# The Periodic Table of Elements Issue

Introduction

Why the Periodic Table of Elements Is More Important Than Ever

By Peter Coy

Dmitri Mendeleev, inventor of the periodic table, circa 1880-82.Photographer: Andrei Osipovich Kareli/Alamy

The inventor Buckminster Fuller once described technological progress as “ephemeralization.” Sunbeams and breezes are replacing coal and oil as energy sources, brands are more important than buildings to corporations, and fiat money has supplanted gold and silver. So it seems reasonable to conclude that the periodic table of elements—that wonky taxonomy of physical stuff such as copper, iron, mercury, and sulfur—is passé, no more relevant than a manual typewriter.

Except exactly the opposite is true. Matter still matters. And on the 150th anniversary of the periodic table’s formulation by the Russian chemist Dmitri Mendeleev, it’s more important than it’s ever been. Read More

## The Periodic Table at 150

Scientists have long sought to catalog the known elements: In 1789, Antoine Lavoisier sorted them by their properties. By 1808, John Dalton was listing them by atomic weight. In 1864, John Newlands argued for a law of octaves, asserting that every eighth element had similar attributes. But it took Dmitri Mendeleev to create a genuinely systematic and predictive table.

Born in Tobolsk, Siberia, in 1834, the youngest of more than a dozen children, Mendeleev graduated from the Main Pedagogical Institute in St. Petersburg in 1855. He studied chemistry in Heidelberg and Paris, then earned a doctorate back home and became a tenured professor at Saint Petersburg Imperial University. Dissatisfied by existing Russian inorganic chemistry textbooks, he decided to write one himself.

The work Mendeleev published beginning in 1869 both laid out the periodicity of the elements and predicted spaces for ones not yet identified. With the discovery of gallium in 1875, scandium in 1879, and germanium in 1886, the theories underlying the table were shown to be true. Increasing scientific acceptance of these theories accelerated research into the material world and its industrial and commercial applications. Mendeleev himself took part in this, investigating processes related to Russian coal, oil, and even cheese production during the country’s fitful drive to modernize.

Since his death from influenza in 1907, the table has changed some, but its fundamental organization remains. Each element has a one- or two-letter chemical symbol, usually derived from its common name but sometimes from another language, making gold, for example, “Au” for the Latin aurum. The atomic number tallies the protons in the atom’s nucleus. The standard atomic mass is sometimes given to multiple decimal places, with the number in parentheses if it’s for the longest-lived isotope.

The columns depict elements that have similar chemical properties. The alkali metals, shown in the first column on the left, for example, have one electron in their outer shell and therefore tend to bond particularly well with the halogens, in the second column from the right, which have seven electrons in their outer shell and lack the single electron needed to complete it. That's how we get compounds such as sodium chloride—table salt—and potassium iodide, which helps protect the thyroid from the effects of radiation.

The column on the far right shows the noble gases, whose outer electron shells are full, making most of these elements useful in lighting since they won't react with others. In most periodic tables, the lanthanides and actinides are placed in rows at the bottom to avoid making the table impractically wide.

Mendeleev didn't get everything right: He believed that elements were unique and resisted the idea that they had the same building blocks. He also produced a convoluted case that ether was an element. But he got the basic design right, and that's why he's regarded as its inventor today—and why its sesquicentennial is being celebrated as the International Year of the Periodic Table. *—Joanna Ossinger*

Hydrogen $0.01/liter, 99.95% Grade B gaseous

## Getting on the Hydrogen Bus

Photographs by Rocco Rorandelli / Text by Jeff Muskus

In Europe's electric vehicle capital, hydrogen fuel might finally have a future.

The Raggovidda wind farm on the Barents Sea coast.Video: Rocco Rorandelli for Bloomberg Businessweek

The building for the electrolyzer being constructed close to the port of the town of Berlevag.Photographer: Rocco Rorandelli for Bloomberg Businessweek

It may not look like it, but the building under construction to the left, near the Norwegian port of Berlevag, is about to become part of the world's most efficient wind farm. By early next year, it will house a device called an electrolyzer, which, powered by that Norse wind, will produce hydrogen fuel for a growing army of forklifts, cars, trucks, and buses. A hydrogen station in the Oslo suburb of Hovik (right, top and middle) will soon be ready to fill them up.

Hydrogen tanks inside the Scania regional service center of Trondheim.Photographer: Rocco Rorandelli for Bloomberg Businessweek

The hydrogen-battery revolution has been 10 years away for decades now. But Norway, Europe's No. 1 in electric vehicles, is on track to become a leading adopter of the universe's most abundant element.

Proponents say it will become an essential component of a more environmentally friendly future as a growing supply of renewably generated hydrogen makes the fuel more competitive.

