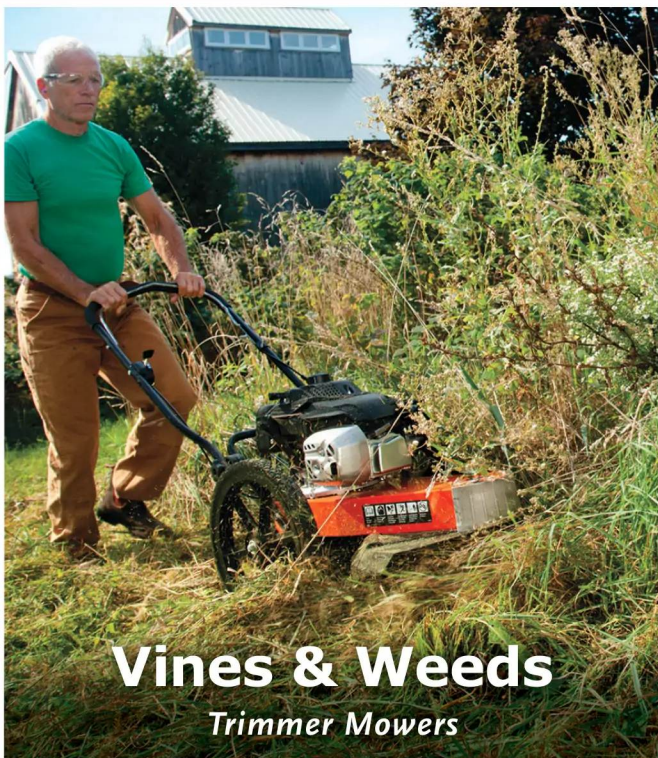


That's the amount of pressure needed to transform a cell of refined, pure graphite from one's ashes to a diamond that loved ones can keep in memory of the deceased. But like the creation of a normal diamond, it takes the right amount of heat. At about 2,500 degrees Fahrenheit, the temp needed in this process nearly matches the inferno of the Earth's mantle, which is about three times as hot as a pizza oven and nearly twice as hot as a cremation oven.—*Manasee Wagh*

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The Army's New Rifle and Machine Gun

RON COHEN RECALLS LUGGING AN M240 machine gun around while he served as a young infantryman with the Israel Defense Forces. At 5-foot-9 and about 150 pounds, Cohen says carrying the 26-pound weapon was a strain. But he remembers something else more vividly.

"The scariest thing that can happen to you as a soldier is when you're shooting at an [enemy] and you've shot him and he ain't dead," he tells *Popular Mechanics*.

That single, frightening thought sums up why the U.S. Army is making the biggest change in soldier equipment since the Vietnam War. The service is introducing a new individual rifle, a new machine gun, and new calibers for both weapons at the same time. The rifle will be called the M7, and the machine gun, the M250. New Hampshire-based SIG Sauer designed the guns, which are currently in production, and Cohen is the company's CEO.

After a 2017 study found that new body armor made and sold by Russia and China is effective in stopping 5.56-millimeter rounds at medium to long ranges—300 to 500 yards—it was determined the U.S. Army needed these heavier rounds. The same year, Gen. Mark Milley, then Army chief of staff, told Congress that body armor as cheap as \$250 could stop the 5.56-millimeter rounds fired by the M4 and M249. Such body armor has since spread around the world, recently in use in places like Ukraine.

SACRED STONE OF THE SOUTHWEST IS ON THE BRINK OF EXTINCTION



Centuries ago, Persians, Tibetans and Mayans considered turquoise a gemstone of the heavens, believing the striking blue stones were sacred pieces of sky. Today, the rarest and most valuable turquoise is found in the American Southwest—but the future of the blue beauty is unclear.

On a recent trip to Tucson, we spoke with fourth generation turquoise traders who explained that less than five percent of turquoise mined worldwide can be set into jewelry and only about twenty mines in the Southwest supply gem-quality turquoise. Once a thriving industry, many Southwest mines have run dry and are now closed.

We found a limited supply of turquoise from Arizona and purchased it for our **Sedona Turquoise Collection**. Inspired by the work of those ancient craftsmen and designed to showcase the exceptional blue stone, each stabilized vibrant cabochon features a unique, one-of-a-kind matrix surrounded in Bali metalwork. You could drop over \$1,200 on a turquoise pendant, or you



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The prospect of hitting an enemy with 5.56-millimeter rounds from an M4 or M249 and not stopping them led the Army to launch its Next Generation Squad Weapon (NGSW) program in 2018.

The Feel of Heavier Metal // To gain an impression of what the new M7 and M250 will feel like in the hands of Close Combat soldiers, I traveled to the SIG Sauer Academy in Epping, New Hampshire, as a guest of the company.

Laid out on two tables were the heaviest firearms I'd ever been in contact with. (I'm a relative gun novice with limited experience using the handguns, rifles, and shotguns many Americans are familiar with.) SIG engineers had set up a selection for comparison, including the M4 and M249, the M7 and M250, as well as the classic M240 7.62-millimeter machine gun and SIG Sauer's MHS military pistol.

We started by picking up each weapon to assess its heft, feel, and features. The difference in weight between the M4 and M7 is immediately evident. The former weighs about 6.4 pounds empty; according to the Army, the M7 tips the scales at 10.07 pounds with its suppressor (which minimizes noise) in place. There's less of a weight difference without the suppressor, but the M7 will generally be used with one to aid verbal communication between squad members in a fight.

As I held each carbine and shifted my weight, I was reminded that, most of the time, soldiers carry their guns—they shoot them only a tiny fraction of their careers.

An often-repeated mantra in the U.S. military is that "ounces equal pounds, and pounds equal pain." The roughly three-pound difference between the two weapons will be apparent on long days and marches over long distances.

Testing Out the New Weapons // I shot the M4 first, both in semi- and full-automatic modes. It felt solid, but still light and easy. There was pronounced recoil, but I was so pumped up—holding the trigger down on a full automatic for the first time and letting 5.56-millimeter rounds fly—I barely noticed. But the M4 never really felt threatening. I could imagine a soldier running and shooting with it at war, or flopping down onto his or her stomach and quickly aiming.

The M7, meanwhile, does feel like a threat. Bringing it to a firing position, I noticed the addi-



tional weight, particularly the nose weight with the suppressor at the end of the barrel. It's more work to cycle the gun through a field of movement. The trigger feels smoother, more substantial. I was immediately aware that heavier rounds were issuing from the barrel at higher velocity, yet the recoil and kickback were less than with the M4. I wasn't really aiming for a tight pattern of bullets on target, but the M7 suggested I could get close to the target at significant distances with practice.

The weight experience of the machine guns was the opposite. At 15.39 pounds, the M250 is easier to hold than the 17-pound M249. I didn't fire either weapon standing up, Rambo-style, but it felt doable with the M250. The 249's kickback rattled my vision, whereas I could focus as the bigger rounds poured out of the new SAW at over 3,000 feet per second.

Both are short-stroke-piston gas-operated weapons, but the M250 better disperses gases, leading to less eye fatigue. Hold the trigger down, and the 6.8-millimeter flies at about 800 rounds per minute.

SIG also gave me the chance to shoot the M240 machine gun. It's a real "shock and awe" experience. But I can truly sense that the M250 can shoot farther with more power and without the M240's energy-sapping weight.—*Eric Tegler*

30 YEARS

The average U.S. Air Force aircraft is about three decades old, and the service must contend with eight fleets over the age of 50.—*Kyle Mizokami*

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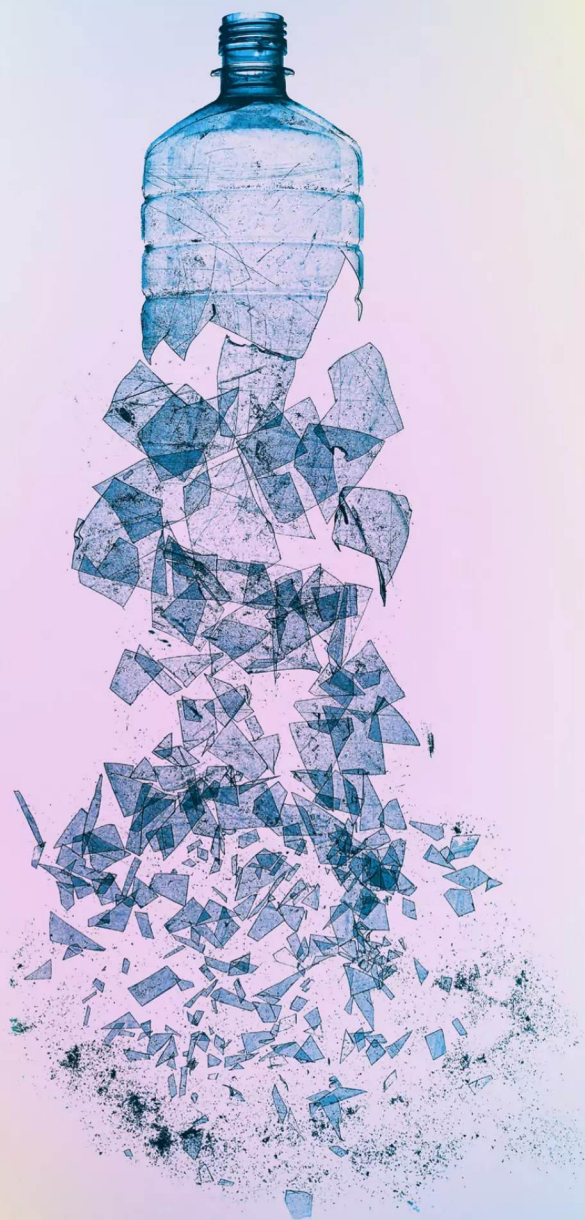


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If We Can Avoid Forever Chemicals

NEXT TIME YOU HELP YOURSELF TO A glass of water from your faucet, think about this fact: More than 45 percent of tap water in the U.S. is estimated to contain at least one type of per- and polyfluorinated alkyl substances, or PFAS. That's according to a study from the U.S. Geological Survey (USGS) published in *Environment International*.

These "forever chemicals" are everlasting, and are found in common products like some food packaging, Teflon, and firefighting foam. Scientists are still learning about all of the potential health impacts from chronic exposure to PFAS, but these substances are linked to an array of health problems, such as weakened immune systems, decreased fertility, and cancer.

Having been in our water supplies for decades, PFAS are now deemed so unsafe that the U.S. Environmental Protection Agency (EPA) has declared they shouldn't exist in drinking water at all.

But there is good news: You can take some easy steps to help prevent PFAS exposure in your own home by installing the right kind of water filtration system.

Which Filtration System Is Right for You? // When searching for a place to start, look for systems containing granulated activated carbon (GAC) or reverse-osmosis membranes.

If the product contains multiple-stage filtration using both of these methods, even better, says Yanna Liang, an environmental engineer at the State University of New York at Albany who tests ways to use synthetic materials or plants to eliminate PFAS chemicals from contaminated water.

If you want more of a sure bet for your water, devices using ion-exchange resins are better at filtering out smaller PFAS molecules than granulated active carbon, says Ezra Cates, an environmental engineer at Clemson University in South Carolina who is developing radiation-based water treatment. Ion-exchange filters are available, but they're not as common as GAC and reverse osmosis filters.

Know Your Terms: Microplastics vs. PFAS // Plastic products eventually break down into microplastics, minute bits of plastic that measure less than 5 millimeters long (four times as long as a grain of sand). They permeate the environment and even our bodies.

Microplastics can contain PFAS, and if the material in the original plastic was fluorinated

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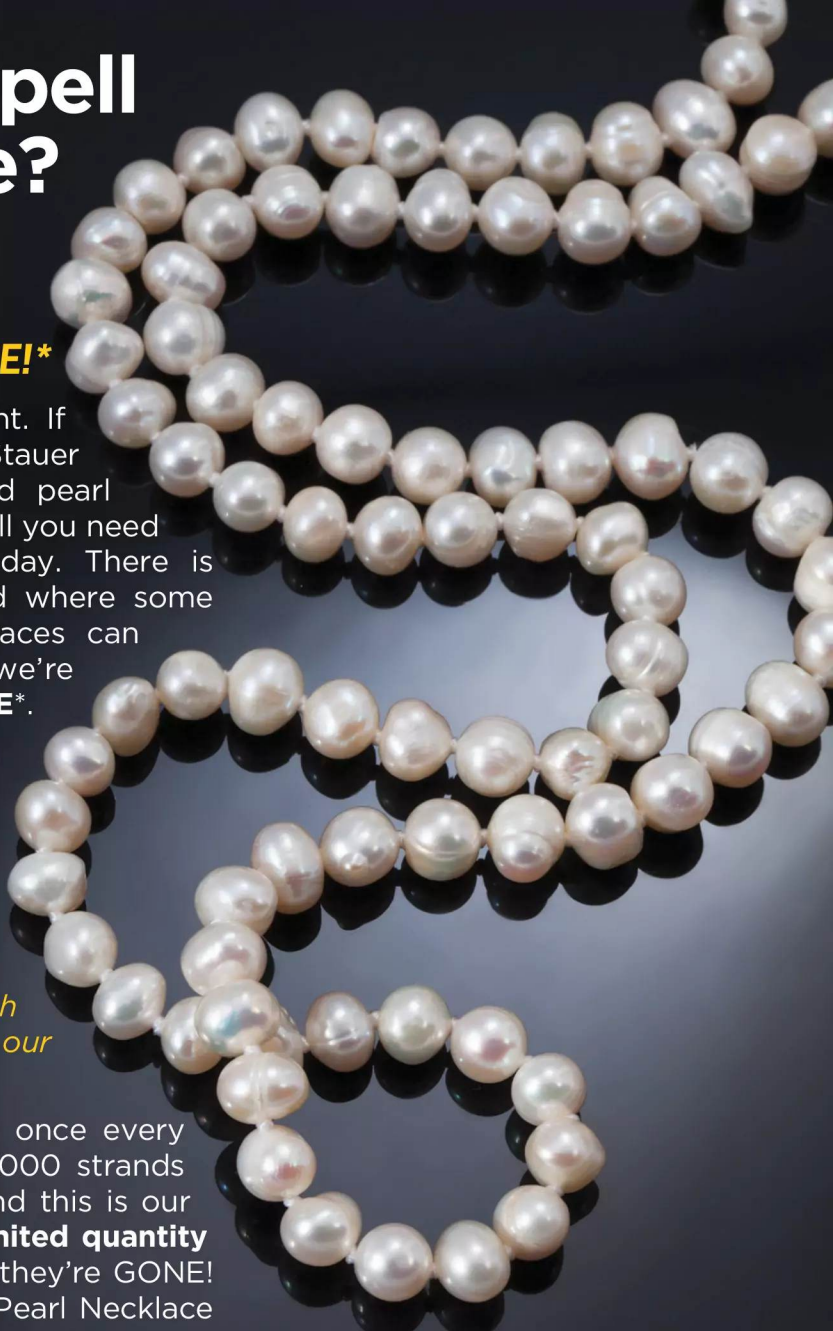
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before it broke down—fluorination makes plastic less sticky and reduces friction, making it good for uses like wrapping greasy fast food—then over time, those microplastics can release PFAS into water or other parts of the environment.

How PFAS Filters Work // Granular activated carbon is a mesh of carbon whose numerous pores range in size from about 15 to 30 microns (less than one-third the width of a human hair) and is made from sources such as bituminous coal, coconut shells, petroleum coke, wood, and peat.

The material is placed into a cylindrical filter tank that attaches on one side to your home's incoming water supply, either as a small cylinder under one sink or as a larger unit that can process all of the water entering your home. As water flows into the GAC, any PFAS compounds stick in or on the carbon's many pores and stay there. The cleaned water continues through to your tap.

Reverse osmosis uses a thin membrane of synthetic compounds. Water pumps through the membrane, whose tiny pores allow its passage but trap PFAS and contaminants.

BEWARE

THESE COMMON WATER TREATMENT METHODS DO NOT REMOVE PFAS!

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Ensure Your Filter Is Working // Do replace your filter materials as often as your product recommends. If you don't maintain the product, its effectiveness will drop over time, Liang says.

Your filtration unit's performance depends on several factors, though, "like concentration [of PFAS] in the incoming water, and other contaminants, like heavy metals, organic matter, [and] other ions...so you have several factors that all play into the overall efficiency," Liang says.

Keep in mind that your state may require a licensed and bonded plumbing or water conditioning contractor for installing a water treatment system.

Check your state's Department of Labor and Industry for a list of qualified licensed contractors.—*M.W.*



How to Program a DIY Car Key

WHILE SOME HARDWARE STORES may be able to program a modern car key, it's something you often end up at a car dealer for—or an automotive locksmith—if a key is lost.

I recently acquired a "new to me" truck that came with only one key. Wanting to avoid the issue of calling a locksmith if I lost it—I've been there before, to the tune of \$450—I called the dealer to see about getting a spare key. It was a frustrating experience in which I couldn't be given an exact price, but the key would be about \$70, and the programming would probably be about \$175.

It was at this point I decided to click on one of those Tom's Key Company ads that I was seeing online, telling me I could program my own key and save some money. Which is exactly what I did. All in, it cost me just over \$110, including shipping and getting my new key cut locally. When you buy or rent the programming kit from Tom's Key, you also have the option of having them cut your key for an extra \$60, with their "Key by Photo" service.

If you don't have Tom's cut your key, you'll get a key blank sent to you, which you'll have to get cut locally. Note that depending on the type of key you have, the price can vary widely. A standard key, with jagged edges on both sides, can cost \$5 to \$10. A laser-cut key—which isn't cut with a laser, incidentally—is flat on both edges, with a ramped shelf cut in the face, and can cost as much as \$50 to cut.

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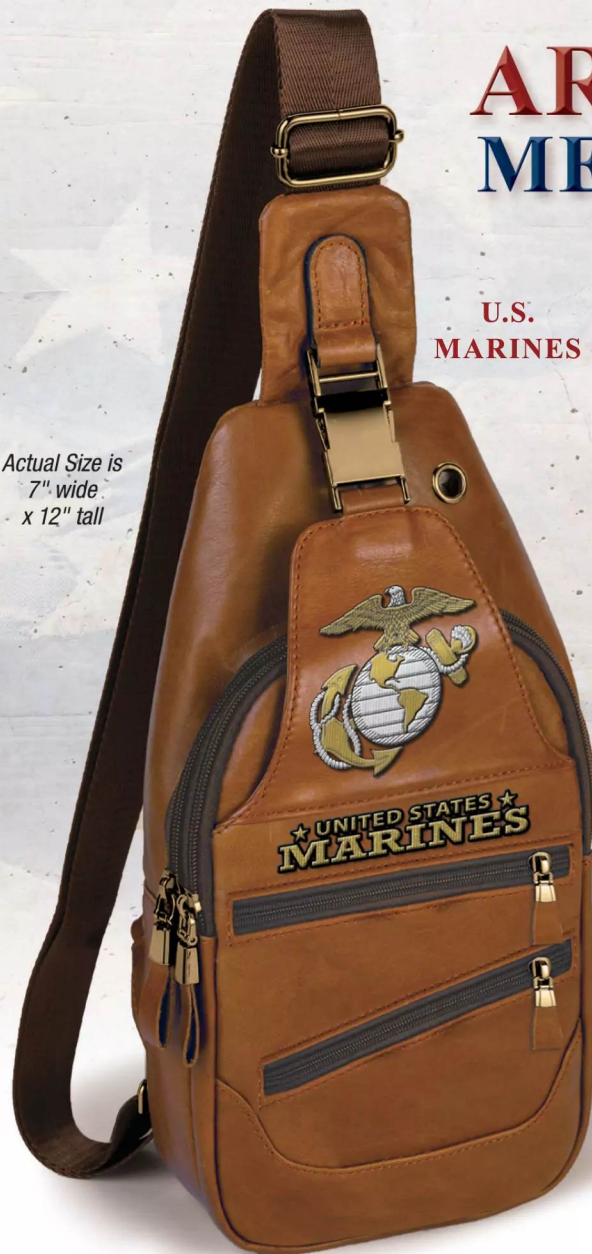


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We're excited to introduce a super versatile bag showcasing a top-notch design! Our **Armed Forces Sling Bag** can be worn as a cross body or over the shoulder and features multiple pockets to carry all your essentials in an organized, compact way. Plus, you can carry the proud symbol and name of the military branch of your choice everywhere you go!

SUPERIOR CRAFTSMANSHIP IN A COMPACT DESIGN

Expertly crafted of brown faux leather, this sling-style bag features a total of 6 pockets (5 zippered and 1 slip for easy access) with plenty of room to carry all your daily essentials. The 48" adjustable strap can be clipped onto either side so the bag can be slung over the left or right shoulder. The strap also features a metal buckle that clips into the front flap to secure your belongings. On the front, you'll find embroidered patches showcasing the seal and name

of the branch of your choice. The attention to detail on this handsome bag is stunning! Metal hardware, brown lining, nylon zippers, and faux leather on the pullers complete the stylish look. A metal eyelet on the top front of the bag allows you to run your headphone cord through for hands-free convenience.

A REMARKABLE VALUE...NOT IN STORES

Our trendy sling-style bag is a remarkable value at \$129.95*, and you can pay for it in 4 easy installments of \$32.49 each. To order yours, backed by our unconditional 90-day guarantee, send no money now, just mail in your Priority Reservation. This versatile brown faux leather messenger bag is not available in stores, so don't miss out. Reserve yours today and share your pride everywhere you go!

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Tom's also has kits for programming cars with proximity keys and push-button start. Check the Tom's Key Company website to see if they offer kits to program a key for your car, as there are some makes and models they don't support.

The Easy Process Saves You Money // Once I had my key cut, I followed the instructions, and the process took about 15 minutes.

For each car, the steps might be a little different, but this is basically how works:

STEP 1 Look up your exact model in the instruction manual and set the dial on the programmer to the correct number.

STEP 2 Get in the car, close the doors, and use the new key to turn the ignition to the on position.

STEP 3 Plug the programming kit into your OBD (On Board Diagnostic) port. Refer to your owner's manual if you don't know where this is.

STEP 4 Push the button on the programmer. It will beep to indicate it has begun to pair with the vehicle.

STEP 5 Wait. In about 10 minutes, the programmer will emit an audible alert to indicate the key has been programmed.

STEP 6 Turn the ignition off, remove the programming, and test the key. I've used Tom's Keys to make duplicates for two different vehicles, and both times everything worked perfectly. Note that you need to buy a kit for each vehicle—even if you have two identical cars of the same year.

The programming kit is linked to your car's vehicle identification number (VIN) and can be used to program up to four keys for that vehicle.

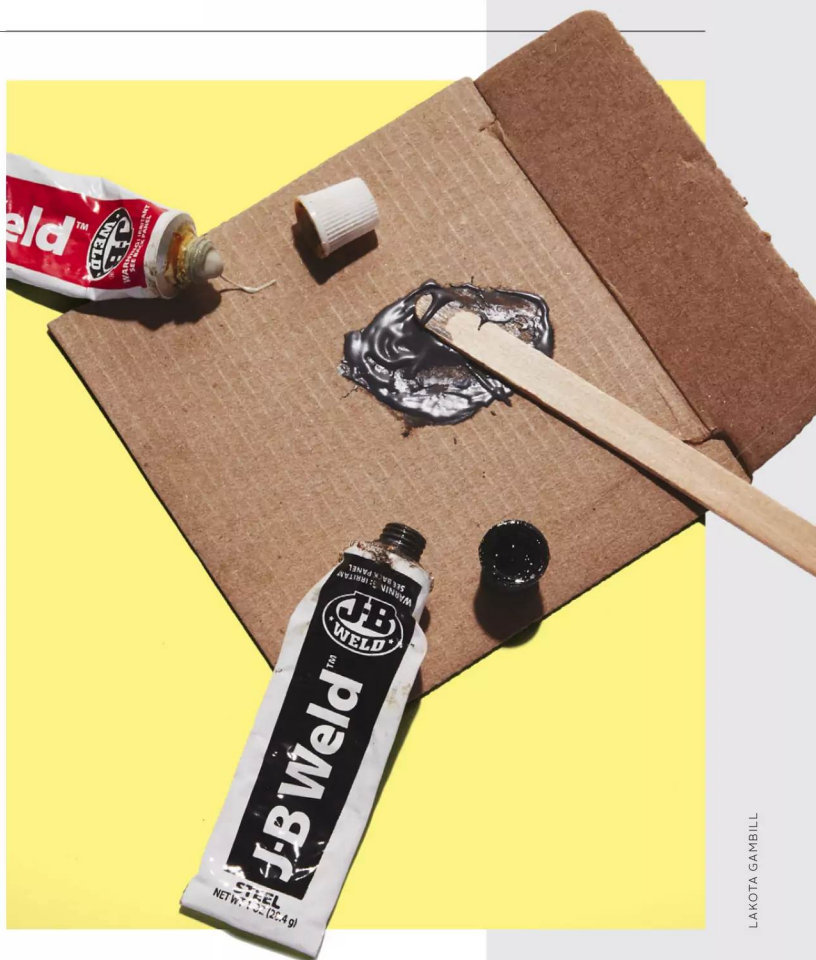
While that seems a bit restrictive for the expense, I saved about \$150 for each of the two vehicles for which I programmed duplicate keys.—Bradley Ford

If J-B Welds Can Break

JUST HOW TOUGH IS J-B WELD? I WONDERED about that recently when I found myself at a Tractor Supply Company buying plant and garden materials and ran across a rack of this well-known repair adhesive. That was about the umpteenth time that thought crossed my mind when I found myself shopping for something else.

I'm not the only person with some curiosity about it. Go online. People repair everything under the sun with this stuff. Most are small fixes to things on cars, signage, and gizmos. Some of these repairs look kind of janky and might have been better executed with welding, bolts, or screws. But who am I to say? The owners seem to be happy with their results.

My encounter with J-B Weld at Tractor Supply was an itch I had to scratch. I bought two types of J-B Weld and brought them into the *Popular Mechanics* shop in an attempt to find out just how tough this repair material really is. I bought one package of PlasticWeld and another of the compa-



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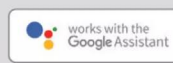
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ny's flagship Cold-Weld Formula Steel Reinforced Epoxy. I used the adhesives to glue together steel, wood, PVC plastic, and combinations of those materials. We let the adhesives cure, then we tried to break the samples apart.

End-to-End PVC Pipe

Test sample: ½-inch PVC pipe bonded end to end with Plastic Weld

Test method: Hand pressure, plier twisting

Comments: The sample was impossible to break with hand pressure but snapped off easily with a pair of locking pliers fastened to the end of the pipe. Such a bond would be more than strong enough to support a small sign, for example, used for indoor purposes. The lack of bonding surface could not withstand the torque applied by locking pliers.

Face-to-Face Poplar

Test sample: Kiln-dried poplar blocks joined face grain to face grain with J-B Weld Original Cold-Weld Formula by applying the adhesive and pressing the blocks together with hand pressure.

Test method: Clamp the test blocks in a machinist vise and deliver repeated blows to end grain and face grain with a ball-peen hammer.

Comments: We were unable to break the bond created by J-B Weld. Repeated side blows to the end grain sheared the block. When we repeated the test delivering blows to the face grain, the block sheared again but the bond remained intact.

Steel T

Test sample: Low-carbon steel joined to form a T, surface and end roughened by grinding with 60-grit abrasive. J-B Weld Original Cold Weld applied to end and face of T and pressure applied by hand. We also used an additional buildup of epoxy to form a fillet around bond joint.

Test method: Clamp the T in a machinist vise and pry apart with pliers. Strike T on anvil face.

Comment: The length of the vertical portion of the T joint was not long enough to permit us to apply

sufficient torque with pliers to break the joint. Only a sharp strike on the face of the anvil was enough to cause joint failure.

Steel Lap

Test sample: Original Cold-Weld Formula applied to both bond surfaces of low-carbon steel sample pieces and squeezed together with hand pressure.

Test method: Clamp lapped piece horizontally in machinist vise and deliver end blows with ball-peen hammer. If needed, clamp sample in vise vertically and deliver blows to face of sample.

Comment: This was by far the toughest sample to break. Several hard blows (nearly as hard as I could possibly swing the hammer) mushroomed the end of the sample but failed to break the joint. The lap failed when the sample piece was turned vertically and a very sharp blow was delivered horizontally to the mushroomed end, causing the upper piece of the lapped joint to break free.

Conclusions

You'll get your best results with J-B Weld by applying it to a clean, roughened surface. First, it increases the bond surface area because a roughened surface has more contact area compared to a smooth one.

Second, the roughened surface provides what engineers refer to as "tooth." That is, the profile of a surface roughened with abrasives provides saw-blade-like teeth that mechanically lock with the adhesive around them.

Also, for maximum cohesion when using J-B Weld, adding reinforcement can increase the strength of the joint. Bonding additional pieces of wood or metal over an epoxied joint can mechanically stiffen the joint and help it better withstand the variety of forces that act on it.

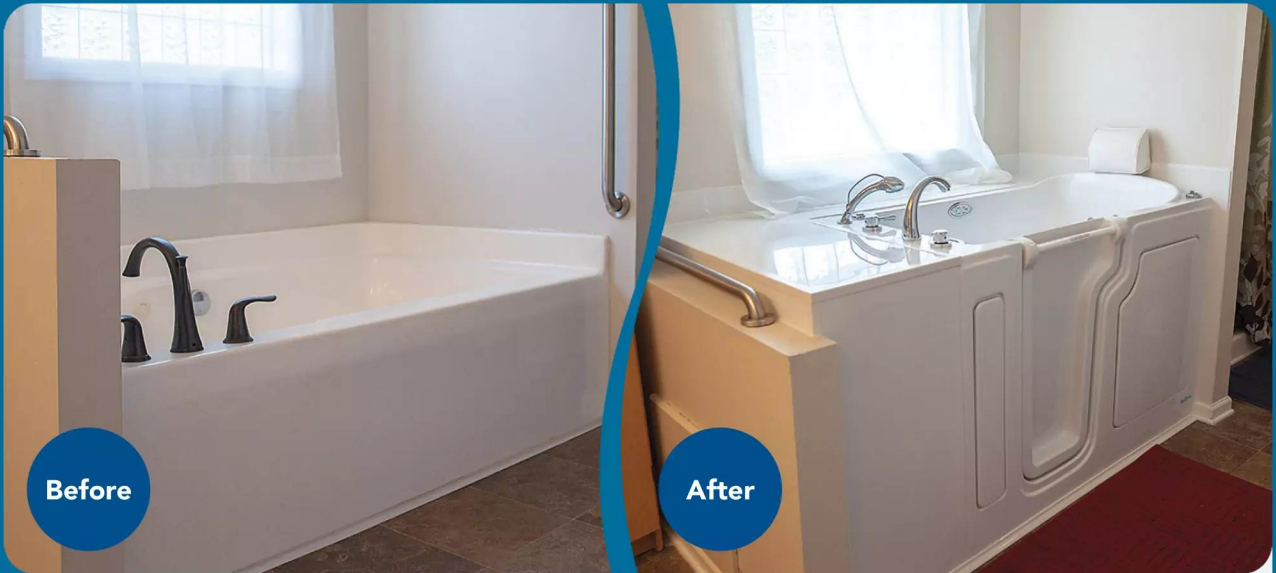
You can improve your odds of bonding success by making use of a mechanical joint that works with adhesive.—Roy Berendsohn

Epoxy. What It Is. What It's Not. // In its cured state, epoxy is a thermoset polymer (it typically cannot be melted by heat and reformed). It starts out as two chemicals (or complex chemical substances) that are mixed together, driving a reaction that turns them from soft putties or syrupy liquids into a hard plastic. Although epoxy has been under experimental development for more than 100 years, it wasn't successfully developed for commercial purposes until the late 1940s. The claim, "tougher than steel," is an exaggeration. You can't take epoxy and form it into a drill bit or a cutter for a milling machine. Still, epoxy is tough stuff.—R.B.



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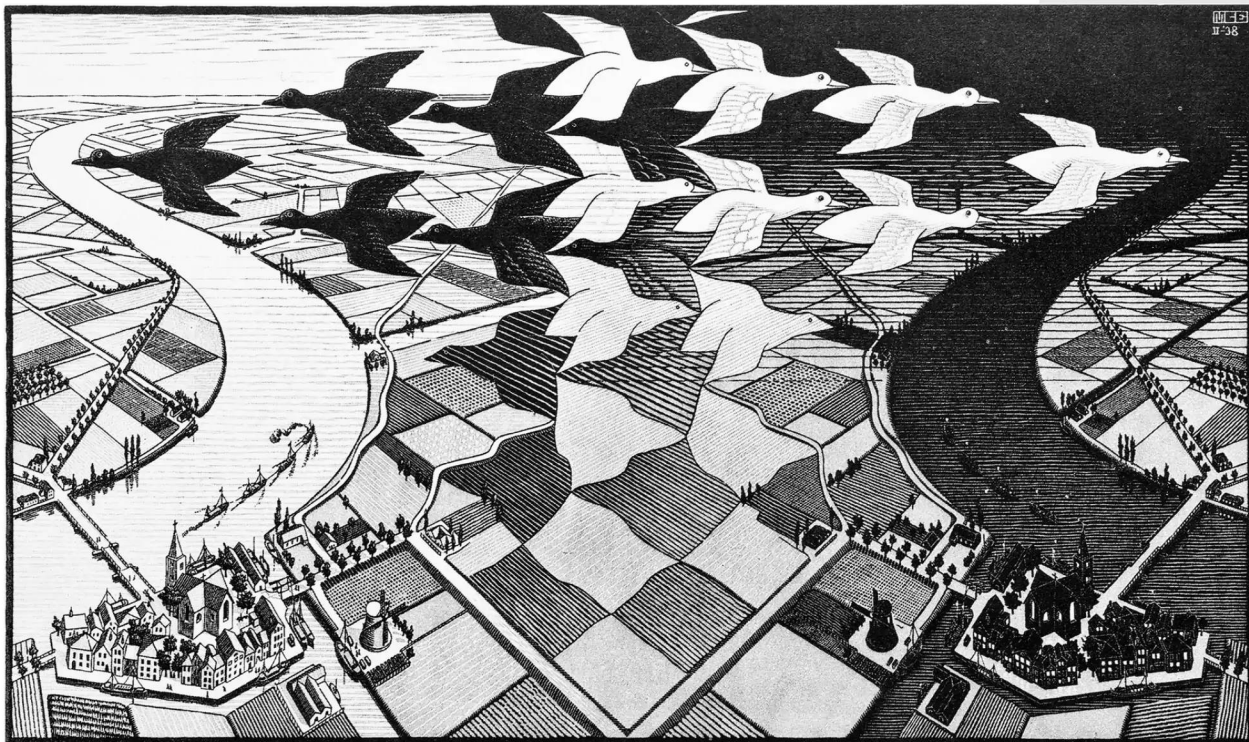
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The Math in M.C. Escher Art

MATH UNDERLIES MANY OF THE ART pieces M.C. Escher created. He was fascinated with the idea of depicting infinity in various ways, producing infinitely repeatable patterns known as tessellations, as well as designs that showed an infinite hyperbolic plane—a surface in which every point of the space curves away from itself—mapped onto a circle.

But his success wasn't due to some natural affinity for math, says Doris Schattschneider, PhD, a mathematics professor emerita at Moravian University in Bethlehem, Pennsylvania. "There's no equations at all that he used. He almost failed his mathematics in high school and never went beyond high school," she says.

Escher explored geometry through tessellations, which are mosaics that fit together like puzzles and can fill an entire plane. Schattschneider says his designs featuring tessellations were inspired by his 1922 trip to the Alhambra, an Islamic historic site in Granada, Spain.

"The tilings in the Alhambra are very geometric, very abstract," Schattschneider says.

Escher studied and sketched the geometry of the tilings in the Alhambra and tried to replicate how the tiles fit together and intersected with one another, she says. The mathematical rules for these repeating patterns say that a pattern can be shifted by moving it, which is called translation.

It can also be rotated or reflected; rotation involves moving around each point in a figure a certain number of degrees around a central point; reflection involves flipping the pattern over across a fixed line.

Escher spent around four years creating a "layman's theory" of how shapes could fit together in a tiled pattern that could occupy a whole plane, Schattschneider explains. She described this process in her book *M.C. Escher: Visions of Symmetry*. His rules state that:

- Every tile had to be surrounded by its copies in the same way
- A minimum number of colors should be used
- No two adjacent tiles could have the same color

"He became very, very adept at producing these tilings or tessellations," Schattschneider says. "The shapes of the motifs or the figures in them are his original imagination... It's rather an amazing story that he did this all on his own." —Kat Friedrich

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The Reason Air Turbulence Is Getting Worse

ONE OF THE MORE COMMON IN-FLIGHT mishaps to garner headlines is when a plane encounters an intense bout of turbulence. Shaken passengers tell an awaiting camera crew about the sudden jerk, the subsequent moment of weightlessness, and the unfortunate injuries. Thankfully, very few of these accidents result in death—National Transportation Safety Board data says less than 40 passengers have died due to turbulence-related accidents since 2009. But there is one small problem: These nasty yet periodic episodes of turbulence are becoming, well, less periodic.

In fact, this past June, scientists from the U.K.'s University of Reading concluded that severe clear-air turbulence (CAT), arguably the most insidious of the bunch, has increased 55 percent since 1979 over the North Atlantic. And yes, the culprit is that unending conveyor belt of bad news called climate change.

"We find clear evidence of large CAT increases in various places around the world at aircraft-cruising altitudes since satellites began observing the atmosphere," the paper reads. "Our study represents the best evidence yet that CAT has increased over the past four decades, consistent

with the expected effects of climate change."

Rising Temps, Rising Turbulence // As humans continue to pump carbon dioxide into the troposphere, global average temperatures are slowly on the rise, bringing with it stronger storms, longer droughts, and increased flooding. This growing meteorological chaos is also being felt at cruising altitude.

Because the jet stream is sandwiched between the warm (and getting warmer) troposphere and the cool (and getting cooler) stratosphere, the increasing temperature differential means increasing wind shear. While climate change is actually decreasing wind shear in the troposphere as temperature differentials decrease, the opposite is true for the lower stratosphere, which is where airplanes fly to avoid atmospheric drag.

"We have global warming in the troposphere, but we have global cooling in the stratosphere," says Ramalingam Saravanan, professor and department head of atmospheric sciences at Texas A&M University. "An increase in carbon dioxide cools the stratosphere, and it does it in such a way that it increases vertical shear... and cruising altitude tends to be in the stratosphere."



KEEP IT MOVING

Why Aging and the Pains that come with it doesn't have to suck

By: Beth Giles

Life really does fly by. Before I knew it, my 50s had arrived, and with them came some new gifts from dear ol' Mother Nature—frequent knee pain, stress, low energy and sleeplessness. Now, I'm a realist about these things, I knew I wasn't going to be young and springy forever. But still, with “golden years” nearly on my doorstep, I couldn't help but feel a little cheated. That is until I found my own secret weapon. Another gift from Mother Nature.

It began a few months back when I was complaining about my aches and pains to my marathon-running granddaughter, Jen. She casually mentioned how she uses CBD rub to help with her joint pain. She said that CBD gave her more focus and clarity throughout the day and that her lingering muscle and joint discomfort no longer bothered her. She even felt comfortable signing up for back-to-back marathons two weekends in a row this year. That made even this self-proclaimed skeptic take notice.

But I still had some concerns. According to one study in the Journal of the American Medical Association, 70% of CBD products didn't contain the amount of CBD stated on their labels. And, as a consumer, that's terrifying!

If I was going to try CBD, I needed to trust the source through and through. My two-fold research process naturally led me to Zebra CBD.

First, I started calling my family and friends. Call me old fashioned but I wanted to know if there were people whom I trusted (more than anonymous testimonials) who've had success using CBD besides my granddaughter.

Secondly, I wanted cold hard facts. Diving deep into the world of CBD research and clinical studies, I came across Emily Gray M.D., a physician at the University of California at San Diego (UCSD) Medical School and medical advisor to Zebra CBD who is researching the effects of CBD. Dr. Gray wrote “early results with CBD have been promising and we have a lot of research underway now. I've had several patients using CBD with good success. It's important that you know your source of CBD and how to use it properly.”

After hearing it from the doctor's mouth, I returned to my research, asking more people and was amazed by the number of close friends and family who were already on the CBD train. Apparently, I was the only one without a clue! And funny enough, a couple of friends who commented were using the same brand as my granddaughter—Zebra CBD. There was no consensus as to why they were using CBD, but the top reasons given were for muscle & joint discomfort, mood support, sleep support, stress and headaches, as well as supporting overall health & wellness.

Eventually, even the most skeptical of the bunch can be won over. With a trusted CBD source in mind, I decided to give it a go.

When I viewed Zebra CBD's selection online, I was impressed by its array of products, including CBD oils called tinctures, topicals, chewable tablets, mints and gummies. After reading on their website that all their products are made with organically-grown hemp, I ordered... and it arrived within 2 days!

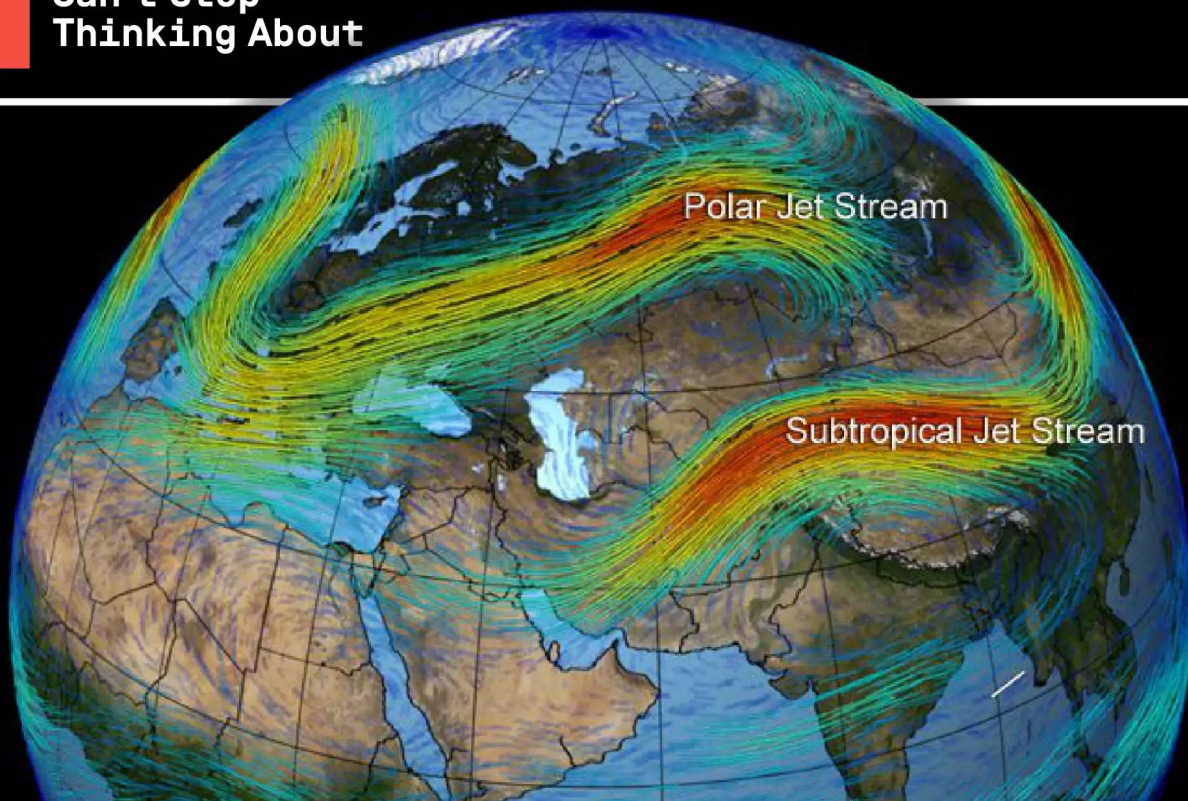
The first product I tried was the Rub. Now this stuff was strong. Immediately after rubbing it on my knee, the soothing effects kicked in. It had that familiar menthol cooling effect, which I personally find very relieving. And the best part is, after two weeks of using it, my knee pain no longer affected my daily mobility.

The Zebra Sleep Gummies, on the other hand, had a different but equally positive effect on my body. To take it, the instructions suggest chewing thoroughly. This was simple enough, and the taste was, well, lemony. After about 15 minutes, a sense of calm came over my body. It's hard to describe exactly; it's definitely not a “high” feeling. It's more like an overall sense of relaxation—and then I fast asleep. Needless to say, I slept great and woke up refreshed. I haven't slept like that in a long time.

While it hasn't been a catch-all fix to every one of my health issues, it has eased the level and frequency of my aches. And it sure doesn't seem like a coincidence how rejuvenated I feel.

All-in-all, CBD is one of those things that you have to try for yourself. Although I was skeptical at first, I can safely say that I'm now a Zebra CBD fan and that I highly recommend their products.

Also, I managed to speak with a Zebra CBD spokesperson willing to provide an exclusive. If you order this month, you'll receive \$10 off your first order by using promo code “**PM10**” at checkout. Plus, the company offers a 100% No-Hassle, Money-Back Guarantee. You can try it yourself and order Zebra CBD at ZebraCBD.com/PM or at 1-888-762-2699.



Research published by the University of Reading confirms this meteorological suspicion. After poring over more than 40 years of climate data, the scientists found that severe turbulence—that is, the injury-causing kind—increased 55 percent.

Thankfully, only 0.1 percent of the atmosphere contains this extreme level of turbulence, but even the more frequently encountered light and moderate turbulence saw significant increases, up to 17 percent and 34 percent, respectively.

“Even though [severe CAT] is increasing, it’s still more rare, so you’re more likely to experience light turbulence even though it isn’t increasing as much,” says Isabel Smith, a PhD student researcher at the University of Reading who uses high-resolution climate models to predict increased turbulence. “So the main issue moving forward... is probably going to be dealing with more and more light turbulence, and it might result in airlines trying to avoid turbulence as much as possible.”

A Turbulent Future // Although remote weather radar can’t spot clear-air turbulence, that hasn’t stopped engineers from trying to design a solution. The Japanese Aerospace Exploration Agency, or JAXA, developed a lidar detection system aimed at spotting turbulence up to 11 miles away. Although JAXA estimates that such a technology could reduce turbulence-induced injuries by 60 percent, adding extra weight to an aircraft is a big ask for most airlines.

While purpose-building laser-equipped air-

planes might be a long-term solution, pilots aren’t flying blind. Whenever a plane experiences sudden clear-air turbulence, the pilots submit a report, called a PIREP, or Pilot Report, detailing the wind shear anomaly and warning planes flying on a similar trajectory.

The International Air Transport Association (IATA) has also developed a Turbulence Aware database that uses National Center for Atmosphere Research software in an airplane’s avionics to report to the database when a plane’s Energy Dissipation Rate (EDR)—calculated from airspeed, angle of attack, and other parameters—exceeds a certain threshold.

The test report contains the EDR value, along with the aircraft’s position, altitude, wind data, and temperature, which is then shared with airlines.

Airplanes are also designed with a huge safety margin, and wings can handle loads 1.5 times stronger than what they’d ever experience during a flight. During a career, most pilots will never experience turbulence so severe that it bends a wing.

But just because a plane can survive a fierce run-in with clear-air turbulence doesn’t mean airlines want to make flying through it a habit. Instead, in a warming world with an increasingly turbulent lower stratosphere, airlines might need to make a few adjustments to fly the smoothest route possible.—*Darren Orf*

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PHOTOGRAPHY BY **TREVOR RAAB**



Cutting boards make great woodworking projects because they can be as easy or as challenging as you choose. Generally, there are two different types of wooden cutting board: side-grain and end-grain. Side-grain cutting boards are the most common type, with the wood grain running from one edge of the board to the other. End-grain boards are made up of multiple pieces of wood, cut and glued together to orient the ends of the boards so they face the cutting surface.

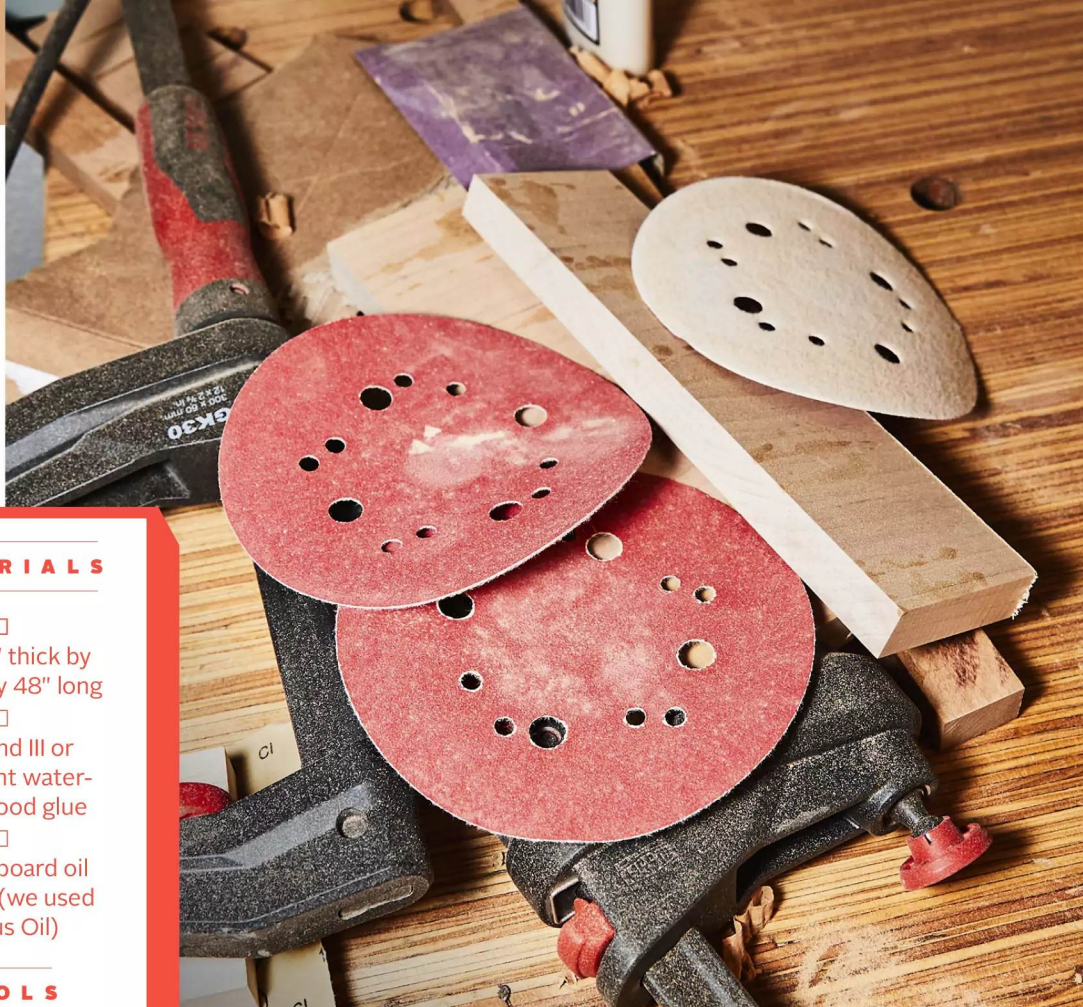
While I understood how to make an end-grain cutting board, I had never actually done it, so I spoke to custom-furniture-maker Shane Kline, of Walnut St. Woodworks in Bally, Pennsylvania, for some expert advice. As I suspected, cutting boards are fairly simple, but there are a few things you should keep in mind to make one that will last for many years. For this cutting board, we chose to use some cherry wood languishing in the shop, left over from another project. While you can make a fine cutting board without many special tools, we've noted some on the following page that'll help make things easier and faster.