One longtime knock on hydrogen fuel has been that fossil fuels are often required to generate it. Not so at the Berlevag wind farm, or in the Norwegian city of Trondheim, where a technician (bottom) employed by Swedish vehicle manufacturer Scania AB is working with hydrogen electrolyzers and tanks that will be fueled by solar panels. This hydrogen setup will power a fleet of trucks and forklifts being tested for ASKO, a local grocery wholesaler.

For now, though, the dirtier forms of hydrogen production remain less than half as expensive as renewable ones. That's a headache for Norway's government, which plans to halt sales of fossil-fuel-powered cars by 2025 and expects to have as many as 500,000 hydrogen cars on the road in the country a few years later. At the very least, that would mean a lot more electrolyzers in places like Berlevag.

Helium $0.95/liter, 200-liter cylinder

## We're Running Out of Helium, and Two Geologists Might Have a Fix

By Paul Tullis

MRI machines, fiber-optic cables, and kids' birthday parties need it. Helium One wants to help. Read Story

Karim Mtili, a geology grad student, collects gas samples in Itumbula, Tanzania.Video: Adriane Ohanesian for Bloomberg Businessweek

Lithium $10.34/kg, 56.5% lithium hydroxide, China market

## Storage Wars

By Mark Burton

If the 20th century was the age of the internal combustion engine, the 21st belongs to the battery. Within a few decades, batteries will probably be the dominant source of power propelling cars and trucks, and they could even become commonplace in helicopters and planes. Far from their golf cart predecessors, today's electric vehicles can reach ludicrous speeds while emitting far fewer pollutants than gas guzzlers. They're also easier to make, and their batteries can be recycled. Carmakers from General Motors Co. to BMW AG are spending billions of dollars to make environmentally friendly transportation a reality. But the effort comes with its own environmental hazards, and pressure is building to ensure the companies are sourcing the critical elements responsibly. It would be all too easy to fall into many of the same traps as the oil industry that EVs are meant to leave behind. In this issue we've taken a look at the raw materials in batteries, from lithium to cobalt to zinc, to see how their green credentials compare.

- *Used in:* Lithium-ion batteries powering cars, cellphones, and power tools
- *What it does:* Enables energy to pass between the batteries' positive and negative electrodes
- *Achilles' heel:* If prices stay low, mining, exploration, and recycling might not be worth the cost. That would leave the industry more reliant on an environmentally riskier method known as brine extraction, which involves pumping underground saltwater reserves and extracting the lithium through evaporation.

Beryllium $500/kg, U.S. market

## A Very High-End Bike

By Caroline Winter

A BE401 mountain bike manufactured by Beyond Bicycles and made with beryllium.Courtesy Chris Hinshaw

Tougher than steel, lighter than aluminum, rather rare, and toxic if inhaled, beryllium is normally reserved for use in such high-tech applications as X-ray machines, spaceships, and nuclear reactors and weapons.

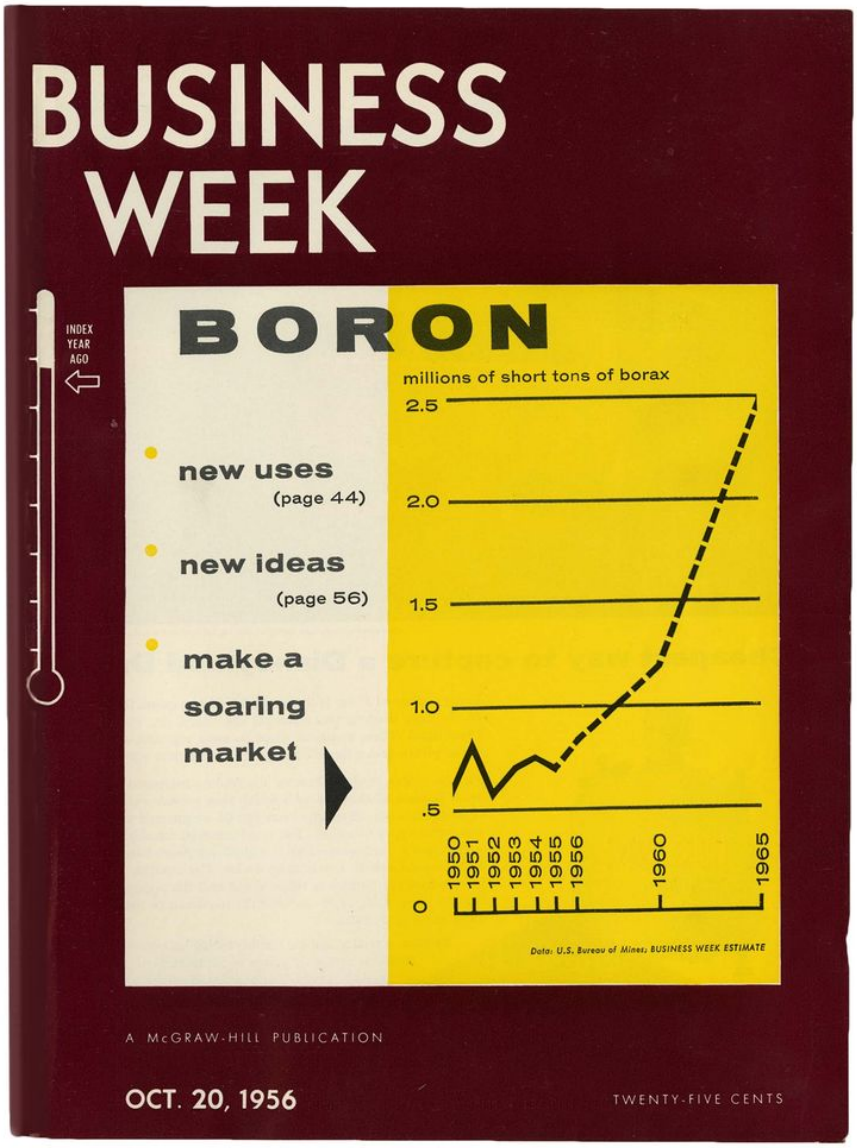
But in the 1990s former triathlete Chris Hinshaw spotted a market opportunity: bicycles. His company in

San Jose, Beyond Beryllium Fabrications, made about 100 bikes with the metal. Most were built using aluminum-beryllium alloys and sold for about $1,900; ones with weapons-grade beryllium went for as much as $30,000. Customers included baseball star Chili Davis.

Hinshaw stopped making beryllium bikes after a few years because his main supplier, a Russian mine and refinery, became unreliable. “When the Soviet Union fell, we realized right away that there wasn’t an infrastructure in place, not only to make product but do it to the standards and expectations set forth in the bicycling industry,” he says.

Boron $0.43/kg, average value of U.S. imports

## Total Borons?




In our Oct. 20, 1956, issue, *BusinessWeek* predicted “a host of big exciting new uses” for boron, particularly in jet fuel. A few years later, scientists realized that boron-based fuels are highly toxic—and also prone to spontaneously combust. Luckily for us, boron continued to prove useful in a growing array of

other products, including laundry detergent, fertilizer, and LCD screens. We wound up being right, just not for the reasons we thought.

Carbon $0.11/kg, minimum carbon price recommended by the UN Global Compact

## The Everything Atom

By Eric Roston

If chemistry were fair, the 118 elements would distribute themselves evenly among the 154 million substances in the American Chemical Society's CAS Registry. It's not. All but about 2 million have a molecular scaffolding of atom No. 6, carbon. It's the diamond on the ring, and also a good bit of the finger wearing it. Here, by size and date of discovery, are a few mighty molecules brought to you by the letter C.

Nitrogen $0.10/kg, 99.99% Grade B liquid

Oxygen $0.17/kg, 99.6% Grade A liquid

## Nitro Pour

By Kate Krader

Nitro cold brew.Photo: iStock/Getty Images

There's not much that can change how you make a cup of coffee, pumpkin spice notwithstanding. Beans are roasted, ground, and then steeped in water with or without pressure. But in recent years, there's been a major update to your basic cup of joe: pumping odorless nitrogen gas into brewed coffee to add frothiness and the tiniest hint of sweetness. A good nitro cold brew will look like an inviting beer, with a soft, foamy top. Since the first one flowed from an Austin tap around 2012, according to the most popular origin story, it's become a staple for coffeeheads and a driver in the $4.1 billion ready-to-drink coffee category.

Stumptown Coffee Roasters Inc., the Portland, Ore.-based national chain, first offered cans of nitro brew in 2015 after experimenting with draft versions. With sales of about 2 million cans a year, it's the company's fastest-growing product. Early on, says head brewer Brent Wolczynski, "the process was very DIY. We would put cold brew in a keg, hit it with nitrogen at a really high pressure, and just shake it around."

Now the process is the equivalent of a marvelous science experiment: Each can is equipped with a small plastic widget that encloses the nitrogen. Cracking open the can exposes the brew to atmospheric pressure, pushing the nitrogen out and through the coffee. The result is a cascade of tiny bubbles as you pour.

La Colombe Coffee Roasters, another premier brand, includes nitrogen's periodic table mate, oxygen, in its version. The draft latte is made with nitrous oxide ($N_2O$), a compound more famously known as laughing gas, that's also used to animate canned whipped cream. A customized valve delivers the kind of foam typically found in a hot latte into the cold beverage. $N_2O$ bubbles last longer than nitro's and create an extra-creamy texture with a more pronounced sweetness. La Colombe has even patented its can.

Another big name in coffee, Starbucks Corp., has announced that its nitro cold brew will be sold on tap nationwide by yearend. No surprise, it will be available in several flavors and finishes, like one with a "cascara cold foam" and another with "sweet cream." There'll even be a pumpkin cream cold brew.