MATERIALS

- ☐ Wood 1" thick by 9" wide by 48" long
- ☐ Titebond III or equivalent water-proof wood glue
- ☐ Cutting board oil and wax (we used Walrus Oil)

TOOLS

- ☐ Table saw
(a circular saw or track saw can also be used)
- ☐ Miter saw or compound miter saw
- ☐ Bar or pipe clamps
- ☐ Sandpaper (80, 100, 150, and 220 grits)
- ☐ Hand plane
- ☐ Planer (optional)
- ☐ Orbital sander (optional)
- ☐ Jointer (optional)



SELECTING WOOD

Start by choosing a species of wood. Kline suggests maple, walnut, or cherry because of their hardness, tighter grain, and smaller pores. This helps make them able to withstand wear from use and to resist water absorption, which can lead to warping and cracking. The boards, or stock, you select should be 1 to 2 inches thick. Thickness is traditionally represented in quarters of an inch, e.g., 4/4, 5/4, 6/4, 7/4, and 8/4. You'll need to find a specialty lumber supplier for these types and sizes of wood—often they can cut and plane wood to the final dimensions you require.

SEASONING

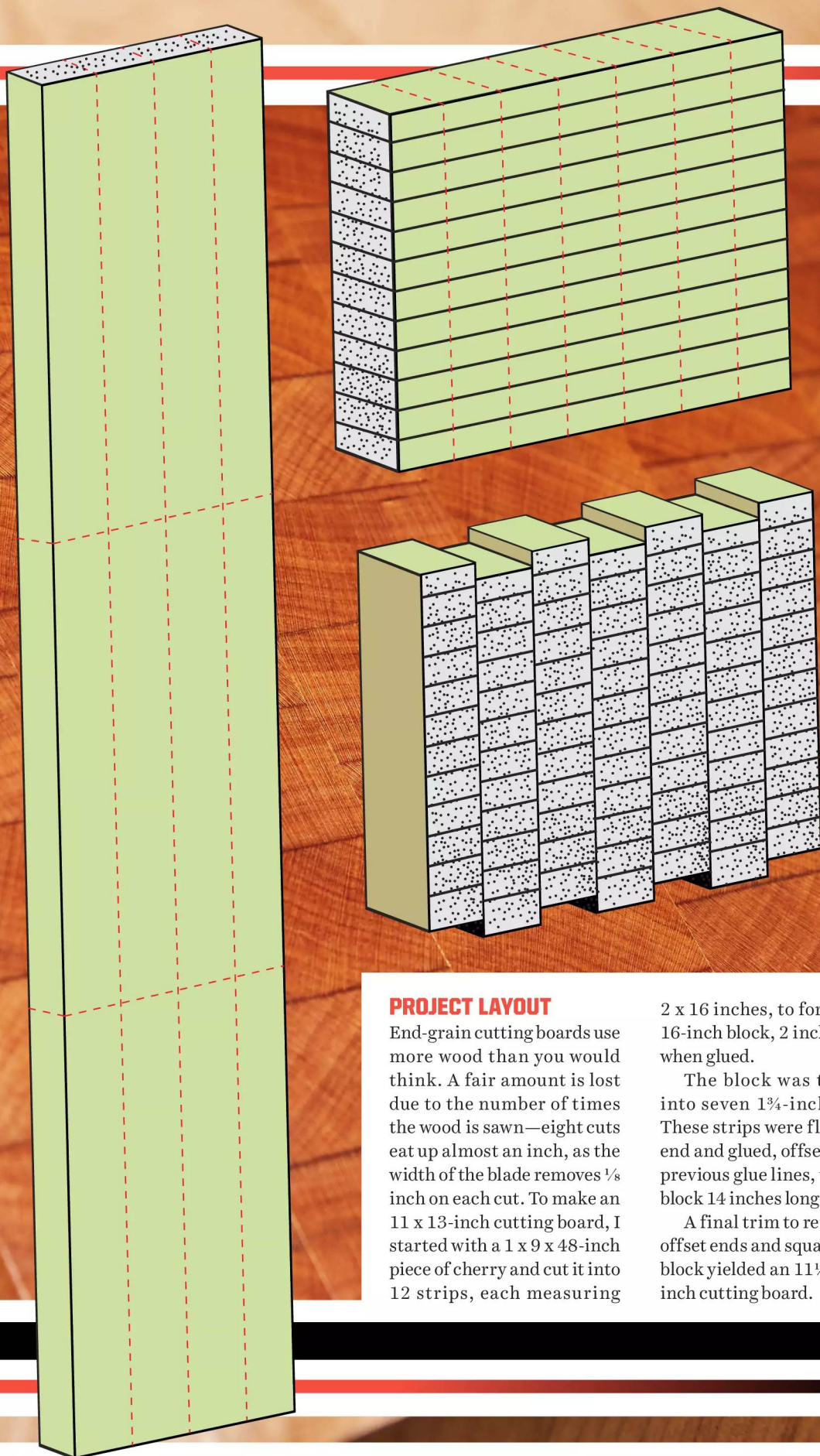
Cutting boards need to be seasoned before use, and then reseasoned regularly. This prevents them from absorbing too much moisture, which could warp, crack, or stain them. For an initial seasoning, Kline recom-

mends a two-step process. First, rub on a cutting board oil and allow it to soak in for 24 hours. Follow that with an application of cutting board wax and then buff with a clean, dry cloth. Reseason every six months, or sooner if your cutting board sees a lot of use.

CLEANING

Wood cutting boards don't require any special disinfection process*. They can easily, safely, and simply be cleaned with a sponge and warm, soapy water. When wood absorbs water or dries out unevenly, warping can occur. Kline advises to be sure to wash both sides, rinse the cutting board completely, and stand on edge in a dish rack so both sides dry at the same rate.

**You need not worry about bacteria surviving on or in the wood. A study conducted at the University of Wisconsin indicated that bacteria was far less likely to be recovered from wood surfaces than it was from plastic.*



PROJECT LAYOUT

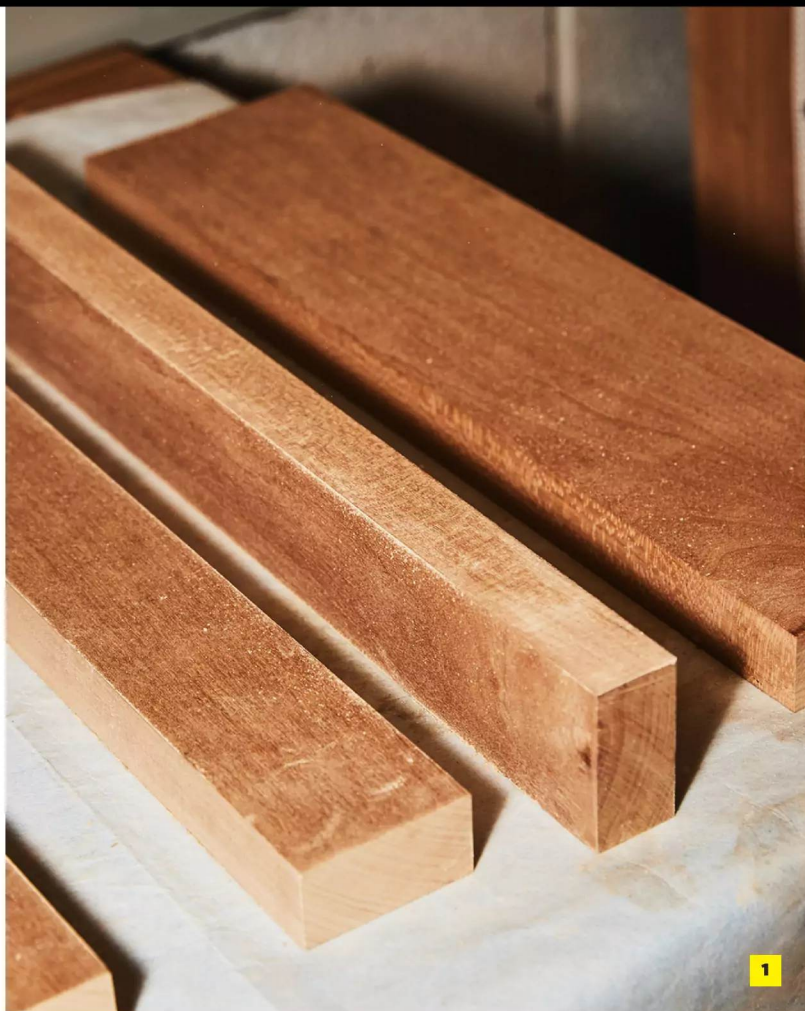
End-grain cutting boards use more wood than you would think. A fair amount is lost due to the number of times the wood is sawn—eight cuts eat up almost an inch, as the width of the blade removes $\frac{1}{8}$ inch on each cut. To make an 11 x 13-inch cutting board, I started with a 1 x 9 x 48-inch piece of cherry and cut it into 12 strips, each measuring

2 x 16 inches, to form a 12 x 16-inch block, 2 inches thick when glued.

The block was then cut into seven $1\frac{3}{4}$ -inch strips. These strips were flipped on end and glued, offsetting the previous glue lines, to form a block 14 inches long.

A final trim to remove the offset ends and square up the block yielded an $11\frac{1}{2}$ x $13\frac{7}{8}$ -inch cutting board.

STEP-BY-STEP INSTRUCTIONS



STEP 1

PREPARE WOOD FOR THE FIRST LAYUP

Be sure both sides are flat and that you have one straight, square edge. Cut the board into strips of the same thickness, width, and length. There are a few ways to do this, but the most common way is to use a table saw.

Set the fence 2 inches from the blade (if you're using our dimensions) and rip the board down its length. Repeat three more times to make four identical strips.

Then, using a miter saw, cut each strip into three equal lengths. You should now have 12 pieces exactly the same size—just a little under 16 inches long.



Prepare all sawn surfaces for gluing. If your table saw has left marks on the edges, they can be removed with a jointer—but be sure every piece goes through the jointer the same number of times to keep their dimensions consistent. You can also sand each edge, but take care to keep the surface flat. One way is to use a flat piece of hardwood as a sanding block.

STEP 2

GLUE FIRST LAYUP

Set your bar clamps out flat on a workbench. Then lay the 12 boards across the clamps. For a cutting board this size, two clamps are enough, but three would be better.

Examine the grain on the ends of each piece and arrange them so that any curved or angled grain opposes the adjacent piece. While people often arrange grain to form attractive patterns, Kline recommends alternating the grain to help make the finished cutting board more stable and less likely to warp or crack.

Once you have them arranged the way you want, flip them on their sides, apply plenty of glue, flip back up, and clamp tightly. Clamping can be tricky: The pieces may want to slide around as you clamp them together. Tighten



gradually, in stages, so you can press them back into alignment. To help keep pieces aligned, Kline suggests using strips of wood called cauls—face them with packing tape so they won't stick—across both ends of your pieces and clamp them above and below.

Let the glue dry for 24 hours.

STEP 3

PREPARE WOOD FOR SECOND LAYUP

Use a sharp wood chisel to shave off all the excess dried glue (3a). Get as much

off as you can—cured glue can quickly dull cutting edges of tools.

If there are obvious high spots from the pieces that may have moved after gluing and clamping, you can shave those down with a sharp jack plane or bench plane. Once any high spots are removed, sand both faces flat—start with 60 or 80 grit and work up to 150 (3b). If you have access to a thickness planer, use it to quickly finish both sides flat. Just watch out for snipe—when the planer digs deeper at the start or end of each pass.

Trim one end of the block to even up where the previously glued pieces may be uneven. Next, cut the block into seven strips across the grain. The width of each strip should be equal to the intended height of the cutting board, in this case $1\frac{3}{4}$ inches. You would typically use a table saw for these cuts, but we chose to use a compound miter saw to quickly make multiple passes through the thick block to prevent burn marks from the blade.

As in step 1, prepare all sawn surfaces for gluing.

STEP 4

GLUE SECOND LAYUP

As in step 2, prepare clamps for gluing and lay your wood strips across them, end grain up. Carefully arrange them to keep opposing angles on the grain. We followed Kline's advice to stagger the glue lines in order to make the board stronger and more stable.

Spread the pieces out, flip them on their sides, and apply glue.

Flip them back, end grain up, adjust positioning of the glue lines as needed, and clamp.



STEP 5

FLATTEN AND TRIM TO FINAL SIZE

As in step 3, remove excess glue, shave down any high spots, and sand through 150 grit.

Trim off uneven ends. This can be done using a sled on a table saw, or using a compound miter saw, as we did.

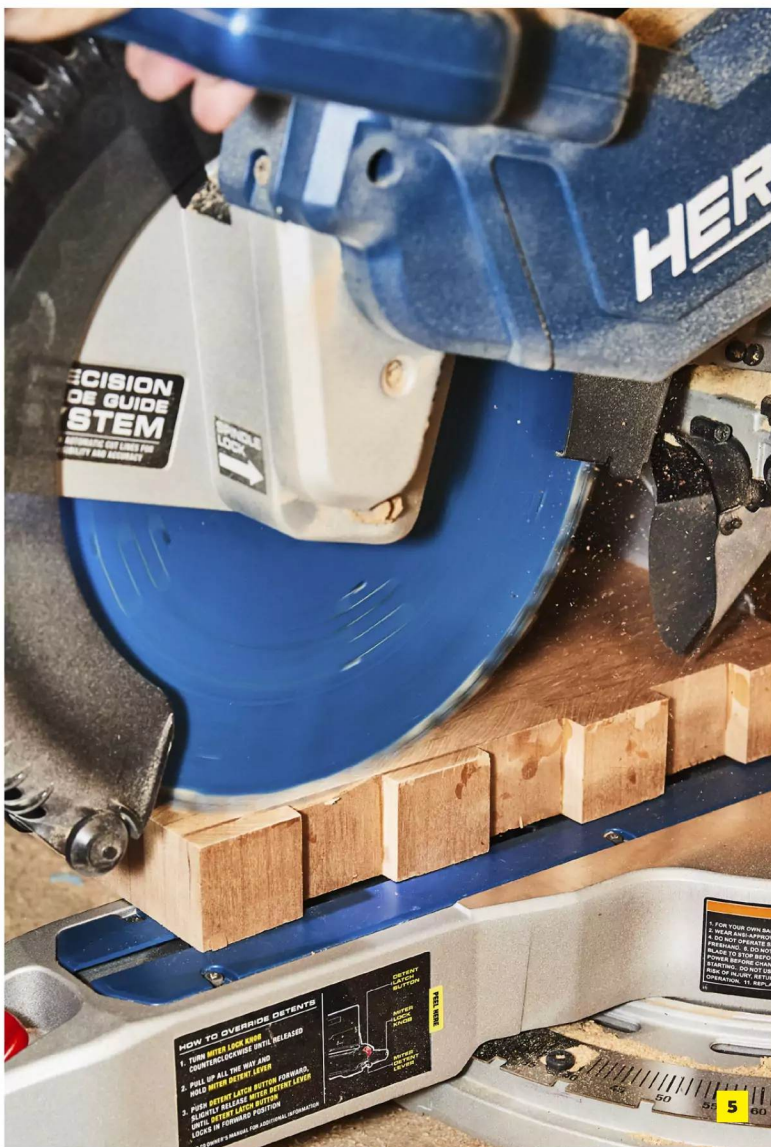
Sand the newly sawn ends to 150 grit. Then sand faces, sides, and ends with 220 grit. The corner edges can be finished rounded or square, depending on your preference. We wanted crisp edges, so we hand-sanded them lightly, using 220-grit sandpaper over a hardwood block. Pass over each edge the same number of times, at the same angle, for a uniform finish.

STEP 6

SEASONING

Use a tack rag or vacuum with a brush to remove any dust from the cutting board. Cover your work area and place two sticks or some blocks under your cutting board. Pour some oil on it and rub it in with a clean rag. As it soaks in, keep adding and spreading the oil until it lies on the wood in a light film. Apply oil to the edges, flip the board over, and repeat. Then wait 24 hours.

Wipe the board down with a clean, dry cloth to remove any excess oil. Then use a fresh rag to rub in some cutting board wax on the top, bottom, and all sides. Wait 15 minutes and use another clean, dry cloth to buff the board to an even finish. You're done.





BONUS PROJECT! DIY KNIFE STRIP ➔

DIY KNIFE STRIP STEP-BY-STEP INSTRUCTIONS



MATERIALS

- (12)
60 x 10 x 3mm
neodymium
magnets
- (2)
1" keyhole hangers

TOOLS

- 3/8" and 1"
Forstner drill bits
- Router and
1/2" straight bit

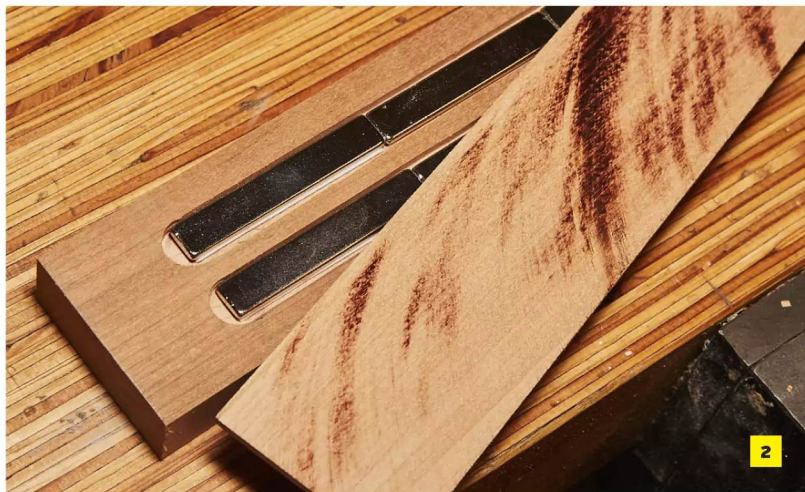
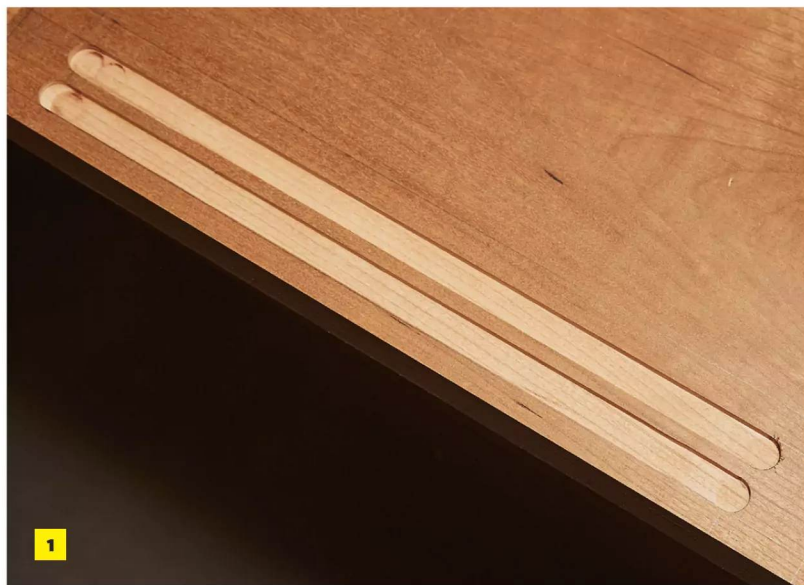
DIY KNIFE STRIP

If you've ever done any kind of wood-working, you know you end up with some scraps—cutoffs that are too big to throw away but that you don't have an immediate use for. This issue's end-grain cutting board produced just those types of scraps. So we decided a magnetic knife strip would be a quick,

easy companion project to use up the leftovers. Making this knife strip should take only a few hours over the course of two days. The tools and materials will be the same as for the cutting board, with the only additional things being some neodymium magnets, two keyhole hangers, a router, and some Forstner drill bits.

STEP 1**LAY OUT AND CUT POCKETS FOR MAGNETS**

The knife strip will be about 2 inches tall, 1 inch thick, and as long as your scrap of wood allows—12 to 16 inches is a good length. Mark 2 inches from the long edge of your wood, then lay out the location for two rows of magnets, $\frac{3}{8}$ inch from either edge. You'll use a router with a $\frac{1}{2}$ -inch straight bit to cut the long pockets for the magnets. This will be easier to do before you cut the wood strip down to 2 inches. Set the depth of the bit to $\frac{5}{32}$ inch to accommodate the magnets. Clamp another piece of wood to use as a fence to guide the router. Cut the pockets up to 1 inch from either end.

**STEP 2****CUT AND GLUE MAGNET COVER**

Use a table saw to cut the 2-inch-wide strip off your scrap of wood. Then stand the strip on edge and trim $\frac{1}{8}$ inch off the side opposite the magnet pockets. This will be used to cover the magnets. It's likely you'll get some burn marks on the wood. Don't worry: You can sand these away later. You can use double-sided tape that comes with the magnets to mount them in the pockets. Be sure to handle the neodymium magnets carefully and do not let them snap together—they are brittle and will break easily if they

do. Carefully lay them out to align their poles, so they stick together end to end, before you install them. Once installed, glue the cover over the magnets and clamp using a scrap of wood as a caul to help the clamps provide even pressure. Cover the face of the caul with clear packing tape so it won't stick to the wood strip if it gets any glue on it.

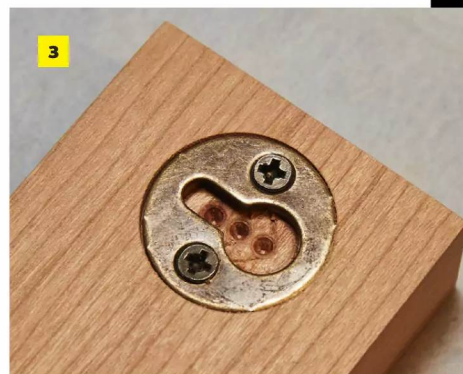
STEP 3**INSTALL KEYHOLE HANGERS**

Mark the locations for two 1-inch-diameter keyhole hangers on the back of the knife strip. You can create pock-

ets for them with a 1-inch Forstner drill bit. Make the pocket deep enough so the hanger sits flush with the surface. Place the hanger in the pocket and mark the location for the center hole where the slot for the wall mounting screw will go. Use a $\frac{3}{8}$ -inch Forstner drill bit to make holes for the top, center, and bottom of the slots. Clean up the edges and reinstall the hangers.

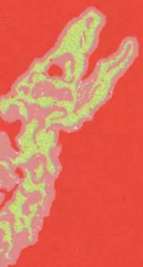
STEP 4**SAND AND SEASON**

Sand the top and bottom edges, ends, face, and back—work from 100 grit up to 220. Then season with Walrus Oil cutting board oil and wax, as directed for the end-grain cutting board. That's it—all that's left is to hang your knife strip over your kitchen work area.





A FEAST FOR *the* (GEOLOGIC) AGES



Ever wondered if you could spatchcock a pteranodon? What sauce to pair with slabs of Columbian mammoth steak?

No? Just us?