Composition

## Night Vision Binoculars

Night vision technology has become reliable and widespread, used by everyone from soldiers to birders. Although a digital approach is becoming popular, light intensification remains the industry standard. As moonlight reflected off an object enters these battery-powered binoculars, it passes through the lens into an image-intensifying tube. A photocathode then converts the light into electrons that are amplified by a photomultiplier and directed toward a phosphorescent screen to produce a visible image. *—E. Tammy Kim*

A

B

C

Photographer: Daniel Shea for Bloomberg Businessweek. Prop stylist: Anna Surbatovich. Product courtesy Night Owl Optics, First Texas Products LLC

Fluorine $1,528/kg, Swix high-fluoro wax

## Cross-Country Skiing’s Dirty Little Fluorinated Secret

By Bill Donahue

Professionals and amateurs alike are hooked on fluoro wax, but the EU is banning it. Read Story

A bar of Swix high fluoro ski wax.Photographer: Evan Ortiz for Bloomberg Businessweek

Neon $2/liter, 200-liter cylinder

## Lights Lights Lights

Photographs and text by Tommy Trenchard

Scientists discovered the presence of neon in the atmosphere at the end of the 19th century. The element and its fellow noble gases—including argon, krypton, and radon—are tasteless, odorless, colorless, and largely unreactive. But when subjected to an electrical charge, they emit various colors. In the 1920s entrepreneurs recognized the advertising potential of this, and within a few years neon signs had started changing the face of the world's cities. They eventually defined the appearance of iconic locations, such as New York City's Times Square and the Las Vegas Strip.

Neon creates the red-and-orange glow most commonly associated with the lights, whose colors depend on the gas, or combination of gases, in the tubes. By the 1970s, Hong Kong had emerged as one of the world's great neon cities. Signs jostled for placement in its narrow streets as restaurants, clubs, and movie theaters tried to outdo each other in style and size. Read more at argon, krypton, and xenon.Video: Tommy Trenchard for Bloomberg Businessweek

Sodium $110/kg, 5-pound bag of Jacobsen pure flake finishing salt

The Salt King of America

By Andrew Zaleski

Ben Jacobsen wants people to think differently about the power of salt. Read Story

Ben Jacobsen, founder of Jacobsen Salt Co.Photographer: Shawn Records for Bloomberg Businessweek

Magnesium $4.74/kg, U.S. spot

## Flashback

By E. Tammy Kim

Two children in a tenement room, circa 1910.Photographer: Jessie Tarbox Beals; Courtesy Community Service Society of New York/Rare Book and Manuscript Library/Columbia University

Light is and always has been the photographer's greatest concern. But in the mid-19th century, the task of capturing and creating light was all-consuming. In 1864, Alfred Brothers, the son of an English chemist, began to experiment with a primitive flash—essentially, a metal-burning lamp.

The key was magnesium, a remarkably lightweight silvery metal. At No. 12 on the periodic table, toward the top left corner, it's one of the most common elements on Earth, yet it's never found in its pure form. On its own, magnesium burns slow and clear and gives off a bright, neutral light—no blue or yellow sheen.

Brothers took a chunk of magnesium ore, bathed it in acid, mixed it with salt, burned it, and captured the vaporized condensation. He hammered this purified metal lump into a sheet, then cut it into ribbons that could be lit like candle wicks. He placed this controlled fire next to his enormous, boxy camera and made a portrait in his studio. "Henceforth it will be next to impossible for mortal man to hide himself from the lens of the photographer. Formerly we were safe after sunset, but that is no longer," a London journalist wrote in the *Standard*. Soon, adventurers such as Charles Piazzi Smyth were taking magnesium on the road to shoot the first scenes of caverns and the insides of the Great Pyramid of Giza.

Piazzi Smyth: Inside the Great Pyramids.Courtesy SSPL/Getty Images

Family around a piano, New York City, circa 1916.Photographer: Jessie Tarbox Beals; Courtesy Community Service Society of New York/Rare Book and Manuscript Library/Columbia University

By the 1880s, the magnesium flash had leapt from the toolbox of explorers to that of journalists. As the story goes, Jacob Riis, then a photographer for New York's *Evening Sun*, read an article about a German manufacturer of flash powder and reacted "with an outcry that startled my wife. … A way had been discovered, it ran, to take pictures by flashlight." Riis acquired a flash gun—which ignites magnesium powder inside a pistol—and took it with him to shoot the dark tenements of New York's Lower East Side. Without magnesium, there would be no *How the Other Half Lives*.

There would also be no tenement pictures from Jessie Tarbox Beals, a schoolteacher-turned-photographer who shot portraits of early 20th century New Yorkers. She was, as historian Kate Flint writes in Flash!, a master of "the surprising illumination of the everyday." In one especially notable Beals portrait, an unnamed woman sits on a kitchen chair, holding a naked infant in each arm, wearing a flat, tired expression. She and her babies are squeezed among mismatched cribs, a worn apple basket, an iron stove, pots, a kettle, and bottles and plates stacked in open cabinets. A calendar and a rag hang from the wall; the floor is all grimy tile. Has any room ever seen more life?

In the decades after Beals's death in 1942, the magnesium flash evolved only in form. It went from the flash gun to the flashbulb—what we now imagine as a blinding burst in mid-20th century paparazzi shots. Dan Tidwell started out as a photographer in the final days of the magnesium flash. In 1965, at the age of 20, he was hired to document an historic project near Sacramento: the final testing stage of NASA's Apollo

program. Tidwell's camera of choice was a large-format Graflex 4x5 with a large flashbulb attached to its right side. "It would not be uncommon for that glass bulb to literally explode," he told me.

In one of his pictures, four men in white coveralls and hard hats stand in front of an enormous rocket. At right, a conical mass of wires, pipes, and balloons twists in shades of black and gray. At left, the flash has merged the men's coveralls, the rocket's curved body, and the wall of the hangar into a bleached plane.

Apollo tests.Photographer: Dan Tidwell

That flash-shocked aesthetic isn't so popular these days. (Just one company, Meggaflash, in Ireland, still sells old-fashioned flashbulbs.) In July I attended a wedding in a dusky, jasmine-scented garden in Los Angeles. As soon as the ceremony began, nearly every guest raised her smartphone. Long after nightfall we continued to shoot without a flash, reflecting a shared preference for subtle edges. Only the wedding photographer used the occasional flash to interrupt our inky surroundings. He clicked the device onto the body of his camera and pressed the shutter. There was no acrid explosion or metallic smoke—just the memory of magnesium's blinding light.

Aluminum $2.54/kg, ingot, U.S. market

## Ink Think

The metallic color shown on this issue's cover is Pantone 877 C, whose shimmery quality derives from aluminum flakes mixed into the ink.

Photographs for Bloomberg Businessweek by Tommy Trenchard (Neon), Shawn Records (Sodium), Kiliii Yuyan (Neodymium), Carlotta Cardana (Gold), and Christie Hemm Klok (Berkelium)

Silicon $3.04/kg, silicon metal, U.S. market

## Sand Blasters

By Drake Bennett

(From left) Sandcastle sand and frac sand.Photo: Getty Images

In hydraulic fracturing, or fracking, drillers pump a viscous, gritty goo down a well at pressures that splinter the rock beneath, releasing trapped oil and natural gas deposits. The resulting channels are kept open using grains of "proppant" suspended in the frac fluid. The most common proppant is sand.

Fracking is now the largest consumer of American sand. And not just any sand will do: The best has round, uniform grains and a high silica content that makes it hard enough to withstand being clamped between giant rocks. "The boom in U.S. hydrocarbon production depends on mining millions of tons of sand," reads a pamphlet from proppant provider Hi-Crush Inc., "and pumping it back into the earth."

## Source

The most desirable frac sand comes from the Upper Midwest. Northern White and Ottawa White are particularly prized for their lack of impurities. Freight trains and barges transport the sand south to the Permian Basin and east to the Marcellus Shale. As the industry has grown, drillers trying to reduce transport costs have begun to look closer to fracking sites, excavating lower-quality Oklahoma sand and mining the dunes of West Texas.

## Mining

Backhoes and loaders scoop sand up from shallow pits. The grains are washed, sorted for size through filters and centrifuges, then dried in rotating drums. Sometimes the sand is coated with resin to make it stronger.

## Blending

Drillers store the sand on-site in silos or other containers. When needed, it's mixed with water, chemicals, and thickeners such as guar gum in giant truck-mounted blenders before being pumped down the well.

Phosphorus $0.07/kg, phosphate rock, f.o.b. (free on board; prices include shipping and loading)

## Conscious Fertilizer

By Kate Krader

Goats at Stone Barns.Courtesy Molly M. Peterson/Stone Barns Center for Food & Agriculture

Chemical fertilizer has helped feed the world since it was developed in 1909. But its damage to the Earth has been documented with increasing alarm. The farmers at Stone Barns Center for Food & Agriculture in Tarrytown, N.Y., are leading the way in eco-minded fertilization. On the 400-plus-acre property, donated by the Rockefeller family, cows, sheep, goats, pigs, and hens are rotated around different pastures, as is their manure, a major source of fertilizer. Phosphorus, a key element in the animal droppings, is one of the most carefully monitored on the property, says Stone Barns farm director Jack Algiere. He calls it the steroids of the plant world—combined with nitrogen and potassium, it can turn a humble zucchini into a show-stopping specimen.

Dan Barber, a chef and co-owner of the property's Blue Hill at Stone Barns restaurant, wants to demonstrate that farmers can still profit if they give up what he calls "their single-nutrient obsession" with elements such as phosphorus and nitrogen. Just like too much of anything, excess phosphorus is harmful. Runoff containing the fertilizer blights waterways by stimulating overproduction of algae and weeds.