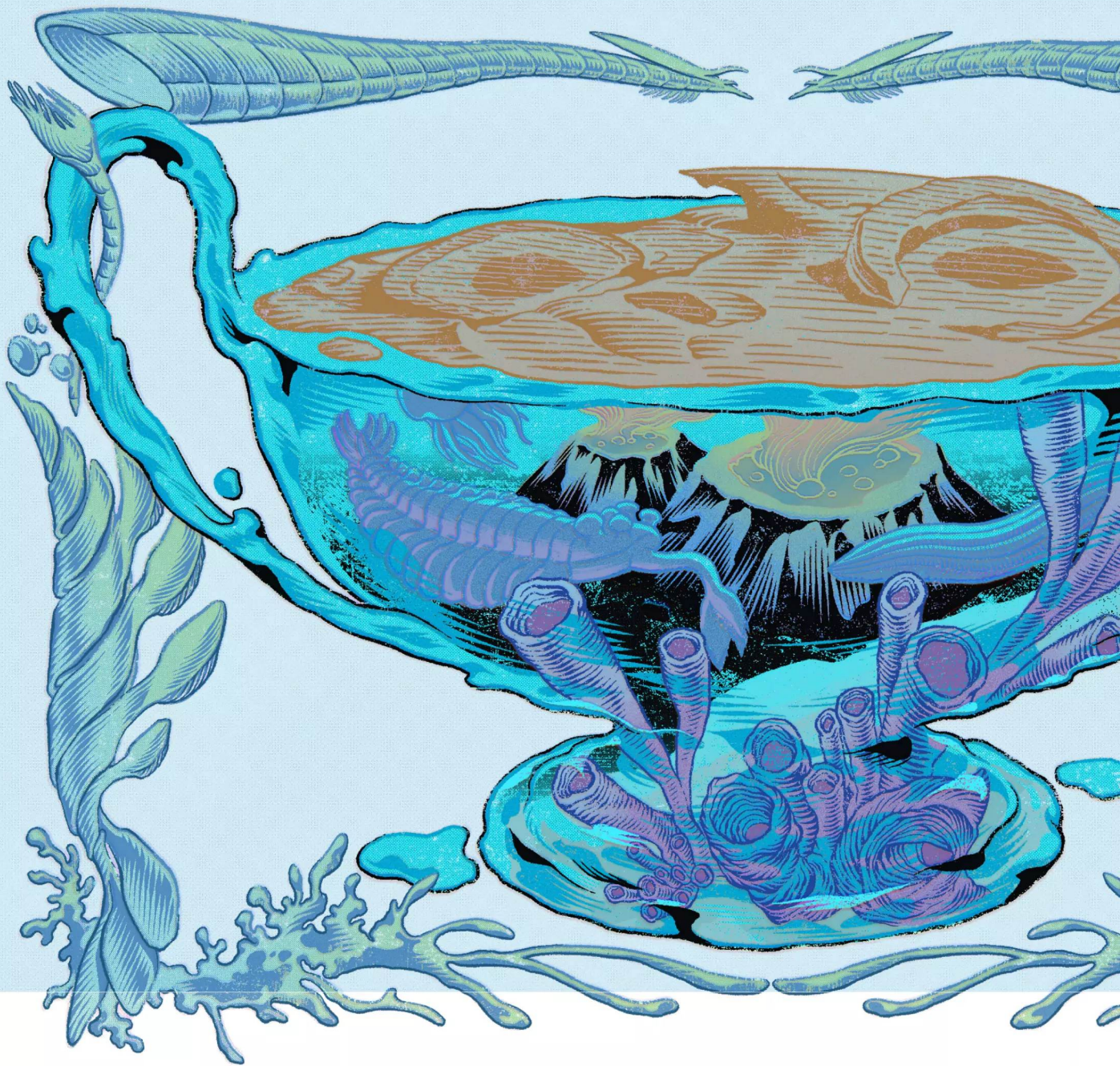
Thanks to advances in paleontology, we now know so much about some of these prehistoric creatures that scientists can almost predict what they might have tasted like. Here at *Pop Mech*, we relish in the weird, so we've cre-

ated a paleontological menu based on the plants and animals found at three important fossil sites: British Columbia's Burgess Shale, Utah's Dinosaur National Monument, and the La Brea Tar Pits in Southern California.

Many of these specimens, with features and traits similar to today's flora and fauna, represent the earliest in their group's evolutionary lineage and have helped the scientific community piece together a clearer picture

of how life on Earth evolved. Some of these specimens, on the other hand, represent seemingly inconceivable life-forms, lost to evolution with no modern-day analogs.

We asked chefs Sohla El-Waylly, Nik Sharma, and Josh Scherer to prepare a prehistoric meal for our modern-day palates using what we know about these incredible organisms. Their recipes, paraphrased within, are rigorously scientific and wildly creative.



BURGESS *Shale*

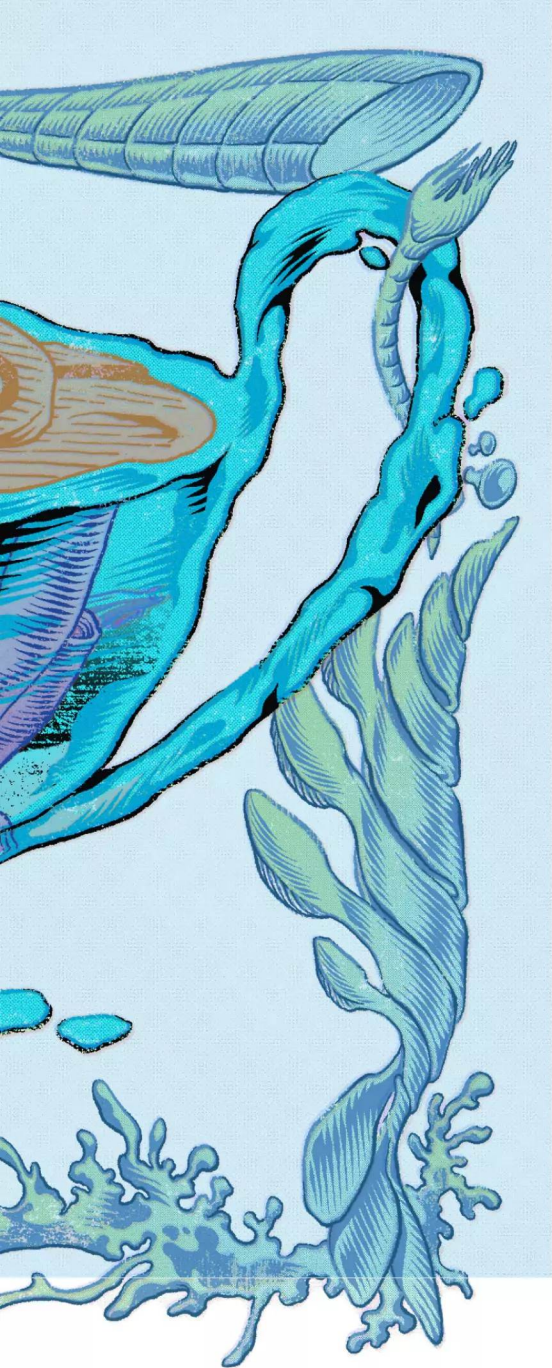
 **British Columbia**

The Burgess Shale in the Canadian Rockies is one of the world's most valuable fossil sites, containing a massive trove of preserved critters from the Cambrian Period, more than 500 million years ago.

These creatures were likely caught in a series of mudslides, where they were flash-preserved—much like the residents and ephemera of Pompeii—in a much better state than would be otherwise possible,

thanks to the layering of minerals that acted as insulation against decomposition. The chemical combination created calcium carbonate, the same hard material many sea creatures' shells are made of.

In addition to bones, these fossils show soft tissue, giving scientists more to analyze as they study and classify them. Some of the more than 65,000 specimens collected from the site are similar to organisms that exist today, such as sea sponges and worms, which suggests they may represent some of these modern-day animals' earliest ancestors. Other specimens appear to be unlike any animal alive today, presenting paleontologists with an evolutionary puzzle to solve. There's still a lot we'll never know about these animals, but the Burgess Shale opens a window into a period whose creatures could otherwise have been lost to time.—*Caroline Delbert*



Opabinia regalis

One of the most famous Burgess Shale creatures, *Opabinia regalis*, is a segmented arthropod with an exoskeleton of chitin and calcium carbonate. (Other arthropods include crustaceans, insects, and spiders.)

Its many segments had fanlike sweepers, creating a skirt like you might find on a hovercraft, and its face was adorned with five beady eyes.

SCHERER'S PREPARATION:

There is no better way to cook

arthropods than a good old-fashioned Viet-Cajun seafood boil.

Throw shrimp, crawfish, crabs, lobster, whatever you got—including *Opabinia regalis*—into a big ol' pot with plenty of butter, garlic, Tony Chachere's creole seasoning, potatoes, corn, and andouille sausage.

Drink enough Abita beers and you won't even notice all the freaky eyes. It's just a butter-suckin', beer-drinking, nightmare-creature-eating festival of fun.

Choia carteri

Most modern-day animal sponges belong to the class demosponge. We're used to seeing one kind, the long, porous, and oft-cylindrical "bath sponges," but many sponges have stems and more developed structures.

SCHERER'S PREPARATION:

Since sponges are porous, they'll likely soak up the flavors they're cooked in, similar to tofu.

First, we'll throw *Choia carteri* into the Instant Pot for about 45 minutes on high, before draining and rinsing to remove impurities. Then we'll simmer them for another hour or so with thin-sliced pork belly, kimchi, scallion, and gochugaru or Korean chili flakes.

Some "experts" say animal sponges are not edible. I say they just haven't pressure-cooked 'em long enough.

Golenopteron tentaculatum

This jellyfish-like critter's body, made largely from a gelatinous material called mesoglea, is packed within an ultrathin membrane—kind of like a water balloon.

SCHERER'S PREPARATION:

I wouldn't want to disturb that sweet, sweet epithelial layer, but I do want to play with it.

Since this gooey beauty is basically already nature's dumpling, we'll wrap it in a thin layer of dough, and then steam it and top it with sour cream, powdered sugar, and lemon zest for a play on the Polish dessert knedle ze śliwkami.

Does *Golenopteron tentaculatum* taste like a late-harvest Northern European plum? Probably not, but we're about to find out!

Pikaia gracilens

This creature looks at first like an eel or fish, but it also has a row of tiny legs, like those on an annelid (segmented worm).

It's one of the earliest chordates, the large phylum that includes mammals and fish. Its closest living lookalike may be the lancelet, a fish-like invertebrate that lives in shallow waters around the world.

SCHERER'S PREPARATION:

Though *Pikaia gracilens* averaged about two inches in length during adulthood, I would actually harvest my ingredients in their infant stage, when they're under half an inch.

To start, we'll gently warm some olive oil with thinly sliced garlic and guindilla chile, and then add the Pikaia to the pan so they can gently warm through.

This recipe calls to mind tinned baby eels—known as angulas in Spain and elvers in England—which are a rare and expensive delicacy that taste awesome spread on some crusty pan gallego. You probably could have made a quick buck selling these 500 million years ago.



OUR CHEF: Josh Scherer leads Mythical Kitchen, part of a YouTube network that tests cooking myths, makes high-cost fast food, and has stars like John Boyega and Tom Hanks choose their last meals. He is an award-winning food writer and the author of *The Mythical Cookbook* and *The Culinary Bro-Down Cookbook*.

DINOSAUR National MONUMENT

Utah and Colorado

About 150 million years ago, among the Jurassic floodplains of what's now eastern Utah and western Colorado, enormous dinosaurs filled a landscape carpeted in ferns and dotted with conifer stands.

Creatures of every size filled the ancient landscape, with a diversity of dinosaur species seldom seen in other times and places. Long-necked, portly giants such as *Apatosaurus*, *Diplodocus*, and *Camarasaurus* reached their heads high to nibble at ginkgo branches while the spike-tailed, plate-decorated *Stegosaurus* nibbled at horsetails and other forage closer to the ground. But this place was no herbivorous paradise. Enormous carnivores stalked through the shadows of the woodlands, especially *Allosaurus*—a 30-foot-long carnivore with triangular horns in front of its eyes and a mouth packed with teeth that evolved to puncture and slice.

The remains of these dinosaurs and many other organisms, including some of our earliest mammalian relatives, were washed into a great fossiliferous slurry that you can now visit at Dinosaur National Monument, along the Colorado-Utah border. The site is part of the vast Morrison Formation, layers of rock across much of western North America that formed over tens of millions of years. Discovered more than a century ago, the bonebed was such a momentous find that its founder, Earl Douglass, tirelessly petitioned that the site become a living museum. In 1915, his efforts finally paid off as the region officially became recognized as a national monument.—*Riley Black*

Camarasaurus

The long-necked *Camarasaurus* would have been abundant on the landscape—its bones are among the most common in the Morrison Formation. Even though this stupendous herbivore may have hatched from eggs about the size of a grapefruit, the adults could reach more than 60 feet in length.

Camarasaurus is thought to have fed on horsetails, ginkgoes, and other fibrous plants, “so I’d imagine that the meat would be pretty tough and gamey,” says University of Wisconsin Oshkosh paleontologist Joseph Peterson. A chef would have to find a way to both mask the gaminess and tenderize the meat, not unlike cooks having to cover the swampy flavor that comes with alligator meat.

SHARMA'S PREPARATION

I would try to cook *Camarasaurus*

like lamb. To start, let's trim some of the fat off and flavor the dinosaur meat strongly with spices and herbs. A lactic-acid marinade—essentially leaving chunks of *Camarasaurus* in yogurt overnight—would help make the flesh more tender. Then we could try to cook the meat similar to, say, stewed oxtail with yellow or red curry paste. Think of it as a *Camarasaurus* curry.

Allosaurus

Nearly as abundant as the *Camarasaurus*, these carnivores were not bone-crushers like the later *Tyrannosaurus*. Instead, they opened their mouths wide and used their powerful neck muscles to swing their heads like hatchets, their curved teeth puncturing flesh and cutting through to carve off a big gob of meat.

Most adult *Allosaurus* got to be about 30 feet long, but some exceptional specimens would have stretched about 40 feet from nose to tail.

SHARMA'S PREPARATION

Allosaurus likely would have had low fat content, and would probably need to be cooked more like alligator often is today. I'm thinking...popcorn chicken? First, we'll marinate the meat in buttermilk before coating it with panko bread crumbs and green chilis. Then we'll fry it, masala-style, and serve with a tomato chutney sauce.

Stegosaurus

The height of Jurassic fashion was body armor, and no dinosaur wore it so ornately as *Stegosaurus*.

This herbivore could grow to be more than 29 feet long, its back decorated with alternating rows of polygonal plates and the dinosaur's tail tipped with four long spikes. *Stegosaurus*'s neck was embedded with pebbly bones called osteoderms, designed to protect the dinosaur's throat.

SHARMA'S PREPARATION

Because our human teeth have not evolved to deal with the *Stegosaurus*'s very strong muscles and ligaments, we'd need to tenderize the meat. So, I'd try to cook it like turkey. Much like the preparation for *Camarasaurus*, we'll brine the



OUR CHEF: Before becoming a chef and food writer, Nik Sharma worked as a molecular biologist. His 2020 cookbook, *The Flavor Equation*, explored the roles science plays in the kitchen through 100 essential recipes. His latest book, *Veg-Table*, illuminates the wondrous versatility of veggies.

meat in a yogurt marinade with plenty of spices and herbs overnight. Then we'll roast it and carve that *Stegosaurus* up.

Ginkgo, fern, and horsetail

There were no flowering plants in the Jurassic, so many greens we're familiar with would not have existed yet. In the Morrison Formation, fossils indicate that the landscape was covered in low-growing ferns, with horsetails planted along bodies of water

and ancient ginkgo species nestled among the forests.

These plants were relatively calorie-rich and formed the base of an ecosystem that allowed dinosaurs like *Camarasaurus* to thrive.

SHARMA'S PREPARATION

Planning greens to accompany a dinosaur dish is tricky, as many plant species growing at the time would be toxic if eaten raw.

Plants like ginkgo and horsetail would first have to be boiled in water to help break down the tox-

ins. We could look to recipes like fermented pinecones, a dish popular throughout northern Europe. Many plants have a natural yeast on them, which we could ferment with a sugar syrup to give the plants some flavor.

Alternatively, we could use the Chinese technique of dry-braising, where we'd fry them up, perhaps with ginger, garlic, chili oil, and sherry, to create a crispy side of Jurassic greens that pairs well with any dinosaur protein.



OUR CHEF: Sohla El-Waylly hosts *Ancient Recipes with Sohla* on the History Channel, where she tests famous historic recipes. (Jesus's last supper, anyone?) She's also the author of *Start Here*, a new science-informed cookbook that teaches fundamental cooking techniques. "When you really know how these cooking techniques work, you can cook anything," El-Waylly says.



LA BREA

TAR PITS

 Los Angeles, CA

trumpeting in panic. It's 20,000 years ago in what is now Los Angeles, and the mammoth has gotten stuck in a pool of natural asphalt.

Thousands of animals have met their end this way in California's La Brea Tar Pits, where asphalt—a type of crude oil—is still seeping to the surface. In addition to plant-eaters such as mammoths, a remarkable number of predators such as dire wolves and saber-toothed cats have also been claimed by the tar pits. Predators are rarely found in the fossil record, compared with their prey. The opposite is true at La Brea, where the cries of trapped animals lured hungry meat-eaters to their doom.

The asphalt preserves a fossilized record of life in that region from at least 50,000 years ago through the modern day. Dinosaurs were long gone by the Pleistocene, replaced by a variety of huge mammals. Many of those mammals went extinct as the climate warmed and humans altered the landscape, while others survived and adapted. Scientists can use the La Brea fossils to understand similar changes happening now.—*Nala Rogers*

Columbian mammoth

Columbian mammoths fed on grass and other plants and, unlike their woolly cousins, had mostly bald skin. The largest may have weighed up to 20,000 pounds.

At similar sites, archaeologists have found mammoth bones alongside spearheads, and some of the bones have cut marks where the meat was butchered.

EL-WAYLLY'S PREPARATION:

The biggest issue is the size, so I think the best way to cook it would be to make a mammoth barbacoa, a form of barbecue which originated in the Caribbean.

First, we'll get together and gut it. Next, we'll dig this giant hole and line it with juniper. (I worked in a Nordic-inspired fine-dining place, so we used a lot of juniper. When you burn it, you get that instant Christmas vibe.) Then we'll just roll the mammoth into the hole. Mix together some kind of barbacoa marinade, like dried chili puree, maybe some citrus. We'll pour the marinade on our mammoth, cover it with more juniper, light a fire on top, and let it slow-roast.

People can just dive in and rip off pieces of meat. It's going to be a party.

Harlan's ground sloth

In the Pleistocene, several species of giant ground sloth roamed the land. The lumbering Harlan's ground sloth could weigh as much as a car and had armor made of bony knobs embedded in their skin.

According to U.S. Bureau of Land Management paleontologist Greg McDonald, ground sloths ate plants and were likely lean, with massive tendons that may have made their meat tough.

EL-WAYLLY'S PREPARATION:

Yakitori, a Japanese method for cooking chicken on skewers, might be the best way to go.

First, we're going to cut that tough connective tissue away, separate out the different muscles, and then skewer them. Next we'll cook the skewers over coals really fast to prevent them from getting chewy, and then glaze them with a simple tare. (Tare is when you just simmer down soy and stock until it's really reduced, and it's got lots of umami and salt.) Brush it on at the end and give the skewers a quick final kiss on the grill. You'd get a lot of char, and it's a really great way to deal with any kind of tough cut.

Picture yourself strolling through a juniper-oak woodland. The birds are singing, the sun is shining, and a Columbian mammoth, a relative of modern-day elephants, is

Giant short-faced bear

Short-faced bears were among the largest meat-eating mammals that ever lived. When they reared up on their hind legs, they would have been about twice as tall as a full-grown person.

While no one today knows what short-faced bears tasted like, the fat-rich meat from modern bears is full of *Trichinella* parasites and must be cooked thoroughly.

EL-WAYLLY'S PREPARATION:

Meat-eating animals tend to be more gamey. So, I think we'll go with a barbecue brisket vibe.

To start, we'll coat it with a simple salt and pepper brine, and then we'll smoke it for a really long time so it'll absorb a lot of that smoky flavor and be thoroughly cooked.

Barbecue comes from the Taino people, so it's been around almost forever. I think it's actually possible that Indigenous people could have cooked a bear this way.

Merriam's teratorn


With a wingspan of up to 13 feet, Merriam's teratorns were huge birds of prey.

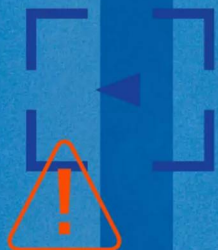
Some scientists believe they ran on the ground and snatched small animals with their beaks, while others think they might have fished like ospreys. Yet another theory suggests that teratorns were like vultures, feasting on carrion.

EL-WAYLLY'S PREPARATION:

My go-to strategy for any bird, especially a bird that I'm not very familiar with, is to fry it. First, we'll break it down into different pieces: wings, legs, thighs, and breast. It sounds like this is a big breast, so I would break it into two parts.

Next, we'll dry-brine overnight. A dry brine breaks down some of the meat's proteins into a gel that retains moisture. Finally, we'll do a traditional Southern, crunchy, Popeyes-style dredge, where you season up the flour and then you pack the flour into every crevice so you get those big crackly pieces.

No matter what this bird is like, it's going to be delicious. 



SELF-DRIVING CARS

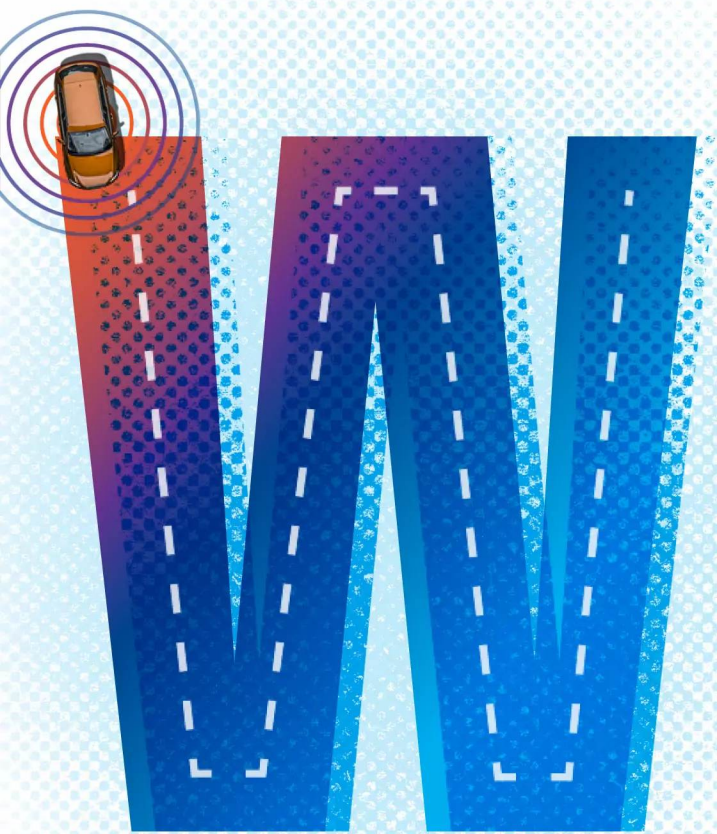
Replacing human drivers with artificial intelligence could save thousands of lives. **That's the promise, anyway.**

BY JOE LINDSEY



VS.

**THE
WORLD**



What Barak Gila's roughly 15-minute commute through San Francisco's Castro and Mission Districts lacks in length, it makes up for in excitement. Gila, a software engineer, knows that on any given day his route will be dense with traffic—some pedestrians and bicycles, but mostly motor vehicles. Those come in every size and permutation possible, including the self-driving cars (also called autonomous vehicles, or AVs) that developers like Google's sister company Waymo and the General Motors-owned Cruise are testing in the city.

Gila commutes by bike, and doesn't mind riding around AVs. While vehicles from both Waymo and Cruise have been documented exhibiting alarming behavior in the city—swarming, blocking traffic, even rolling through an active firefighting scene—Gila says he's "never had a self-driving car behave unsafely" around him. And it wasn't an autonomous vehicle that right-hooked him in May 2021; it was a human-driven Porsche, whose driver told him the car's blind-spot detector hadn't alerted him to Gila's presence. Gila had been vigilant and was able to avoid injury, but the episode was a troubling harbinger.

An article of faith among proponents of autonomous vehicles is that most (94 percent is often cited) traffic crashes are caused by human error. Pedestrians and people on bikes made up a minority of the 42,939 road deaths in the United States in 2021 (the most recent

year for which we have data), but they're killed at higher rates than vehicle occupants. Aside from a slight dip in 2020 when we drove less early in the pandemic, pedestrian and cyclist fatalities have risen for over a decade. In 2021 the annual total of cyclists killed jumped 5 percent to an all-time high of nearly 1,000, according to preliminary data from the National Highway Traffic Safety Administration (NHTSA). Pedestrian fatalities were up 12.5 percent to 7,388, the highest since 1981.

But an autonomous vehicle will never be distracted by a text message; nor will it drink and drive or road-rage, says Anne Dorsey, a software engineer in Waymo's behavior division. Removing humans from the driving task, or dramatically reducing their role, could save thousands of lives and countless injuries every year, especially among vulnerable road users.

That's the promise, anyway. But autonomy's safety benefits aren't yet proven, and even if they do pan out, a decade of halting development progress suggests that rolling out true self-driving vehicles on a scale that could achieve those gains will likely take far longer than what the AV industry has promised. In the meantime, car manufacturers are pushing forward with advanced driver assistance (ADAS) technology, offering "autonomy lite" features like the ones in that Porsche. But that approach comes with its own issues: Studies suggest that the misleading marketing and tech terminology is often so confusing that a frightening number of drivers treat their cars as self-driving when they're not.