Westchester County, home of Stone Barns, has banned commercial phosphate fertilizer because of the

threat it represents to the ecology of the Hudson River. Naturally derived phosphorus is less soluble—and not banned—so Stone Barns is in the clear.

Sulfur $0.08/kg, elemental sulfur, f.o.b.

## Sulfur Is the Oil Industry's Other Problem

By Jack Wittels
The noxious byproduct has been linked to acid rain and lung cancer. Read Story
Sulfur crystals.Photographer: Susan E. Degginger/Science Source

Chlorine $0.33/kg, liquid contract, U.S. market

## Political Chicken

Illustration: Steve Bell

There was a time—2017—when Brexit seemed to hang on chickens washed in chlorine. The sterilization practice is banned in Europe but common in the U.S., which insisted it wouldn't sign a trade deal with a post-EU Britain that didn't include its poultry. Two years, one prime minister, and no Brexit later, the possible arrival of chlorinated birds still rankles "remainers."

Argon $0.48/liter, 200-liter cylinder

## More Hong Kong Lights

By Tommy Trenchard
The city's signs have been disappearing by the day. The Hong Kong government has cracked down on signage it says doesn't comply with building and safety codes. Many business owners replace the removed neon signs with cheaper mass-produced LED lights. Other shopkeepers have chosen to take down their signs because they look dated. "In the '80s, if you walked down the streets, you'd see neon everywhere," says Cardin Chan, executive director of the Hong Kong Neon Heritage group. The once-modern aesthetic is now more associated with seedy bars and red-light districts. Streets that once were bathed in neon often carry just a solitary, flickering sign—or none at all.


Argon is the third-most abundant gas in the atmosphere and the second-most common of the noble gases used in neon lights. It emits a pale blue-violet hue—the intensity of the color is weaker than the red of neon. A sign for the Hong Kong Cafe hangs over Tung Choi Street in the Mong Kok neighborhood.Photographer: Tommy Trenchard for Bloomberg Businessweek


A neon sign hangs above the Regency Spa in Yau Ma Tei.Photographer: Tommy Trenchard for Bloomberg Businessweek


Neon lights jostle among LED ones on Portland Street in Kowloon.Photographer: Tommy Trenchard for Bloomberg Businessweek


A neon sign advertises the Mido Cafe in Yau Ma Tei.Photographer: Tommy Trenchard for Bloomberg Businessweek

A half-illuminated neon sign hangs above a street market on Canton Road in Mong Kok. Streets that once were bathed in neon often carry just a solitary, flickering sign—or none at all.Photographer: Tommy Trenchard for Bloomberg Businessweek

Potassium $0.82/kg, potash, f.o.b.

## Potash Mine

Using drones and advanced cameras, the Canadian artist Edward Burtynsky has captured the grisly beauty of global industry, from clear-cutting and strip mining to the mass slaughter of elephants. This 2017 photo comes from the Uralkali mine in Berezniki, Russia, where the potash salts containing potassium—a key component of commercial fertilizer—are extracted. On Sept. 25, Burtynsky will release his third documentary, *Anthropocene: The Human Epoch*, which chronicles humanity's large-scale and now intractable alteration of the planet. *—James Tarmy*

Uralkali potash mine in Berezniki, Russia.Photographer: Edward Burtynsky; Courtesy Howard Greenberg and Bryce Wolkowitz Galleries, New York/Nicholas Metivier Gallery, Toronto

Calcium $6.27/kg, China spot

## What If You Eat It?

Calcium is a soft, gray alkaline earth metal. It's the fifth-most abundant element in the Earth's crust.Photographer: Charles D. Winter/Science Source

- *Who eats calcium?*
  Pretty much everyone. Since it's most prevalent in dairy, vegans have to rely on leafy greens and supplements.

- *What does it taste like?*
  Raw metallic calcium is unstable and highly reactive and would corrode the inside of your mouth. Most

of us consume it in one of its chalky salt forms—calcium hydrogen phosphate (as in milk) or calcium carbonate (supplements).

- *What does it do?*
  Calcium strengthens bones and teeth. If you don't get enough, you can lose bone mass, leading to osteoporosis. If you get too much, you can become constipated. It may increase the risk of kidney stones as well. *—Silvia Killingsworth*

Scandium $5,592/kg, 99.95% total rare-earth mineral, China market

## Coal Comfort

By Michael Belfiore

Duke Energy coal ash ponds in North Carolina.Photographer: Will Warasila

U.S. efforts to diversify its supply of rare-earth elements (REEs) have led to an unlikely source: coal. A program begun in 2014 aims to wean the U.S. from its dependence on China for these 17 difficult-to-extract minerals, essential to many high-tech applications including weaponry. "Our current projections are that if high REE extraction efficiencies are achieved, there are sufficient domestic coal-based resources available to supply the U.S. demand," says Mary Anne Alvin, REE technology manager at the Department of Energy. Managers say the program's 22 projects piggyback on existing coal mining and consumption and don't cause additional environmental harm. The major challenge is to develop separation and concentration technologies that can be scaled up to viable commercial operations. Efficiently recovering scandium, a particularly expensive REE, would help achieve that goal. Here are two projects at different ends of coal's production cycle.