As Gila found out, that technology—which ranges from blind-spot detection to systems that can handle all driving tasks in limited conditions—is far from fool-proof. "The [driver] was relying on it, but it doesn't work 100 percent of the time," Gila says. "That false promise of safety can be almost worse than nothing."

And with bare-bones regulation of driver assistance features as well as the testing of fully autonomous vehicles, it's difficult to tell which aspects of each approach work and which don't, raising valid concerns that some of the very features intended to make the roads safer for everyone could be doing just the opposite. Meanwhile, in the search for future technological solutions, we're ignoring existing—if less sexy—tools that could improve safety today and solve other problems as well.



THE IDEA OF CARS THAT CAN DRIVE THEMSELVES

first emerged in the 1950s; in 1960, GM and RCA partnered on an experimental project that used electrical circuits in a road surface to control steering, acceleration, and braking and demonstrated the technology on a test track. Then, as now, safety was a central selling point: One advertisement from the time reads, "Science promises a future free of traffic accidents."

That belief is so widely accepted today that even NHTSA agrees that improved public safety "promises

to be one of automation's biggest benefits." But more than six decades later, we're still waiting for that future.

In terms of perception abilities, the Level 4 autonomous vehicles that Waymo and others are testing are already vastly more capable than human drivers. (According to the Society of Automotive Engineers, Level 4, or "high automation," means the vehicle drives itself while the occupants are hands-off passengers. But it can operate only in limited service areas; full-on, go-anywhere autonomy would be Level 5, which is almost a sci-fi dream.) Level 4 vehicles use a sophisticated array of sensors, including high-definition cameras, microphones, radar, and a kind of powerful laser scanner called LiDAR (light detection and ranging) that can create three-dimensional maps of the driving environment.

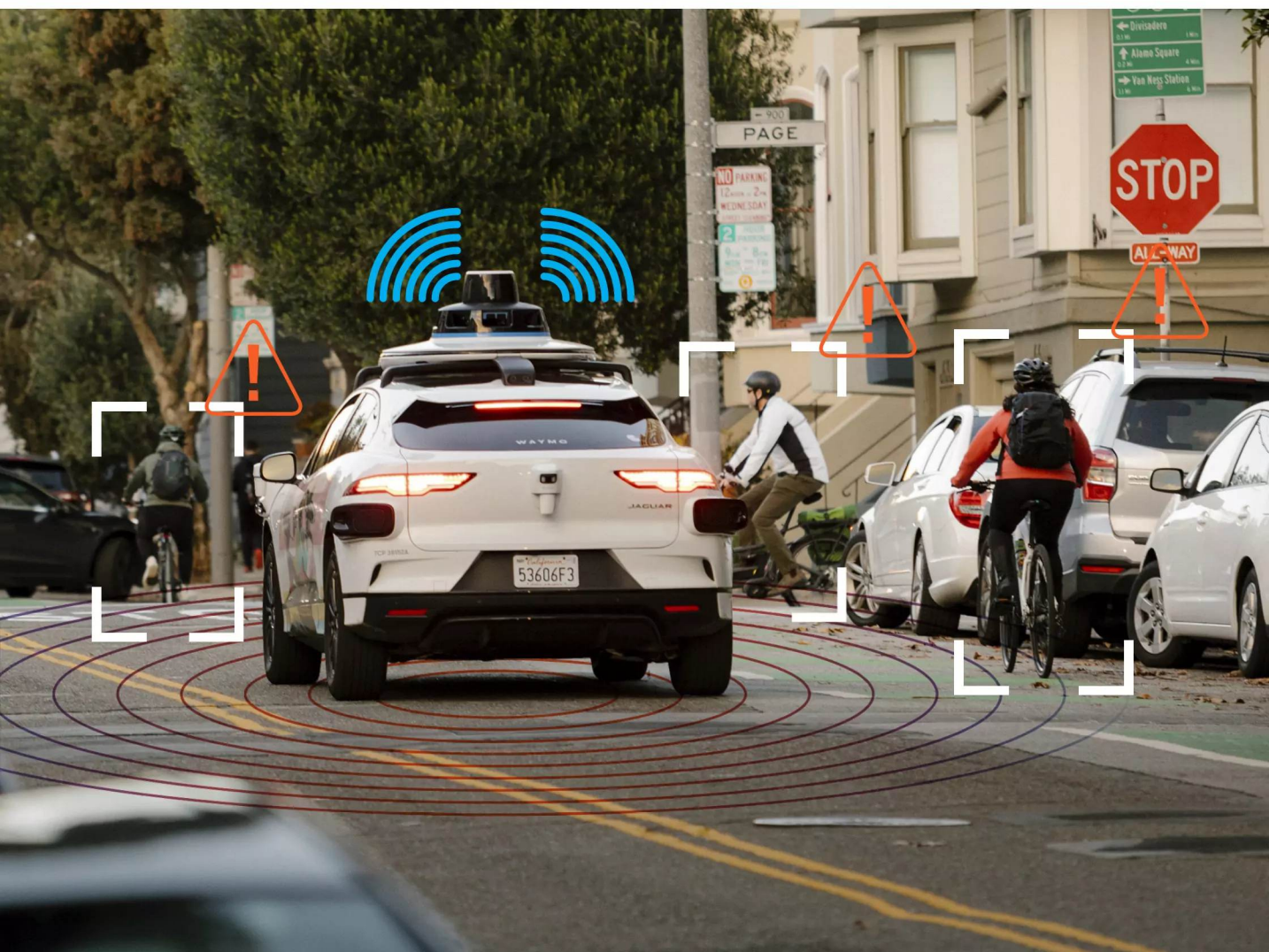
Together these tools scan the vehicle's surroundings dozens of times every second. Pointed in every direction, they capture a full 360-degree view around the vehicle (versus a human's roughly 180-degree vision).

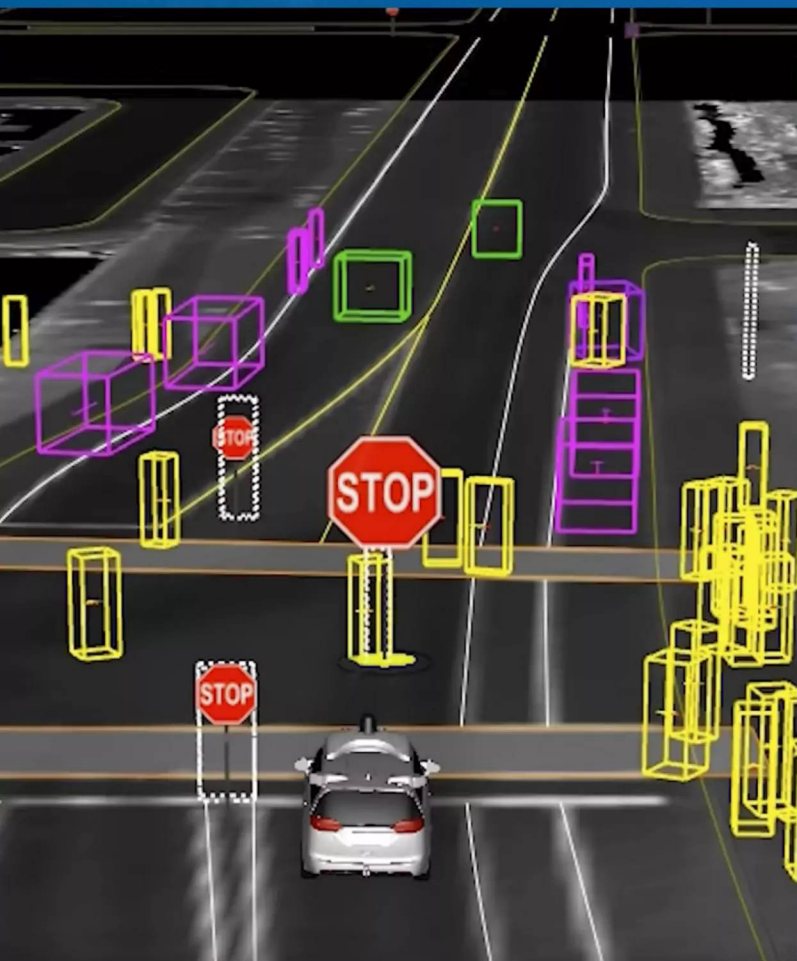
All of that data can be stitched together in a kind of pan-optic super vision that can see hundreds of feet away, at night, even through some solid objects.

Sensors are only a small part of the perception game. Autonomous vehicles use machine learning, a subset of artificial intelligence that employs algorithms and massive image databases to "teach" the driving software how to properly identify objects the sensors detect, including all their variations: assessing whether a child scooting on a balance bike is a cyclist, or if a woman carrying grocery bags is a pedestrian and not a mailbox. They're accurate to varying degrees, in part due to their databases, and sometimes struggle to identify dark-skinned people or those with disabilities.

Still, a 2023 test drive video from Waymo offers a stunning preview of autonomy's perception capabilities. In the split-screen video, the bottom half is the passenger's-eye view; the top half is a graphic representation of what the company's self-driving tech, called the Waymo Driver, "sees" from its sensors. As the

A Waymo driverless vehicle navigates around bike riders and pedestrians in a San Francisco neighborhood.





▲ In this split-screen video clip, a Waymo Driver waits for students at a school crossing. Multi-layered sensors produce a 360-degree view around the car.

vehicle navigates downtown San Francisco, dozens of pedestrians and cyclists show up as bright silhouettes in the Driver view, clearly identified even blocks away or partially obscured by parked cars or buildings. A human might struggle to pick out half of them.

Another area where autonomous vehicles have an edge over humans is consistent behavior. “If the Driver responds the same way every time, that can increase safety for cyclists because they know what to expect,” says Dorsey. Consider a four-way stop with human drivers and someone on a bicycle: Cyclists often don’t know if someone will wave them through even when they have the right of way, or ignore them and cut them off. In the same scenario with a self-driving vehicle, the car should react the same way every time—and not only that car, but every car in the fleet. The cars share the same software, so it’s essentially as if they all have the same driver. This fact makes safety scalable, says Clay Kunz, a robotics software engineer in Waymo’s perception division. Say a car responds unsafely to a pedestrian during testing. A software update can change the behavior of every vehicle with that operating system. “Once you solve the problem,” he says, “the behavior is distributed across the fleet.”

But proper behavior—which involves judging what other road users are doing and then responding

appropriately—is exceptionally difficult because of the massive variety of possible driving scenarios. “Cyclists and pedestrians are challenging because they can be anywhere in the driving space,” says Stephanie Villegas, Waymo’s former lead of structured testing. They can be following traffic rules or going against traffic. They can be in a lane or between lanes, and the difference matters a lot insofar as predicting what they’ll do next. “It’s hard to list all the ways they interact with drivers,” she says.

That’s a challenge even for human drivers, but we have a built-in advantage. “Humans are really good at predicting the intent of other humans based on things like posture and explicit gestures,” says Justin Owens, PhD, a research scientist with the Virginia Tech Transportation Institute. “We’re hardwired to do that, with capabilities we’ve evolved over millions of years.” As Sam Anthony, founder and former CTO of the autonomous vehicle software company Perceptive Automata, wrote in a 2022 Substack post, it takes a fraction of a second for a human driver to see a pedestrian and process a massive amount of contextual information on the person’s age, attention level, and even emotional state, all of which influences how the driver responds.

Autonomous vehicles don’t have that ability, so developers program vehicle behavior partly by trying to test and catalog every possible interaction. They use

COURTESY WAYMO

a combination of software simulation and on-the-road testing, including at places like Castle, a decommissioned military air base about 120 miles east of Waymo's headquarters in Mountain View, California. Waymo isn't the only AV developer testing there, but its 113-acre facility is the largest at Castle, with roads, intersections, street signs, and other elements of a basic cityscape where engineers can test a wide variety of situations in a controlled but real-life setting. That's especially valuable for what are called edge cases, unusual events that would be hard to find and/or unsafe to test in public: a person on a bicycle emerging from in front of a box truck, for example, or riding through a cloud of sensor-obscuring debris kicked up by a leaf blower.

Waymo and other companies also test on public streets, most notably in San Francisco and parts of Phoenix. But there isn't much in the way of independent oversight of that testing. And in at least one instance, the result of that was tragic.

AT 9:58 P.M. ON MARCH 18, 2018, A HEAVILY modified Volvo XC90 sport utility vehicle from Uber's self-driving division, Advanced Technologies Group (ATG), accelerated northbound along a stretch of North Mill Avenue, a four-lane divided arterial in Tempe, a Phoenix suburb. The vehicle was in autonomous mode, on a testing loop that Uber vehicles had driven roughly 50,000 times.

The vehicle's sensors scanned the roadway ahead, synthesizing the data against high-definition route maps, and its onboard computers crunched complex algorithms of object detection, prediction, and behavior response to calculate its speed and path. In the driver's seat sat Rafaela Vasquez, an operator responsible for monitoring the system and taking over in any situation that exceeded the vehicle's self-driving ability.

Up ahead, Elaine Herzberg, 49, walked a bicycle into the roadway from the raised median, several hundred feet from the nearest crosswalk. Herzberg was a grandmother and had been on the verge of securing an apartment that would have ended a period of homelessness.

The vehicle's sensors registered Herzberg's presence in the road from more than a football field away. But over the next 4.5 crucial seconds, the system became confused, bouncing between identifying her as another vehicle, a bicycle, and a category simply called "other." Each time the classification changed, the vehicle recalculated her expected path and speed or determined that she was not moving at all. Vasquez, meanwhile, was looking down at her cellphone. Herzberg was just a few feet from the safety of the curb as the car approached at the 45 mph speed limit. By the time the Uber's software recognized the collision risk, at 1.2 seconds to impact, the crash was unavoidable, but it gave no alert

Bare-bones regulation raises concerns that some features intended to make the roads safer could be doing just the opposite.

to Vasquez, who was still distracted. An audible alert finally sounded at 0.2 second, as the vehicle began to brake. Vasquez retook the wheel just .02 second before the fatal impact at 39 mph.

North Mill Avenue is straight, with unobstructed sight lines and overhead street lighting. Even at night, such a collision should have been easy to avoid. A damning 2019 crash investigation report from the National Transportation Safety Board (NTSB) cited numerous failures by Uber, including the fact that engineers had disabled the car's standard emergency braking system so it didn't interfere with the self-driving software, which itself failed to register Herzberg as a pedestrian because she was crossing mid-block "and the system design did not include consideration for a jaywalking pedestrian."

Despite lengthy criticism of what it called Uber's "inadequate safety culture," the NTSB assessed the probable cause of the crash as Vasquez's distraction and failure to monitor the vehicle and driving environment. Vasquez was the only person ever criminally charged for Herzberg's death. Although indicted in August 2020, her trial date was repeatedly postponed; in July 2023, she pled guilty to endangerment and was sentenced to three years of supervised probation. (Vasquez's lawyer did not respond to a request for comment.) Uber separately settled a civil suit with Herzberg's family.

At the very least, Herzberg's death should have been a signal to Congress and federal regulators to start paying attention to the autonomous vehicle industry. However "it was not the wake-up call that it really deserved to be," says NTSB chair Jennifer Homendy. (The NTSB investigates crashes and makes recommendations but does not make or enforce regulations.)

Arizona suspended Uber's vehicle-testing permit following the crash, and the company voluntarily paused testing elsewhere. Its ATG division was offloaded to Aurora Innovation in 2020 for just 55 percent of its previous year's valuation. But now, almost five years later, little has changed on the regulatory front.

No federal rules govern public road testing of fully autonomous vehicles. Two bills in Congress that would address regulation at the federal level—the AV START Act and the SELF DRIVE Act—have been circulating since 2017 without legislative action.

Without federal laws (or dedicated funding for regulators such as NHTSA), oversight is largely left to a patchwork of state and local authorities, and the specifics vary widely. In California, companies that are actively testing autonomous vehicles under permit are required to submit collision reports to the state's DMV within 10 days of any crash that involves property damage, personal injury, or death, identifying who was likely at fault and whether the test vehicle was operating in autonomous or human-driven mode at the time of the collision. In 2022, Waymo reported 71 crashes in the state and Cruise reported 33. (Because fleet sizes differ, these numbers may not reflect crash rates per miles driven; also, some of those reported crashes involved vehicles in human-driven mode). A separate reporting system focuses on what are called "disengagements," or times when a test vehicle's self-driving system stops operating for any reason. Companies criticize disengagement as a garbage metric, and the data is available only in raw format, without analysis or context to help the public understand performance or trends. Still, together those reports represent the most transparent and stringent regulation in the U.S.

In Arizona, oversight is considerably more lax: To get a permit, companies need only self-certify that test vehicles comply with Federal Motor Vehicle Safety Standards and that the software "is capable of complying" with local traffic laws. No reports are required.

Herzberg's death is—so far—an outlier. And it's tempting to think that autonomous vehicles could end those 94 percent of crashes caused by human error. But that widely cited figure refers simply to "the last event in the crash-causal chain" and ignores other factors, such as road design, that play key roles in crashes. Assuming that autonomous vehicles would remedy that depends on believing that they would not only end all human driving errors, but also avoid making any of their own. In fact, some experts contend that self-driving vehicles would struggle to get anywhere close: According to a 2020 study of 5,000 serious crashes by the Insurance Institute for Highway Safety (IIHS), autonomous vehicles would avoid only about a third of crashes.

Developers of autonomous vehicles rarely release detailed safety data on their own, but the last significant report from Waymo backs up the notion that autonomy's proponents haven't proved its safety case.

The report, an October 2020 research paper focusing on Waymo's Phoenix operations in 2019 and most of 2020, found that in Arizona, its vehicles were involved in 75 percent more crashes per million vehicle miles traveled than human-driven vehicles in the state, although the company did not note any serious injuries. Waymo researchers argue that the stats aren't comparable, noting that the analysis included several "minor contact events" that it claims resulted in no damage, and also pointing to research showing that human-driven crashes—both injury-related events and those involving only property damage—are underreported. But even after adjusting reported crash data numbers with the highest underreporting estimates, the Waymo vehicles were still involved in crashes at the same or higher rates than human drivers, whether you use NHTSA crash report data from the same years or those from the Arizona Department of Transportation. Waymo says it plans to publish more safety data soon, but it did not respond to our request for comment on why adjusting crash data for underreporting bias doesn't allow for even broad comparisons. A 2023 paper compared crash rates in Arizona to human-driven crash rates in comparable conditions and found the Waymo Driver had less-severe outcomes. Both datasets were relatively small.

Zoom out more, and the data tells a similar story. Uber's ATG test fleet had driven more than two million autonomous miles before Herzberg's death. Waymo claims that it has surpassed 20 million miles total. Altogether, autonomous vehicles in California drove more than four million miles in 2021. That's tens of millions of miles driven over years of testing, with one death. That may sound impressive, but the most recent fatality statistic for human driving in the U.S. is 1.33 per 100 million vehicle miles traveled. Autonomy literally has a long drive before it can show that it can match, let alone exceed, human safety performance, even such as it is.

And outside of those sporadic data disclosures and California's reporting system, there are few ways to monitor progress. Without federal regulation, there's not even a widely accepted benchmark for how safe autonomous vehicles should be to use as a target. "I understand there's a balance between innovation and regulation, but right now that oversight isn't happening," says Homendy. "It's disappointing."

States and cities continue to push ahead on the technology, often with fragmented oversight. In August 2023, California's Public Utilities Commission, which regulates robotaxi operations, approved larger fleets and fewer operational restraints for Waymo's and Cruise's San Francisco robotaxi services just weeks before a Cruise vehicle was involved in a crash with a pedestrian. Meanwhile, the California Department of Motor Vehicles, which oversees AV-testing permits, accused Cruise of initially misrepresenting the vehicle's behavior to DMV officials. Cruise denies the accusa-

tion, but the incident led the DMV in late October 2023 to suspend Cruise's permit except with a human backup driver. Two days later, Cruise itself announced on X (formerly Twitter) that the company was pausing all autonomous testing and robotaxi operations nationwide.

THE LACK OF REGULATION GOES BEYOND THE AV test fleets. While no autonomous vehicles are available to buy today, cars equipped with driver-assistance technologies are widely sold—sometimes marketed as capable of automation far beyond their true abilities—and operated on public roads by drivers who don't understand the limits of the technology. Those features are largely unregulated as well.

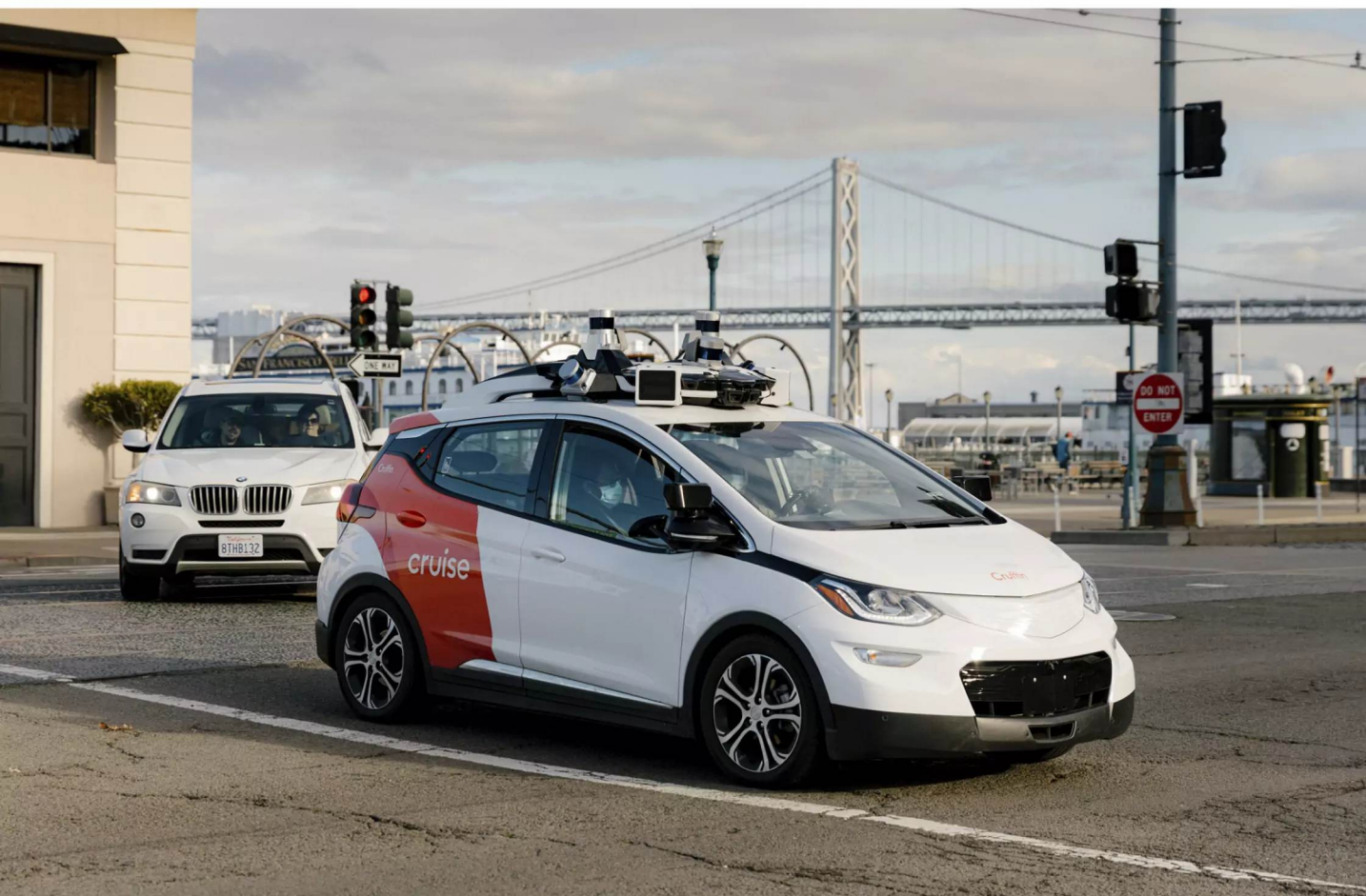
In the auto industry, the clunky term Advanced Driver Assistance Systems, or ADAS, includes everything from Level 0 passive-driver alerts (like the blind-spot warning system in the Porsche that hit Barak Gila) to Level 2 features that can steer, accelerate, and brake in certain situations, such as driving on highways. (Level 3 “conditional automation” systems exist at the

boundary between ADAS and full autonomy, and are so new that the first one, Mercedes-Benz's Drive Pilot, won't debut in the U.S. until the fall of 2024, and will operate only in restricted conditions.) Roughly half of car models sold today have at least Level 1 ADAS—the ability to control both speed and steering in some situations—according to *Consumer Reports*.

Like full autonomy, the promise of these features is to make driving safer, but their efficacy ranges widely. The IIHS says automatic emergency braking, for instance, can reduce the number of rear-end injury crashes with another motor vehicle by 56 percent. But in extensive testing by the IIHS and another major automotive-related nonprofit, the American Automobile Association (AAA), some of those features don't always perform as they should, especially around smaller vehicles like bicycles.

In May 2022, AAA tested how ADAS systems from Tesla, Subaru, and Hyundai interacted with other passenger vehicles as well as with people riding bicycles. In tests of a vehicle's ability to avoid a crash with another vehicle traveling in the same direction, the systems easily avoided all crashes. But when overtaking the cyclists, the systems were far less reliable.