## North Dakota Coal Stocks

This project seeks to capture REEs from lignite, a low-grade coal. Nolan Theaker, technical lead of the University of North Dakota project, says extraction can be easier from lignite than from higher-rank coals. The prototype process crushes, screens, and chemically treats 44 pounds of lignite an hour to produce a third of an ounce of rare-earth oxide products—about 1/100th the amount needed for an electric vehicle motor, according to Theaker. He says the project will advance to half a ton of coal processed per hour for a planned pilot in 2023.

## Kentucky Coal Ash

The advantage to extracting at the tail end of the process, according to Prakash Joshi, former head of the effort at Andover, Mass.-based Physical Sciences Inc., is that coal ash contains six to 10 times the concentration of REEs as unburned coal. The project's pilot plant, to be completed in 2020, will wash the

glassy matrix containing REEs out of half a ton of ash a day from a power plant in Ford, Ky., then use a chemical process to produce up to 17 ounces of dry material that's at least 20% scandium and yttrium.

Composition

## Computer Chip

Silicon Valley gets its name, of course, from element 14, the essential stuff of the computer chip. In the early days of computing, the three parts of a chip—the wafer, or substrate; the transistors layered on top; and the wires connecting to a circuit board—required only a handful of elements. Today, chipmakers draw on a large swath of the periodic table. *—E. Tammy Kim*

Photographer: Daniel Shea for Bloomberg Businessweek. Prop stylist: Anna Surbatovich. Product courtesy advanced science research center at the graduate center, CUNY.

Titanium $9.10/kg, titanium sponge metal

## Card Creep

By Jeremy Keehn
Courtesy Apple

"Stronger than steel at high temperatures, titanium got named after the Titans of Greek mythology," says Bill Nye, aka the Science Guy. "Not only can it take the heat, it can reflect it." That's the kind of metal people want to associate themselves with—and the reason why, as the August release of the Apple card showed, titanium is the "it" material for credit cards. Even so, Apple Inc.'s laser-etched version joins a crowded metal-card bandwagon. Review website Credit Card Insider counts 22 on the market, which the companies tout as being made with titanium, or stainless steel (i.e., iron, carbon, and chromium), or even 24K gold.

For all the fervor, few are truly pushing the limits of metallurgy. JPMorgan Chase & Co. gets an honorable mention for its J.P. Morgan Reserve card—née the Palladium card and actually made with the platinum-group metals. Other companies might consider the:

- VANADIUM CARD
  A proton above titanium

- TIN CARD
  So far ahead of the pack you're in back

- PROMETHIUM CARD
  Only the rarest earth will do

- TUNGSTEN CARD
  The true wolfram of Wall Street

- MERCURY CARD
  The ultimate liquid asset

- PLUTONIUM CARD
  Simply the bomb

Vanadium $30.86/kg, vanadium pentoxide

## Ford’s Miracle Metal

By Eva Holland

Ford Model T, 1908.Courtesy Library of Congress

At the turn of a new century, Henry Ford, a two-time automobile-industry failure seeking a third crack, had an idea for a new kind of car. Early models coped with the rugged road conditions of the time through sheer heft, and they were expensive to make and buy. “The greatest need to-day,” Ford wrote in 1906, “is a light, low-priced car.”

Ford’s account of his eureka moment ran like this: The year before, at a race in Palm Beach, Fla., he’d seen a French driver crash. The vehicle was badly damaged, but its lightweight steel didn’t break. Ford salvaged a part from the wreck to investigate further; the steel, he learned, was a vanadium alloy. Historians are skeptical of the tale—there’s no record of a race in Palm Beach that year, let alone a crash, raising the less romantic possibility that Ford’s engineers read about vanadium steel in trade magazines. However it happened, the discovery was transformative. Ford placed an order for $750,000 (more than $17 million in today’s dollars) worth of vanadium steel with United Steel and the fledgling American Vanadium Co.

In October 1908 the first Model T rolled off the line. It was by far the lightest and cheapest car yet, with half its steel parts made using the vanadium alloy and a retail price of $850. An early print ad, showing dozens of children piled on top of one, proclaimed, “Only springs and axles of Vanadium Steel could safely carry such a load as this.” We all know what ensued: Fifteen million Model Ts sold in two decades. Mass production. The dawn of drive-ins and drive-thrus, the rise of the road trip. The interstate. Dean Moriarty. Thelma and Louise. And smog, gridlock, and greenhouse gases.