In October 2023, GM-owned Cruise announced on social media that it was pausing operations. ▼





▲
The
Waymo
Driver in a
simulation
that helps
evaluate
how it
might
perform in
real-world
situations.

While no collisions were recorded, detection and response times varied widely, and in one test run, the Hyundai vehicle “avoided” hitting the cyclist test dummy with a separation distance of 0.0 feet. In tests with a cyclist dummy crossing perpendicular to the vehicle path, the Tesla barely avoided crashes in two of five runs, and the Subaru failed to even detect the cyclist in all five runs, hitting the dummy every time.

In response to a request for comment, Subaru indicated that AAA had tested a previous version of its EyeSight system, which has since been improved with a wider-angle camera system better able to detect peripheral motion. Hyundai’s statement did not answer specific questions but noted that its system is not autonomous and the driver is responsible at all times. It said it’s reviewing the AAA report. Tesla, which disbanded its PR department in 2020, did not respond to several emailed requests for comment.

That inconsistent performance is partly because the systems are designed primarily to prevent low-speed vehicle-to-vehicle crashes; vulnerable road users like pedestrians and bike riders are smaller and harder to detect. AAA, which has been testing various ADAS systems for years, found in 2019 that pedestrian detection systems from four different carmakers failed to function more than half the time, with especially high

failure rates linked to three factors: speeds over 30 mph, small, child-size subjects, and low-light conditions. While car companies like Subaru are regularly updating their systems with better hardware and software, Toyota’s own information on its Safety Sense ADAS suite currently lists two pages of scenarios where its pre-collision feature might fail to detect certain bike riders and pedestrians, including short people (3 feet or less), tall people (6-foot-6 or more), people wearing white clothing in daytime, and people riding small bikes or bicycles equipped with large bags.

More concerning, as those tests and others show, the systems don’t always fail consistently. Ben Bauchwitz, a graduate research assistant at Duke University and a scientist at Charles River Analytics, has investigated Tesla’s ADAS systems extensively. In a trial of various capabilities of Tesla’s Autopilot technology, Bauchwitz found that the systems in three different cars reacted differently to the same test situation, which shouldn’t be the case if they all shared the same software. Worse, sometimes the same car behaved differently in subsequent test runs.

Some types of driver assist may actually impair driver performance, namely those like Level 2 hands-free highway systems that take over some of the driving task. The problem is called automation com-

placency: The less of the driving we do, the more likely our attention is to wander. It's an established phenomenon in disciplines as diverse as health care and astronautics. As Alexandra Mueller, an IIHS researcher who studies ADAS technology, says, "People are not good automation supervisors."

Better training is not a reliable fix. In *Driven*, a history of the development of autonomous vehicles, author Alex Davies recounts how Chris Urmson, an AV pioneer and early executive at Waymo (then a Google division called Project Chauffeur), was horrified to find in 2013 that even trained Google employees testing the system grew so confident in its abilities that while it drove 65 mph on the freeway, they worked on their computers, played with their phones, and even, in one instance, fell asleep. (Urmson is now CEO at Aurora Innovation, the company that bought Uber's ATG unit.) A 2021 study of driver behavior while operating Volvo's Pilot Assist technology found that the longer drivers used the system, the more likely their attention was to drift from the driving task, including taking both hands off the steering wheel.

And once we're distracted, it can be hard to reengage effectively. Two 2022 studies reveal that drivers may need as long as 20 seconds to "stabilize" their driving when a Level 3 ADAS, like the one Mercedes will soon sell, disengages and gives control back to the human.

Confidence in a system can create problems even if a driver is paying attention. It's referred to as overtrust. "We've done research where even when the systems are struggling to handle the driving conditions, overtrust actually encourages people to not participate in a necessary takeover even when a collision is imminent," says Mueller. In a 2018 study, more than a quarter of test subjects failed to prevent a crash when the system handed control of the vehicle back to the driver. Basically, right up to the point of the crash, drivers are still confident the system will prevent it.

Distraction and overtrust are expressions of what's called the handover problem. Essentially, in any partially automated driving situation (even conditional automation like a Level 3 system), the vehicle may encounter a scenario that exceeds its abilities, and the driver must take over. Unless its driver is ready to respond, there will be a period—which can last 5 to 10 seconds—when no one is controlling the vehicle.

All of this makes the IIHS and AAA decidedly ambivalent about ADAS: Both generally favor driver monitoring and emergency-intervention features like automatic emergency braking but are more cautious about features that partly automate driving. But even as advocates call out the risks, carmakers are largely pushing ahead on partial automation. And the way it's marketed confuses drivers about its capabilities. In 2020, a consortium including AAA, SAE International, and the National Safety Council created a standardized list of names for specific driver-assist features

like forward collision warning or lane-keeping assistance. But most carmakers market those features as a suite, using names that invariably suggest competence, even expertise: Co-Pilot 360 (Ford), Drive Pilot (Mercedes-Benz), and Tesla's long-running Autopilot system. (Ford did not respond to a request for comment, but a Mercedes spokesperson said the company believes Drive Pilot is an appropriate term for a Level 3 system that can perform all normal driving tasks within its operational design domain. Driver education, a key component of safe use of ADAS systems, is done at the dealer and customer levels, and the system uses technology such as high-definition maps to prevent its use outside its intended domain.)

Tesla is the most prominent example of this kind of marketing, exemplified by a 2016 video that misrepresented Autopilot's capabilities, according to the company's director of Autopilot software at his recent deposition in a civil lawsuit. In addition to Autopilot, Tesla markets a second ADAS suite called Full Self-Driving, or FSD, even though Tesla itself has noted in regulatory filings that FSD is Level 2 driver assistance. Tesla's systems have key differences from those of industry competitors, most prominently the advanced access to "beta" or prerelease versions of FSD that the company offers to some owners. In doing so, Tesla is essentially relying on untrained

In any partially automated driving situation, the vehicle will encounter a scenario that exceeds its abilities. **Unless its driver is ready to respond, there will be a period when no one is controlling the vehicle.**

► Barak Gila often encounters self-driving vehicles on his bike commute. He says he's never seen one behave unsafely.

Tesla owners—as much as 400,000 at last count—to product-test its software on public roads.

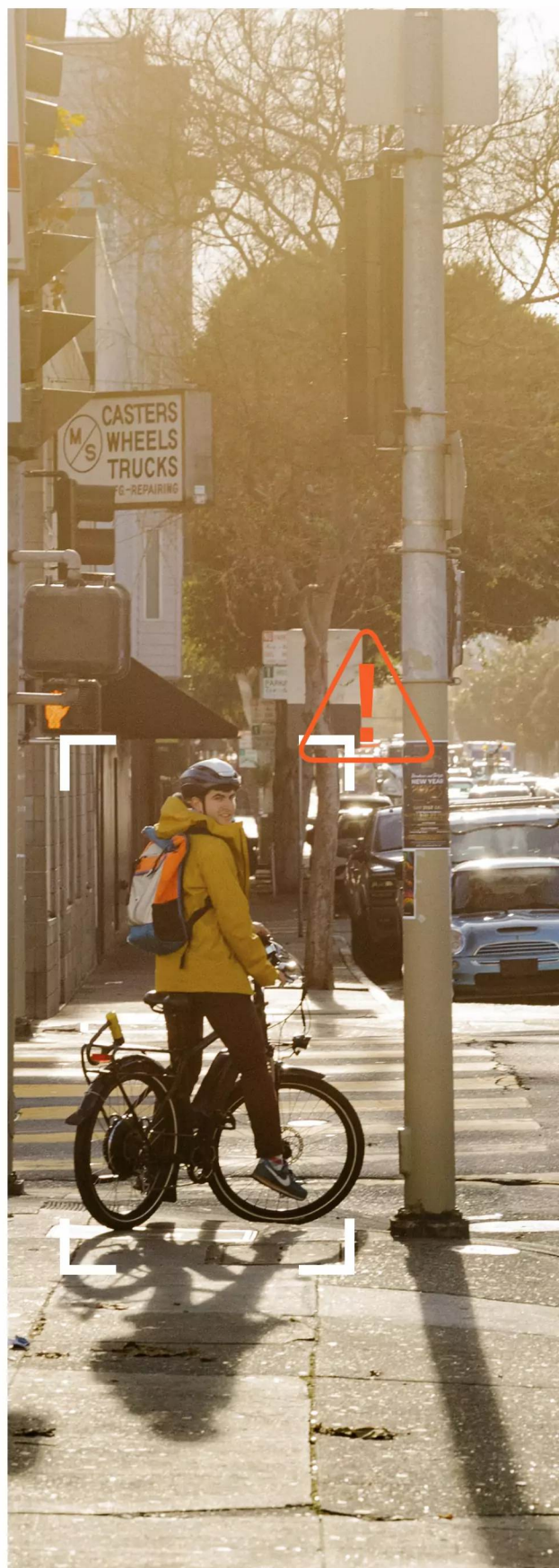
But because there is so little federal regulation of ADAS, Tesla isn't breaking any vehicle-safety laws by testing FSD beta in public. For years, the company has freely marketed and sold its ADAS packages in the U.S., at prices of up to \$15,000, and Tesla's legions of fans regularly post video to social media of them using it in unsafe ways, like riding in the back seat while on the highway.

Confusion around ADAS's real capabilities and limitations compounds the inattention and overtrust problems; a recent IIHS survey found that almost half of Tesla and GM drivers treat their vehicles as fully self-driving. And in 2020 research from AAA, study participants who were trained and tested on a vehicle with an ADAS system called "AutonoDrive" rated the car in survey responses as far more capable in scenarios like actively avoiding collisions than those who were told the same system was called DriveAssist. The AutonoDrive subjects said they would be two to three times more likely than DriveAssist subjects to engage in distracted-driving behavior like eating or having a handheld phone conversation while driving. Finally, in drive testing, 23 percent of subjects in the AutonoDrive group took longer than five seconds to retake vehicle control in an unexpected handoff, versus just 6 percent of the DriveAssist subjects.

"There are people who think these cars are fully self-driving, fully safe," says NTSB chair Homendy. And it isn't just the general public. In 2022, Homendy told Bloomberg News that at a conference of state highway officials, she was "stunned" to learn that many transportation officials thought autonomous vehicles were available for sale to the public today.

The real-world outcome is hundreds of crashes, some fatal, which have been blamed on distracted drivers who were relying too heavily on driver assistance. Thankfully, regulators are beginning to understand the scope of the problem and take some initial action. Tesla, for instance, is the target of several inquiries and investigations—including by the U.S. Department of Justice (according to Tesla's own SEC filings), NHTSA, and the California Department of Motor Vehicles—that focus on Autopilot and FSD's possible role in dozens of crashes, as well as Tesla's marketing of it.

In February 2023, NHTSA announced that Tesla agreed to voluntarily recall more than 360,000 cars equipped with FSD software. In a brief post titled "Full Self-Driving Software May Cause Crash," the agency noted that FSD allows drivers to set it to exceed the speed limit, and FSD can "act unsafe around intersections," such as failing to stop at stop signs. (Tesla is said to be fixing the vehicles with a software update, but what that involves isn't yet known.) And, as of January 1, 2023, a new state law in California prohibits manufacturers—not just Tesla, but all carmakers—from





Around 400,000 Tesla drivers in North America are beta-testing Tesla's Full Self-Driving feature on public roads.



advertising or marketing ADAS systems as self-driving.

Tesla is also the defendant in numerous civil lawsuits brought by families of people who have been injured or killed in crashes involving Tesla vehicles in which the systems were operational. The company has denied all allegations—even arguing that its software update for FSD shouldn't be considered a recall—and is defending itself against both the civil suits and the various investigations. On October 31, 2023, in the first civil case to go to trial, a jury found Tesla's software was not responsible for the crash.

Regardless of who manufactures it, ADAS technology is not subject to independent federal testing and approval; automakers don't have to ask permission to sell it, although as the Tesla FSD recall shows, they may have to beg forgiveness at times. Just as companies that make space heaters, for example, attest that their products meet safety requirements, automakers self-certify that their Level 1 and Level 2 ADAS suites meet Federal Motor Vehicle Safety Standards—which is mostly silent on ADAS-specific technologies. A separate initiative, NHTSA's New Car Assessment Program, recommends

four technologies but mandates none. A substantial majority of automakers voluntarily agreed to include one ADAS technology—automatic emergency braking—on new cars as of September 2022.

One other small step in the right direction came in 2021 when NHTSA issued a first-of-its-kind order requiring carmakers and AV companies to submit incident reports when they learn of serious crashes involving a vehicle with Level 2 or higher technology that was activated for more than 30 seconds prior to the crash. In June 2022, NHTSA released data from the first year of collection and found that 367 crashes were reported in vehicles actively using advanced driver-assist systems (nearly three-quarters of which were Teslas). The agency cautioned that this was almost certainly an undercount; without in-car telemetry (which Tesla has) or an occupant complaint, companies—and therefore the agency—likely wouldn't learn about these crashes.

Also of concern are the 130 crashes reported in Level 4 autonomous vehicles during testing. In the absence of federal regulation, the public and safety watch-



dogs are left mostly with AV companies' annual safety reports, but those (voluntary) documents mostly outline how companies say they perform testing. Waymo's annual safety report, in contrast to its 2020 research paper, relies heavily on the phrase "rigorous testing," but includes almost no data.

"There's a huge amount of 'trust us,'" says Ken McLeod, policy director for the League of American Bicyclists. McLeod talks regularly with companies in the AV industry, as well as researchers at academic institutions like Carnegie Mellon University, where some of the industry's most prominent engineers studied. But he says industry engagement varies widely. In 2022, the League worked with Argo AI—a startup backed by Ford and Volkswagen—to help create a technical guide for proper AV behavior around people on bicycles, which Waymo also recently adopted. But some other companies, McLeod says, ignore the League or pay lip service to cyclist safety. That could add risk to all road users—even drivers using ADAS systems and anyone operating a vehicle near them.

DESPITE A DECADE OF PREDICTIONS OF THE imminent arrival of autonomy by proponents and prominent industry leaders like Elon Musk, America will not become a self-driving utopia anytime soon. True, any-road-any-time Level 5 autonomy may not happen for decades, and maybe never.

Now the industry is showing signs of the strain of those expectations. Ford abruptly shut Argo AI down in October 2022. Aurora's stock price dropped about 75 percent from December 2021 before rebounding slightly, and Cruise lost \$500 million in just the second quarter of 2022. After six years of work in Phoenix, Waymo's autonomous taxi service still only operates in parts of the city, and not in bad weather. Service in a limited area of San Francisco began in November 2022, and on February 27, 2023, CEO Dmitri Dolgov announced the company had started testing in Los Angeles. Limited ride hailing began rolling out there this past October.

Even if autonomy proves its safety argument, the obstacles of scale render its benefits unattainable in the near term. Right now, Level 4 autonomous driving exists only in small fleets; Waymo operates 300 to 400 vehicles in Phoenix, for instance, and just 700 total. Even if companies like Waymo and Cruise succeed with their autonomous taxi business, they may not account for a large enough slice of traffic—at least 20 percent by one recent study—to create noticeable safety improvements. If, tomorrow, every new car sold were fully autonomous, it would be almost four years before even 20 percent of the 276 million registered vehicles in the U.S. were self-driving. Of course, that's a totally unrealistic scenario; the reality is, any safety benefits from

autonomy are almost certainly a decade or more away.

Achieving that goal will also be costly. Upgrading and maintaining roads with better pavement, lane markings, and the cellular-communication infrastructure needed by autonomous vehicles will require a massive, astronomically expensive overhaul. And a number of studies suggest that even if a fully autonomous vehicle fleet could be achieved, traffic and pollution would actually worsen because the technology would potentially spur more driving and longer commutes. Meanwhile, we're missing the chance to implement proven, relatively affordable (if unflashy) tools we already have—congestion pricing, better public transit, protected bike lanes—that would deliver on safety and other goals.

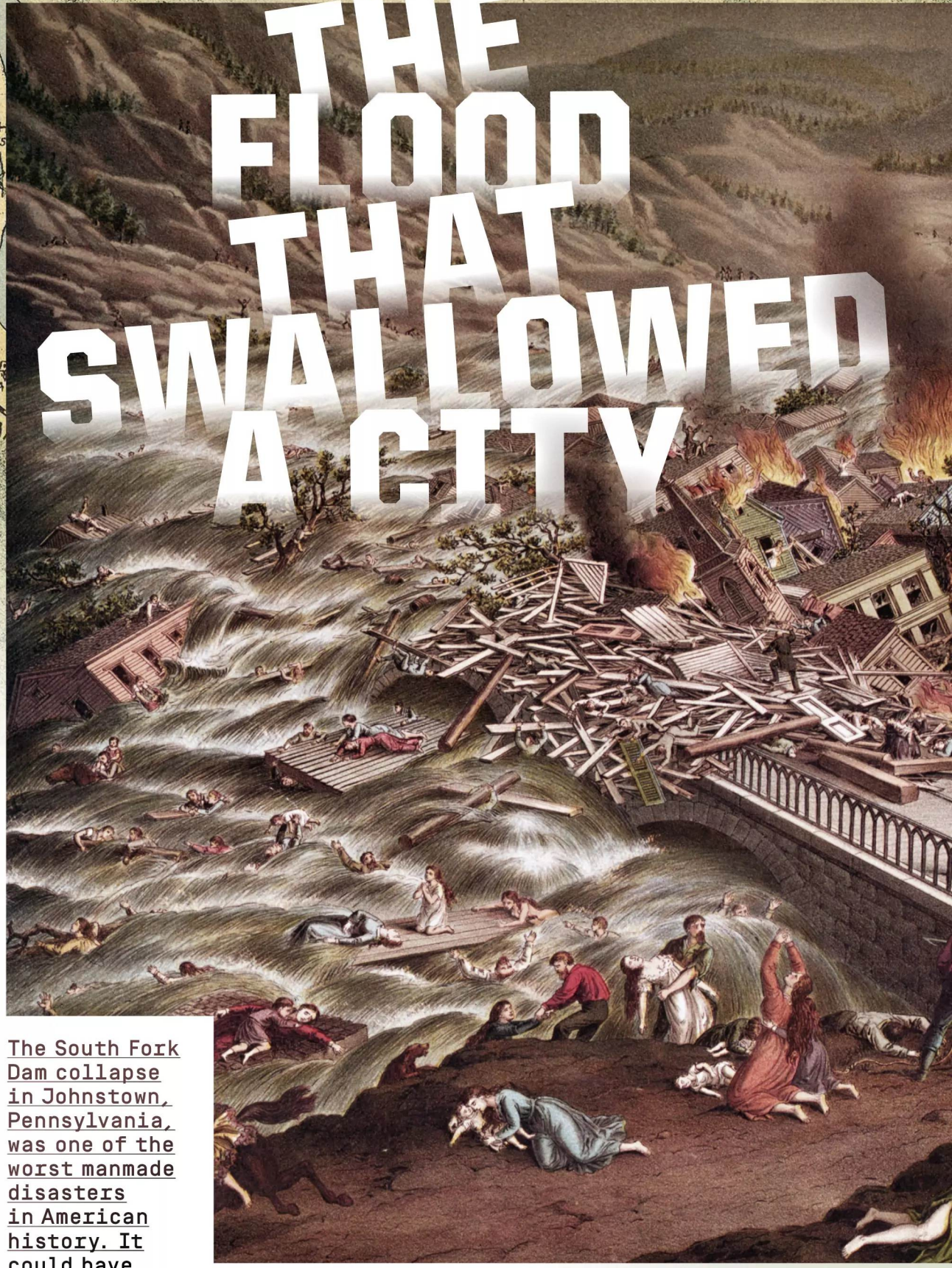
"Every day we think autonomous cars will yield a future of safe car dependency, we divert essential attention and resources from the things that can actually help right now," says Peter Norton, a technology historian in the University of Virginia's department of engineering and society and the author of *Autonorama: The Illusory Promise of High-Tech Driving*.

Norton's argument is that you can't solve the safety and livability issues endemic to cars—climate change, pollution, and traffic congestion—with better cars, even ones that drive themselves. "The problem should never have been 'How do we let drivers get where they want safely and without delay,'" he says. "The question should always have been 'How do we help people meet their daily mobility needs?' When you frame the problem that way, suddenly you have a much bigger menu of tools you can choose from."

A growing number of people agree—including Barak Gila, who criticizes the "unrealistic technoptimist perspective" that self-driving cars will solve everything. For the past two years, e-bike sales have outpaced sales of four-wheel electric vehicles, and handily so. Colorado recently announced a 10-year transportation funding plan that halts two highway expansions and will devote the \$100 million saved to transit, bike, and walk networks. And in 2024, residents of Los Angeles will vote on a ballot measure to require the installation of bike and bus lanes on any major road project in the city. Those kinds of programs, if backed long enough, would result in transit, bike, and walk networks that are realistic alternatives to car travel. The goal of that multimodal investment, says Norton, is to give people a real choice in how they travel, something we largely lack now.

Could autonomous vehicles make city traffic safer? Maybe we're asking the wrong question. What if, in our search for ways to make getting around our cities safer, we ask how to make cities themselves cleaner, greener, and more pleasant places to live? Then the answer that emerges might not be to make better cars. Maybe the answer is to make fewer of them, and more of everything else. **PM**

THE FLOOD THAT SWALLOWED A CITY



The South Fork
Dam collapse
in Johnstown,
Pennsylvania,
was one of the
worst manmade
disasters
in American
history. It
could have
been prevented.

→ BY DYLAN TAYLOR-LEHMAN





Witnesses described the 60-foot wall of water as a churning black hill, clogged as it was with debris from the forests, railroads, and homes it had destroyed on its way down a valley in central Pennsylvania's Allegheny Mountains.

SURVIVORS COULD HEAR the water coursing down the Conemaugh Valley, like the howl of a hurricane blowing through the mountains. They saw the tops of distant trees bend under the pressure. By then, it was too late to escape.

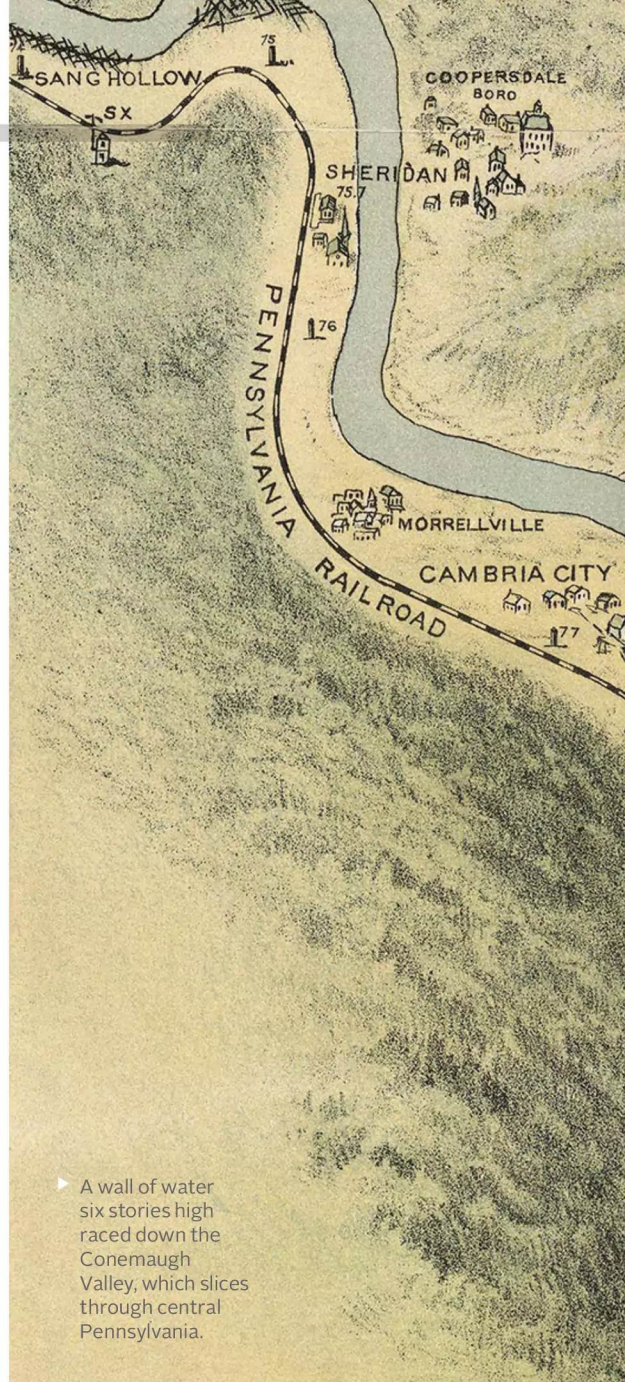
On May 31, 1889, the collapse of the South Fork Dam released almost the entirety of a manmade lake into the narrow valley below. The water—495 million cubic feet of it, enough to fill more than 13 Empire State Buildings—scoured bare the hillsides and the budding fields and entire small towns on its way toward Johnstown, an industrial city with more than 30,000 residents.

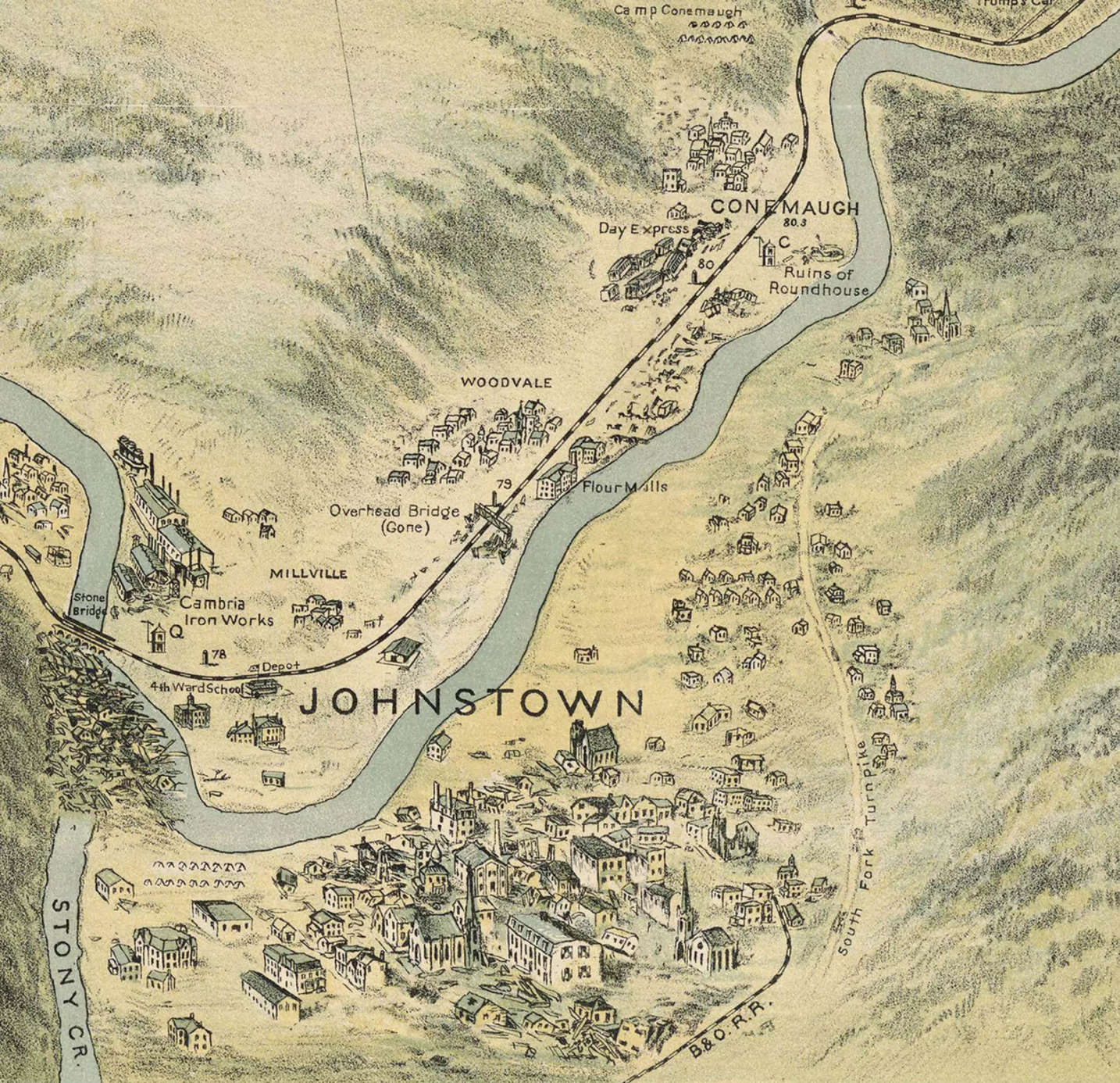
When a train conductor saw the deluge coming, he flipped into reverse and sped backward to warn people in the flood's path, blasting a protracted whistle that everyone knew meant danger. But then the train itself was swept off its tracks and swallowed by the roiling abyss. The water continued its hellish stampede and annihilated the Gautier Steel Works barbed-wire factory, adding miles of razor-sharp metal to the mass of debris.

Approximately 57 minutes after the dam collapsed, the water had traveled almost 15 miles, obliterating most of downtown Johnstown. More than 2,200 people died, making the Johnstown Flood the worst single-day loss of civilian life in American history up to that point. It remains the worst dam failure the United States has ever seen. And among disasters not related to weather, only the bombing of Pearl Harbor and the 9/11 terrorist attacks have resulted in more deaths.

The failure occurred just as the U.S. had begun pouring money into massive federal dam projects. In 1866, Congress appropriated approximately \$3.7 million on dam

and waterway programs. By 1882, the government spent five times that much, earmarked for 371 dam and waterway projects across the country. With national attention on building dams, the American Society of Civil Engineers quickly dispatched a commission to investigate the flood. Two years later, the group issued a seemingly comprehensive report about what had led to the collapse of the dam. But only in the past decade have we gained a more accurate picture of what transpired that tragic day. Using new technology, researchers at the University of Pittsburgh at Johnstown have created a precise look at the hydrological processes that led to the catastrophe. Their research has clarified the historical record and underscores sobering lessons that still apply to dams and waterways today.





→ **CENTRAL PENNSYLVANIA'S CONEMAUGH** Valley is a narrow, winding path through the Allegheny Mountains, where the region's abundant streams and rivers drain down into the lowlands. Small towns were built in the hills to take advantage of the waterways.

In the early 1800s, canals were crucial to the area's industry, and an ingenious system had been developed to bring barges over the mountains via a series of inclines that rose 1,400 feet over 36 miles. The canals, which ran east toward Ohio, were designed to compete with the Erie Canal. But the erratic weather was a problem. Intense periods of rain were often followed by long dry spells, and sometimes the canals went almost dry in the summer. The South Fork Creek, a tributary of the Little Conemaugh River, was dammed

approximately 15 winding miles east of Johnstown to build a reservoir that would keep the canals supplied with water. Designs for the dam were drawn in the 1830s, but financing issues halted progress, and some of the work washed away in the years between periods of active construction.

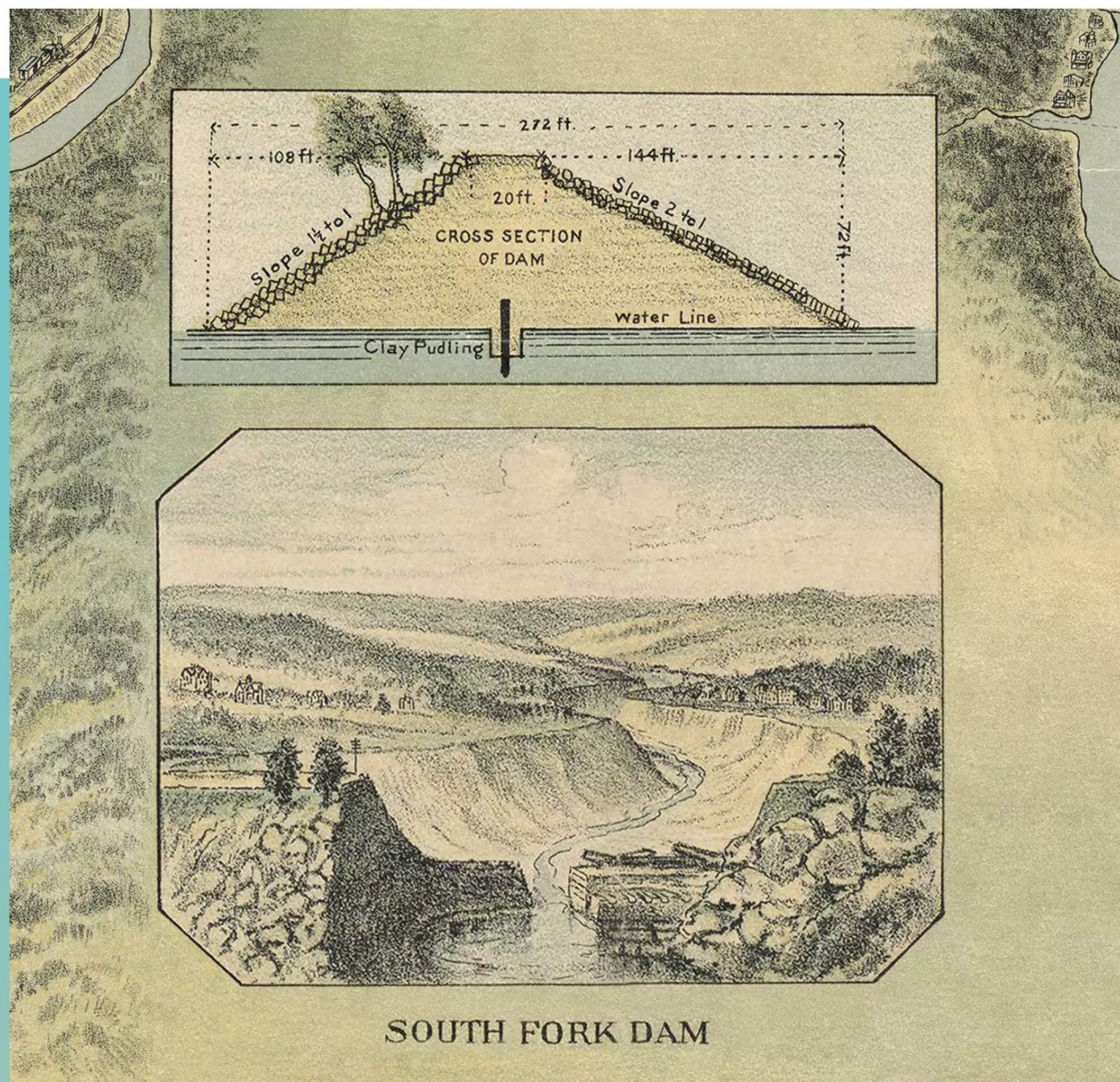
The South Fork Dam was finally finished in 1853 and stood 72 feet tall and around 900 feet across, with a base thickness of more than 220 feet tapering to a top ridge 10 feet wide. The dam was known as a "gravity dam" because its own weight acted as a force to secure it in its bedrock foundation and resist the outward pressure of the water it contained. The upstream side (or the side underwater) consisted of horizontal layers of "puddled" clay, which were soaked in water and compacted to make them watertight.

The clay slope was covered with a layer of cement and heavy stones, and the downstream slope was made of earth and massive boulders called riprap.

At the bottom, located near the middle of the dam, was a stone culvert with iron pipes that drained water to the river. That runoff, with a control tower nearby, fed the canals. A 98-foot-wide spillway was carved into the rock on the northeast side of the dam, a stunning feature that guided the overflowing water to the river below. Engineers added a

smaller spillway on the southwest side of the dam. Although its size dwarfed most dams of the era, the South Fork Dam used proven construction methods—nothing about the design should have concerned the engineers who built it, or the thousands of residents living in its shadow.

Once the dam was complete, Lake Conemaugh, or the South Fork Reservoir, as it was commonly called, quickly filled behind it. The lake was nearly two miles wide and a mile long at its widest points, covering approximately 465



▲▲ Despite its massive size—stretching about 900 feet across the valley—the South Fork Dam used a proven design that should have survived the storm that toppled it.

▲ Remnants of the South Fork Dam reveal its colossal size.

acres. But in the time it took construction crews to complete the dam, railroads had begun to dominate industrial transportation. The canals—and therefore the reservoir—had become irrelevant less than a year after the dam was completed. The dam, lake, and surrounding acreage was sold by the state to the Pennsylvania Railroad in 1857, which wanted the rights of way that came with the property. Little came of that deal, however, and 22 years later, a group of wealthy investors bought the land and then opened a retreat for Pittsburgh's elite on the idyllic reservoir. The South Fork Fishing and Hunting Club was known for its "sailboats up in the mountains," and its members included millionaire industrialists like Andrew Carnegie and Henry Clay Frick.

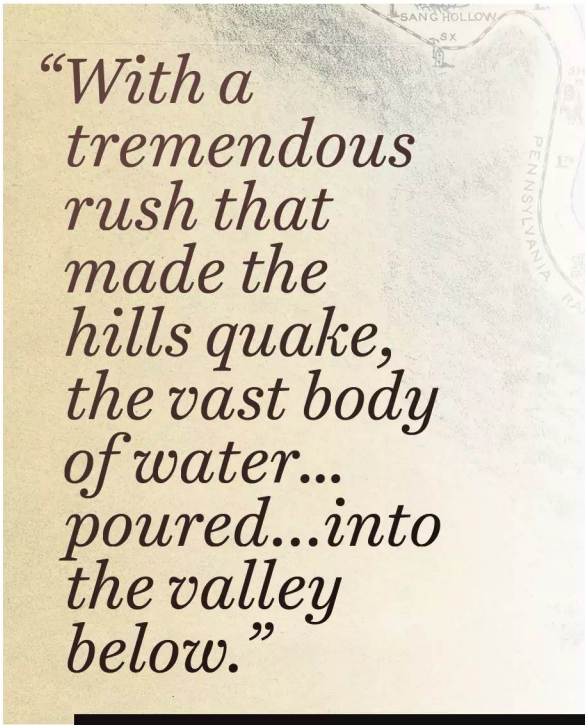
There had long been visible problems with the dam regardless of who owned it. Small leaks were commonplace, with numerous streams of water creeping down its face. Neighbors routinely stole lead fittings from around the culvert, allowing water to seep into and corrode the interior of the dam. The puddled-clay blocks were taken and used in the foundations of a nearby home and barn. In 1862, just 15 years after completion, a section around the culvert collapsed and most of the lake drained through the dam. Luckily, the dam operator caught the breach in time and opened the culvert pipes to relieve some of the pressure, preventing any serious damage or uncontrollable flooding. Despite several signs that the dam was degrading, it was neglected over the years as its various owners attempted to sell the land. Residents began to worry.

The South Fork Fishing and Hunting Club was not well known to the people of Johnstown, who were envious of the splendor but kept off the vast acreage of private property, historian David McCullough notes in *The Johnstown Flood*. The reservoir was very well known, however, and rumors about the dam's imminent collapse were commonplace. "I doubt if there is a man or a woman in Johnstown who at some time or other had not feared and spoken of the terrible disaster that might ensue," recalled one survivor in a later interview.

→ **TODAY, TWO LARGE** sections of the South Fork Dam remain on either side of the Conemaugh Valley, massive mounds now covered with trees and grasses that abut the valley walls. They are reminders of how enormous these structures can be, and the catastrophic damage they inflict when they fail. And fail, they do. According to the Association of State Dam Safety Officials (ASDSO), there have been around 1,600 dam failures in the United States since the South Fork disaster, resulting in approximately 3,500 deaths. On average, 20 of the 90,000 dams in the U.S. fail each year. Luckily, many of those problems occur in smaller dams that don't release enough water to cause significant damage.

Charles Thompson, the ASDSO president, points out that our understanding of geology and dam construction has vastly improved since the South Fork Dam was begun in

the early 1830s. Engineers and planners can better anticipate the potential damaging effects of seismic loading and heavy rainfall. But as with South Fork, the real concern isn't construction, it's upkeep. In the U.S., we simply don't have the resources to inspect and maintain the staggering number of dams on our waterways. In fact, the integrity of dam infrastructure in this country is more precarious than we might want to believe.



"With a tremendous rush that made the hills quake, the vast body of water... poured...into the valley below."

The average age of a U.S. dam is more than 53 years old. That's a lot of time for water, whether through force or by corrosion, to wear on the structure of a dam. Anything made of metal, such as the drainpipes that are essential to control water levels and prevent breaches, will corrode and weaken over time, says Mark Baker, founder and cochair of ASDSO's Dam Failures and Incidents Committee. Older dams used formulations of concrete with minerals and aggregate that have caused it to corrode over time, he says. Plus, many dams are in regions that experience frequent freezing and thawing—a cycle that can harm the integrity of a dam the same way it can create potholes on our roadways. But unlike potholes, the deficiencies inside a dam are difficult to monitor.

The potential consequences can be serious. In February 2017, heavy rains damaged the spillways on the 770-foot-tall Oroville Dam in California, leading to the evacuation of 188,000 people. In August 2021, the remnants of Hurricane Ida caused water to overtop a dam in the Conemaugh Valley near Johnstown and required the evacuation of about 3,000 people.

According to ASDSO's Cost of Rehabilitation Report, it would take around \$75.7 billion to repair all non-federal dams. Funds are available through FEMA and the U.S. Army Corps of Engineers for dam repair, and the recent Infrastructure Jobs Act contains provisions for rehabilitation, but any kind of dam repair is an enormous undertaking, Thompson says.

"We have learned a lot over the years about how to build good dams, but every dam is unique. There aren't too many off-the-shelf designs," he says. "It's difficult to do these projects; they're technically complex and very expensive. Dam owners across the country need funding, but they also need the technical support."

In the case of the South Fork Dam, the lack of maintenance almost looked like deliberate neglect, or at least seemed to suggest a remarkable indifference to fixing obvious structural issues. The leaks that flowed down its face between rocks were explained away as "natural springs" to the South Fork Hunting and Fishing Club's curious members. It wasn't until 1879 that the Club began repairing some of the damages from the partial collapse of the culvert in 1862 that led to a continuous leak at the bottom of the dam.

But the Club didn't hire hydrology experts or professional engineers to strengthen the dam. Instead, its laborers filled depressions with dirt, shale, hay, manure, old bricks, and "cheap and easily attainable coal- and clay-mining wastes" that were not "puddled" and were barely compacted. The crest of the dam had been lowered by two feet, ostensibly to widen the footpath to accommodate carriages, bringing the top of the dam within six feet of the water. The riprap used on repaired parts of the dam was undersize. The work on the dam completely prevented drainage: There had been no attempt to replace the five sluice pipes after they were removed and sold for scrap, and the Club placed screens in front of the spillways to prevent the stocked fish from escaping.

Only a few residents of Johnstown were members of the Club, including Daniel J. Morrell, a town patron and founder of the local steelworks. He recognized just how vulnerable the town was, situated between two steep mountain valleys where the surrounding waterways converge on an almost level floodplain. Most of downtown Johnstown's business, industrial, and residential areas were built on this plain, and flooding—sometimes filling stores with a foot of water—was practically a seasonal occurrence. Morrell was bothered by the condition of the dam and in 1880 hired an engineer and geologist to report on the problems; he then offered to contribute generously to proper repairs. But Morrell's suggestions were rebuffed by the Club, which was now aware of the dangers but apparently unconcerned.

→ **HEAVY RAINS WERE** falling on the evening of May 30, 1889, driven by a storm system that originated across Kansas and Nebraska before heading east over Pennsylvania. They weren't considered particularly unusual until the next morning, when the rivers and creeks would not stop rising.

Survivors recalled children playing in the flooded streets with makeshift boats in ankle-deep water. The water kept coming. By 10:44 a.m., the surge had washed away the town's rain gauge, and by noon, according to a local reporter, it had reached levels "higher than ever known."

The workers up at the South Fork Dam kept a wary eye on the rising water. The Club's resident engineer was a recent college graduate with no dam experience who had spent the preceding months overseeing the installation of a plumbing system for the resort. As the waters rose behind the dam, he directed a group of workers to fortify the edifice. At first, they built up the ridge on its crest to prevent overflowing. When that proved unhelpful, they tried to deepen the spillways to allow more water to escape. But the crew soon hit impenetrable bedrock and could only watch as water lapped at the crest of the dam. Soon enough, water began pouring over the top and through a sag that had formed in the middle, a depression from the uncompacted fill placed years earlier that nobody had bothered to repair.

"The greatest risk that can befall any earthen dam is to be overtopped. You want to avoid that at all costs," says Neil M. Coleman, a professor in the Department of Energy and Earth Resources at the University of Pittsburgh at Johnstown. "If water flows over the top of the dam, erosion can happen very quickly," he says. "It will start eroding the top of the dam itself, but as it flows over, it starts tearing out the material in the downstream side, the toe of the dam. If you undermine that side, a break can occur."

Observers attempted to send messages warning of the increasing danger by way of telegraph and by riders on horseback, who were able to reach Johnstown despite the morass of mud and water affecting almost the entire route. In spite of the significant rains and floods, many residents didn't take seriously the threat of the dam breaching and stayed put, focusing on shoring up their homes. Train tracks had been washed out to the east and west of Johnstown, stranding the locomotives, but passengers stayed in the train cars to wait out the storm.

Back at South Fork, the water finally washed away a large chunk of the downstream side of the dam in a slurry, weakening its structure. The loose fill in the middle of the dam allowed the water to penetrate and turn the interior structure to a semi-solid state, Coleman says, compromising it to the point that it began to collapse from the inside out.

Then, sometime between 2:50 and 2:55 p.m., after the Club's engineer had retreated to a nearby hill following fruitless attempts to carve out a bigger spillway, he saw the dam disappear in one massive push. "It is an erroneous opinion that the dam burst. It simply moved away," he later said.

"Only a few minutes were required to make an opening more than 300 feet wide and down to the bottom. I watched it until the wall that held back the waters was torn away, and the entire lake began to move, and finally, with a tremendous rush that made the hills quake, the vast body of water...poured...into the valley below," wrote Reverend G.W. Brown, who was watching from nearby.



- ▲ Illustrations based on firsthand accounts reveal some of the devastation. Entire houses were swept off their foundations and destroyed by the churning floodwaters.

The water rushed forth at an estimated 424,000 cubic feet per second, similar to the average discharge of the Mississippi River. Or, as McCullough writes, “it was as if someone turned on Niagara Falls to spill into the valley for 36 minutes.” The mass of water crashed down through the valley, claiming its first victim in the nearby town of South Fork. The wave rose to 70 feet, smashing down trees, bridges, and a 75-foot-tall stone viaduct as if they were toys. Friction meant the water on top of the wave was moving faster than the water below, creating a churning force that annihilated much of valley towns like Mineral Point (population 200) and East Conemaugh and its substantial train yards, sweeping hundreds of train cars and engines into the wave. In some places the land was completely denuded—everything human and natural removed as it was scoured down to bedrock. The same fate awaited Woodvale, just outside of Johnstown,

where 300 people were killed and the destruction of the barbed-wire factory added to the unfolding horror.

People in Johnstown took a cautious sigh of relief not long before the water hit, as it appeared the floodwaters were receding. But a “roar like thunder” suddenly echoed through the town and the water came crashing straight into the heart of the city. Everything in its path—stores, factories, barns, homes, animals—was swept up in the black, debris-choked wave, which spread across the city as the land flattened out in the valley. The water rode up against the hills surrounding the town, causing a backward surge that hit the city from a second direction and destroyed the buildings and homes that had escaped the first pass. Wreckage accumulated at a stone bridge in town and created a temporary blockage higher than the bridge itself. Though it is unclear what caused it (perhaps a coal stove or



- ▲ Only after the flood subsided were survivors able to photograph the destruction. While donations poured in from across the globe, the South Fork Hunting and Fishing Club contributed only a few thousand dollars plus blankets to the efforts.

oil from a train car), the pile erupted in flames, burning to death at least 80 people trapped in the homes and buildings that had sailed on the floodwaters and backed up against the bridge. A newspaper editor watched in horror as people were subjected to “cremation in your own home, perhaps a mile from its foundation; dear ones slowly consumed before your eyes, and the same fate yours a moment later.”

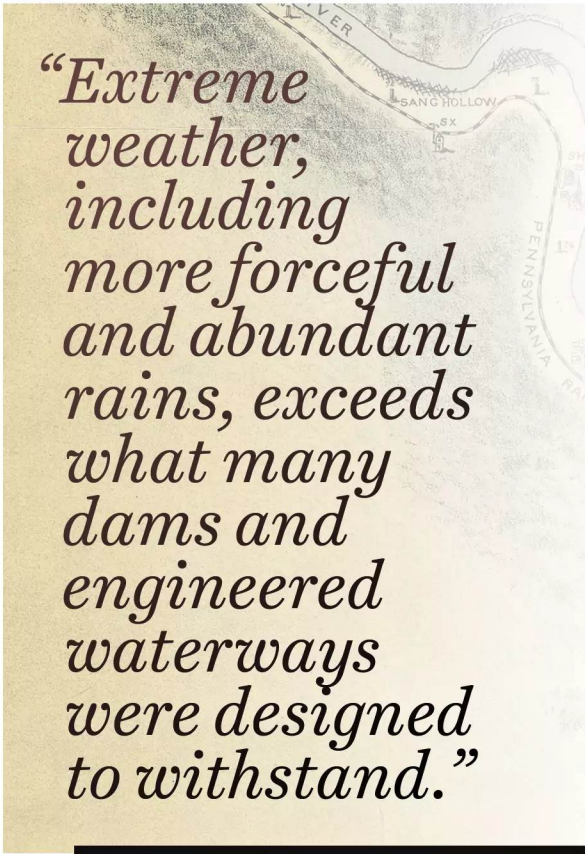
By the end of it, four square miles of downtown Johnstown had been turned into a muddy, corpse-strewn hellscape. A photo taken just after the flood shows a tree sticking horizontally out of the window of a house that had been carried off its foundation, one of 1,600 residences that were destroyed. Though the six people in that house miraculously survived, the final death toll stood at 2,208 with more than 25,000 people displaced. According to Richard Burkert, CEO and president of the Johnstown Area Heritage Association, it was not until July 10—41 days later—that a day passed without the recovery of a corpse. Bodies turned up 600 miles away in Cincinnati, and as late as 1911.

→ **ACCOUNTS OF THE** devastation almost immediately resounded through the world, and rescue efforts were mobilized to provide food, dry clothes, and medical attention to the tens of thousands of cold, wet, and hungry survivors. Word quickly spread that a failure of the South Fork Dam caused the deluge, and a contingent of infuriated residents made their way to the Club looking for the wealthy members who’d apparently been cavalier about the lives of the people in the valley below. The Club’s members were mostly in Pittsburgh when the dam broke. When the distraught survivors didn’t find anyone at the club, they destroyed many of the club’s cottages.

While the average member of the Club knew little or nothing at all about the condition of the dam before it broke, many avoided media questions or refused to assist with rescue efforts, creating an air of guilt. While people around the world collectively sent millions of dollars in donations, the wealthy Club members offered only a few thousand dollars and a thousand or so blankets.

The perception of their indifference was strengthened by the report published in 1891 by the American Society of Civil Engineers, which sent a commission composed of some of the top hydrologists of the day to study the catastrophe. Among them was ASCE president William E. Worthen, who was an industrial engineer that had built numerous dams and mills. Joining him was James B. Francis, a dam and canal expert and past president of the organization. The group was forthright in its findings, calling out issues with the dam’s construction and negligent repairs over the years.

Among its findings, the report concluded that, to save money, the state of Pennsylvania failed to include a masonry ‘heart wall’ in the middle of the dam, which would’ve provided a vertical structural support for earth and riprap to be built around. The ASCE report also faulted the South Fork Hunting and Fishing Club for the unpro-



“Extreme weather, including more forceful and abundant rains, exceeds what many dams and engineered waterways were designed to withstand.”

fessional quality of the work it commissioned, which “materially diminished the security of the dam.”

Despite those findings, the report came to the conclusion that the dam would have eventually failed on its own despite the breadth of unprofessional work the Club had undertaken. “[The breach] occurred a little earlier in the day on account of the changes,” but disaster would have happened either way given a storm of appropriate size, just like the one that rolled through central Pennsylvania on May 31, 1889.

That didn’t sit right with Coleman, the professor at University of Pittsburgh at Johnstown, who’d learned of the flood growing up in Pennsylvania. Drawing on extensive hydrological experience as a geophysicist who has studied the Little Conemaugh River watershed, he found what he thought were troubling inconsistencies and omissions from the 1891 ASCE report. The investigating committee didn’t acknowledge that the Club had lowered the crest of the dam by almost a meter, for example, and the southwest emergency spillway was not included in the hydrological calculations used in the report to determine why and when the dam failed. “Seeing the report by some of the most prominent engineers of their day and the things they overlooked made no sense,” he says. He began to study the hydrology of the disaster in an attempt to comprehend how the ASCE made what he thought were glaring errors.

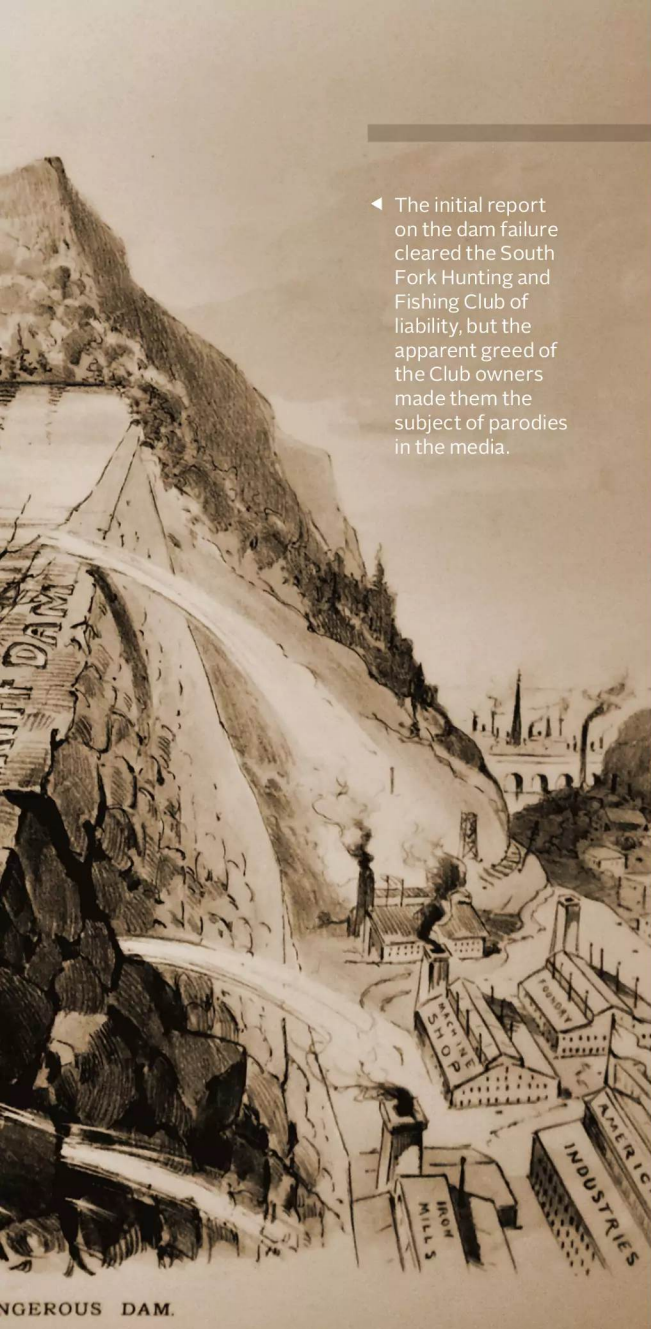
Coleman and his colleagues conducted on-the-ground research of the remains of the dam and compiled contemporaneous newspaper articles, help-wanted ads, worker and survivor testimonies, and even the journals of the



THE REPUBLICAN MONOPOLY PLEASURE CLUB AND ITS DAM

original builders to recreate the conditions of the dam the day it collapsed. The team ran geographic information systems (GIS) analyses of light detection and ranging (LiDAR) readings of the valley previously at the bottom of the lake to determine the precise water volumes when the dam failed, and developed storage-elevation and spillway-rating curves comparing the dam as it was originally built and as it was modified by the South Fork Club. Modern research also reconciled some discrepancies (such as culvert-pipe length in the original build and influx of storm discharge) used by the ASCE commission in their calculations. Taken together, these modern techniques provided a much more accurate picture of what the ASCE's commission report intended to do. The team published their research in 2013 and 2016 papers and expanded upon it in Coleman's 2019 book, *Johnstown's Flood of 1889*.

Their calculations found that adding 0.9 meters to the dam's crest—basically bringing the dam to its original height before the Club built the carriage path across it—would have allowed it to store an additional 1.6 million square meters of water without overtopping. Ultimately, as opposed to the ASCE's conclusions published in 1891, Coleman and his colleagues found the dam would have survived hydrologically had it not been for the repairs commissioned by the Club. "Even if extremely high lake inflows had continued unabated, overtopping of the dam at its original design height would have been averted for around 14 hours," Coleman wrote. "In the absence of alternate failure mechanisms such as piping, the dam would have been preserved because lake inflows would have substantially diminished during the afternoon and evening."



◀ The initial report on the dam failure cleared the South Fork Hunting and Fishing Club of liability, but the apparent greed of the Club owners made them the subject of parodies in the media.

→ **WHEN THE ASCE** report failed to assign fault for the dam breaking, it shielded the state of Pennsylvania and the South Fork Hunting and Fishing Club against lawsuits. Flood survivors never received compensation for the tragedy, and despite the colossal death toll, the U.S. continued to construct dams at a frenzied pace with little additional oversight or regulations. But floods continued to occur across the country.

In 1936, Johnstown suffered another devastating flood, whose damages caused the equivalent of nearly \$1 billion today. Improved communication systems helped warn residents earlier, and only 25 people were killed. Congress passed legislation in 1936 and 1937 that authorized the federal government to construct dams, levees, and other flood-control measures in flood-prone areas in response to disasters affecting much of the country around that time.

In Johnstown, the Works Progress Administration added nine miles of flood-control improvements, and thousands of area residents embarked on a letter-writing campaign when work was completed in 1943, telling friends and family across the country that Johnstown was now “Flood Free” and “A Good Place to Live, Work, and Do Business.”

Higher safety standards, better understanding of hydrology, and engineering improvements have led to the construction of massive dams whose sheer size would have been unthinkable in the mid-19th century. That said, infrastructure ages, and there are often limited resources to maintain and update these immense structures.

Climate change further stresses aging dams. Extreme weather, including more forceful and abundant rains, exceeds what many dams and engineered waterways were designed to withstand. Rising atmospheric temperatures increase water molecules in the air; when it falls as rain and is collected across large areas that feed a water system, the prospect of heavier and more frequent flooding rises in areas historically known for regular inundations.

The Pennsylvania Department of Environmental Protection reports that precipitation in the state has increased between 10 and 20 percent over the last century. That’s enough to overwhelm dams, but it’s a nominal amount compared to other regions in the United States. Some places in the northeastern United States have experienced a 70 percent increase in heavy-rain events between 1958 and 2010. In dry areas, drought-fueled wildfires burning above spillways can fill reservoirs with sediment, which can more easily overtop dams and impede spillways, says ASDSO President Charles Thompson. “That’s a whole new problem we’re facing and trying to get our hands around now.”

The race is on to keep up with aging dams and stay ahead of changing weather patterns to prevent another Johnstown. “It’s becoming clear that there are floods in this country that are happening in places that are above what the old maps showed were flood lines,” Coleman says. “People are seeing floods their parents didn’t see, their grandparents didn’t see.” **PM**

Coleman doesn’t doubt the investigating engineers carried out their work using the best methods available to them at the time, but his team’s research into the report showed rounds of anonymous edits and repeated delays in publication that seemed designed to minimize the Club’s responsibility and report the findings to the public only after some of the anger about the disaster had subsided. Importantly, the team also noted that social connections between members of the ASCE and the South Fork Club likely influenced the conclusions the commission reached.

“The fact that it contains so many important omissions tells me that someone edited stuff out of this report,” Coleman says. “All I can go by is the science and engineering in the report and the things that are missing that don’t make sense.”



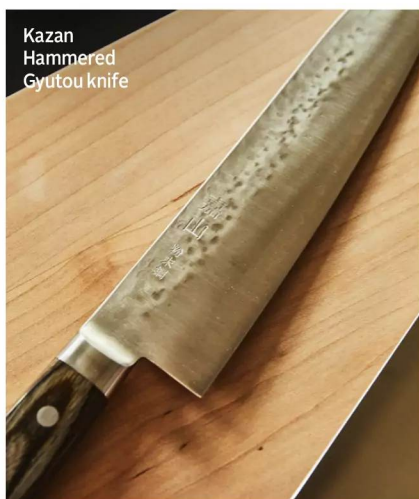
The Workhorse of Kitchen Cutlery

WORKING ON THE CUTTING BOARD PROJECT IN THIS ISSUE got us thinking about kitchen knives. All too often we care for them by storing them in a knife block but toss them in the sink or dishwasher without a thought. In our kitchen at home, I have one knife set aside for when I'm trimming meat, carving a bird, or preparing vegetables. This knife is set next to the sink and cleaned quickly after use, so it stays sharper much longer than others and is a pleasure to use. That's why I highly recommend keeping a special knife in your collection.

But what should that special knife be? To answer that, we reached out to David Joachim, author of *The Science of Good Food*. While there are many different types of knives for specific tasks, Joachim tells us, the chef knife will be able to accomplish about 90 percent of what gets done in the kitchen. If you're often doing a specific thing, like filleting, for example, then you'll want a knife best suited for that. But the reality is, if you invest in one good knife, you'll benefit most from an 8-inch chef knife, like the ones we tested here.

The Ubiquitous Chef Knife

Originating in Germany, chef knives were designed to cut or slice beef. For this purpose, they tend to be heavier, with a thicker blade made of softer metal, which makes them durable and less prone to chipping the edge or breaking when contacting bones. But chef knives have been adapted for use in many cultures' cuisines, according to Joachim, and you'll find something resembling one in most commercial kitchens anywhere in the world. French-influenced chef knives will have a similar shape, but the sharpened edge of the blade will be flatter, for example. Similarly, the Japanese Gyuto knife shares the same basic shape, although it has a thinner, lighter blade made of harder steel. The Gyuto is designed for precision and agility—think of the prep required for the presentation of sushi and other Japanese dishes. The harder steel can hold a sharp edge well, but it can be more prone to chipping when hitting bones.



Kazan
Hammered
Gyuto knife



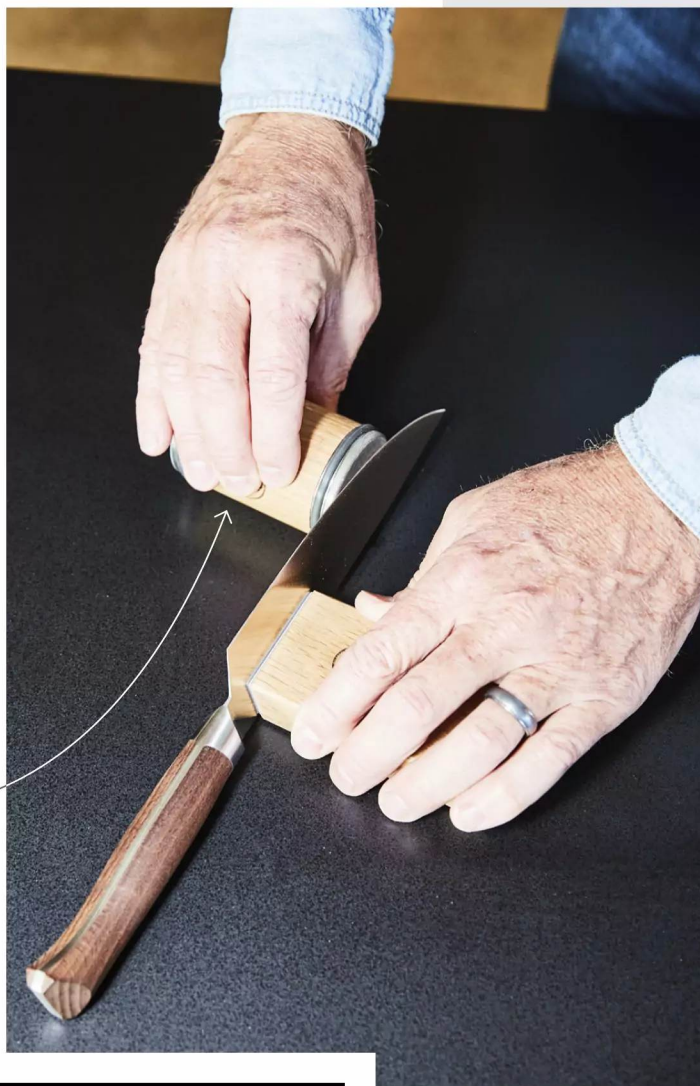
HOW WE TESTED

As the knives arrived ready to use right out of the box, we first tested how sharp they were, using an Edge-On-Up Professional Edge Tester. We then moved on to practical testing, using the knives to cut a variety of vegetables—large, small, hard, and soft. Additionally, we cut slices off a London broil, cooked to medium on a grill. Each knife was used to prepare the same amount of each item during the test, and we made sure to use all portions of the sharpened blade. Following that practical section of the test, we measured knife sharpness again. Finally, the knives were weighed, measured, and assessed based on sharpness, ease of use, performance, and comfort.

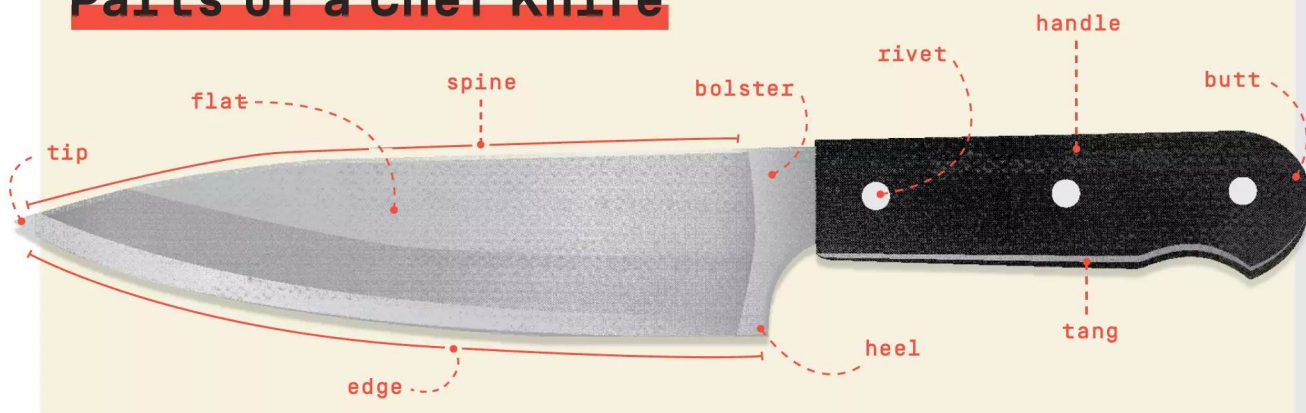
SHARPENING KNIVES

Whether you have fancy kitchen cutlery or not, you'll get the most out of your knives by keeping them sharp. There are plenty of gadgets out there intended to help you achieve this—some are a bit gimmicky, some legit. Ask a knife expert and they'll tell you to get a set of traditional whetstones and learn how to use them. They come in a variety of grits identified by number—lower numbers are more coarse, higher numbers are finer. The stones are first soaked in water until saturated, and then the knife edge is drawn across the stone at a constant angle, working through the grits to the finest one. They work great, but it takes some practice and patience and can be a little messy.

This is where sharpening kits come in. These are designed to make the process easier, though some can be complicated, with multiple parts that need to be assembled before you can use the kit. We recently tried out one of the simplest sharpeners we've seen in a while. The **Horl 2** consists of just two parts that don't require assembly. The first one is simply a strong magnet to hold the knife at 15 or 20 degrees, the two common angles for kitchen knives. The second is a cylinder with abrasive surfaces on each end. Roll the cylinder with one end against the blade to sharpen the length of the knife. It's simple, it works, and it's a legitimate shortcut to a sharp edge. The kit comes with 400- and 1000-grit abrasive discs—but for the sharpest edge possible, we recommend also getting their optional 3000- and 6,000-grit discs.



Parts of a Chef Knife



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BEST OF THE TEST

KAZAN HAMMERED GYUTOU

★★★★★

Price: \$219 | **Blade type:** Forged
Material: Semi-stainless steel alloy
Handle: Wood | **Weight:** 6.2 oz
Length: 13.25 in | **Blade length:** 8.13 in
Hardness (Rockwell scale): 65–66

While the Kazan Gyutou wasn't the sharpest knife right out of the box, due to its harder steel blade, it managed to maintain sharpness throughout the test, measuring exactly the same at the end. It has typical features of Japanese knives, being lighter than others tested largely due to the thinner blade—about 40 percent thinner at the spine than the heaviest knife tested. This helped the Kazan easily glide through vegetables with minimal pressure. On larger, harder items like the red onions we sliced, we found we could maintain an even thickness without difficulty. The Gyutou cut our London broil just fine, but overall, it excelled at what gyuto knives were designed for, and that's agility and precision cutting of fruits and vegetables.

VICTORINOX GRAND MAÎTRE

★★★★★

Price: \$155 | **Blade type:** Forged
Material: High-carbon stainless steel
Handle: Synthetic | **Weight:** 9.8 oz
Length: 14.87 in | **Blade length:** 8 in
Hardness (Rockwell scale): 55–57

Victorinox's Grand Maître was the heaviest knife we tested. A thick blade and longer handle contribute to the weight. But that handle, as well as a smooth transition to the heel, made the knife comfortable to hold and control. The Grand Maître was the sharpest knife right out of the box, measuring in a range reserved for the sharpest, high-end knives. It dropped off a bit after testing, but remained in the top-tier category for sharpness. Thus, it had no issues slicing or cutting. However, on larger, hard vegetables like red onions, we found it more difficult to get slices of even thickness. We attributed this to the thicker blade. The softer metal and heft of the Grand Maître make it an ideal choice for folks whose culinary tendencies lean toward meats.

OPINEL LES FORGES 1890

★★★★★

Price: \$179 | **Blade type:** Forged
Material: High-carbon stainless steel
Handle: Wood | **Weight:** 7.2 oz
Length: 13.13 in | **Blade length:** 7.5 in
Hardness (Rockwell scale): 57–59

Opinel's Les Forges 1890 falls between the other two knives for price, length, weight, blade thickness, and hardness. Though it was the least sharp right out of the box, it dropped off only slightly after testing—later we sharpened it, bringing it into range of others tested. The 1890's biggest difference is that the blade edge curves up to the tip more sharply than either the Kazan or Victorinox, making it easier to chop vegetables using a rocking motion. In testing, it took us more effort to slice tough grapes and tomatoes, which we credited to the knife's initial sharpness. It tended to kick out a little on cuts in hard, thick vegetables, but less so than the Victorinox. Overall, performance increased after sharpening, and the 1890 exhibited versatile capabilities.



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PRODUCT

Ridgid Straight Pipe Wrench

PRICE: \$28–\$400, depending on size

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FUNCTION: Grip and turn pipe and fittings

▶ **EVERYTHING ABOUT A** Ridgid pipe wrench is highly specific, from the exact metallurgy of the cast-iron handle to the ductility of the forged-steel hook jaw that bears down against a pipe. Even the sand and binders used to form the cavity into which the molten iron is poured are ruthlessly monitored to ensure chemical and structural integrity. The dogged attention to detail helps explain the tool's durability and why it is so highly prized by plumbers, pipe fitters, oil field workers, and even do-it-yourselfers.

What we state above may come as something of a surprise. The tool seems so outwardly simple, consisting of just seven parts. But watch a seasoned plumber work a run of pipe and fittings, and you come away with a new respect for it. Pick up a Ridgid pipe wrench, and that respect deepens when you notice its smooth I-beam handle, the precision of its machined surfaces, the way the threads in its hook jaw eject dirt as you turn the knurled nut that moves it. And there are those viciously sharp pipe-grabbing teeth, like something off a fossil in a museum.

And in its own way, the Ridgid pipe wrench is sleek, the way an anvil is. This is welcome in a tool used to grip and turn slippery and stubborn pipe and fittings. With a century of hard pipe work behind this heavy red tool, we can also say this: The world and the pipe trades have been better off for it.—Roy Berendsohn

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**Rite in the Rain
No. 935
Notebook**
| \$5

A Rite in the Rain notebook is more tool than stationery. It's produced by J.L. Darling, a Tacoma, Washington, company that got its start in the 1920s making notebooks for loggers in the Pacific Northwest. Any paper tough enough to withstand those soggy, sweat-soaked conditions has my respect. Since then, the company has branched out to supply pads and notebooks to the military, law enforcement, ranchers and farmers, foresters, marine biologists, contractors, and DIY folks like me.

Speaking of which, I found my Rite in the Rain No. 935 notebook at my local Lowe's, hanging (appropriately) in the tool aisle. It measures 3 inches wide by 5 inches long, and I counted 48 pages in it, but I was immediately taken by its rugged build. Its two covers

are PolyDura, a form of polyethylene plastic; its paper is a special water-repellent 20-pound stock (the pounds refer to the weight of the uncut paper in a ream, a 500-piece stack). Imagine notebook paper meets Dixie Cup, and that gives you an idea of its thickness and water repellency. You can write on both sides of the page without seeing through it, and each tears out cleanly, leaving no detritus in the Wire-O spiral binding. That binding is important, too. After looking it up on stationery websites, I learned that Wire-O is tougher and higher quality than the typical spiral and permits the pages to be flipped without catching. It's a small but thoughtful feature that reflects the care that J.L. Darling applies to its products. A care that shows, even in the rain.—*Roy Berendsohn*



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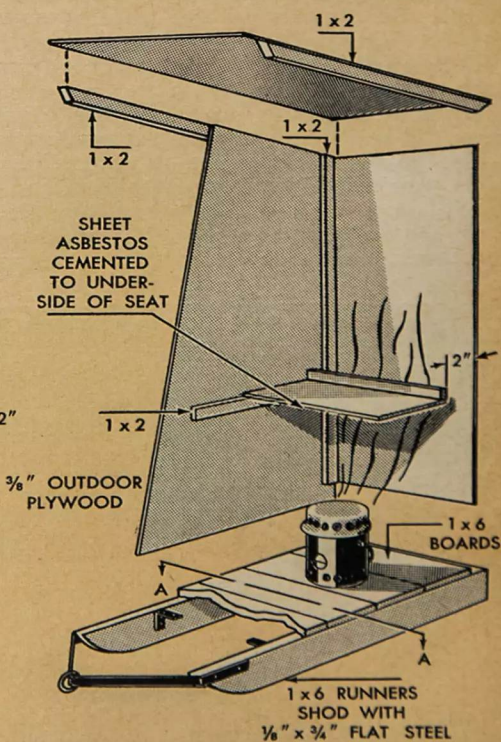
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