All of it came courtesy of a little-known metal that had been discovered only after a false start. In 1801 a Spanish mineralogist, Andrés Manuel del Río, claimed to have found a new element in a sample of a mineral he called “brown lead,” but his peers convinced him it was just a form of chromium. It was left to a

Swedish chemist, Nils Gabriel Sefstrom, to rediscover the element 30 years later and name it after the Norse goddess Vanadis. Known for its stability at high temperatures and across valences, it was initially used to help set black dyes in fabrics and inks. By the turn of the century, it was being used in alloys for tools and dies.

After Ford came along, it became everyone's not-so-secret ingredient. Mixing as little as 0.05% vanadium into a steel alloy can as much as double its strength—thanks, scientists now know, to the fine precipitation of vanadium carbonitrides as the steel cools. This reduces the amount of steel required for a given purpose, making it appealing for railways, rebar, and more.

And it's still essential for automobiles. "The intensity of use of vanadium in cars is only increasing," says Terry Perles, president of supplier Motiv Metals LLC. "It's all about government-driven fuel economy standards." A century ago, a lighter car meant an affordable car. Today it also means a more fuel-efficient one. Perles is excited, too, about the potential for vanadium-based batteries, which promise to reduce carbon emissions by storing vast solar power reserves. There are significant kinks to work out, but the next act for Henry Ford's wonder metal could be undoing the excesses it helped engender.

Chromium $0.31/kg, chromium ore
Manganese $0.01/kg, 46%-48% metallurgical ore, China spot
Iron $0.08/kg, iron ore
Kabul's Iron Lady
By Matthieu Aikins
Nargis Nehan is trying to reform a troubled ministry and get her country's vast mineral resources out of the ground. Read Story
Nargis Nehan, Afghanistan's minister of mines and petroleum.Photograph by Kiana Hayeri for Bloomberg Businessweek

Cobalt $32.12/kg, London Metal Exchange cash spot
Nickel $15.88/kg, London Metal Exchange cash spot
Copper $5.68/kg, London Metal Exchange cash spot
Zinc $2.22/kg, London Metal Exchange cash spot
Storage Wars Continued
By Mark Burton
Assessing the raw materials in batteries to see how their green credentials compare.
*Based on December 2018 prices. Data: Bloomberg New Energy Finance

- *Used in:* Zinc-air batteries for renewable energy installations and maybe EVs.
- *What it does:* It's used in the battery anode and reacts with air during the discharging process, yielding power.
- *Achilles' heel:* Investment. Billions of dollars continue to pour into the development of lithium-ion batteries, and advances in the incumbent technology are still coming hard and fast. If zinc-air batteries are going to take market share, they'll need to prove themselves with far less money behind them.

Gallium $350/kg, high-quality refined
Germanium $1,300/kg, germanium metal
Arsenic $1.40/kg, arsenic metal, China market

## An Obsession With a Useless Element Helped Build the Digital World

By Robert Kolker
Gordon Teal's dedication to germanium led to the first commercial transistors. Read Story
Gordon Teal (right), working on a junction transistor, 1950.Courtesy Nokia Bell Labs

Composition

## Fiber Optics

A successor to the humble copper-wire telephone line, fiber optics carry all manner of data around the world in the form of light. Specialized fiber optics are also used in lasers, medical imaging, and underground sensors that detect faint vibrations or monitor temperature and pressure. *—E. Tammy Kim*

Photographer: Daniel Shea for Bloomberg Businessweek. Product courtesy OFS Fitel, Furukawa Electric Co.

Selenium $44.09/kg, U.S. market

## What If You Eat It?

Brazil nuts.Photo: Zoonar GmbH/Alamy

- *Who eats selenium?*
  You, if you take a multivitamin.

- *What does it taste like?*
  It might taste like Brazil nuts, which have the highest concentration of selenium, followed by seafoods and organ meats.

- *What does it do?*
  The mineral is an essential antioxidant. But too much of it can cause selenosis, a condition marked by hair loss, brittle nails, and a metallic taste in the mouth. *—Silvia Killingsworth*

Bromine $4.40-$5.40/kg, U.S. market
The Woman Who Got Bromine Out of Kids' Pajamas Fears It's Coming Back

By Tiffany Kary

Chemist Arlene Blum battles a new form of an old foe. Read Story

Arlene Blum hikes a trail in Tilden Regional Park in Berkeley, Calif.Photographer: Rachel Bujalski for Bloomberg Businessweek

Krypton $3/liter, 200-liter cylinder

## More Hong Kong Lights

By Tommy Trenchard

Choy Chun Wa, 52, has been working alongside a master neon maker, 78-year-old Wong Kin Wah, for three decades. He mostly focuses on finishing the signs. Choy says he worries constantly that the factory in China that produces the glass tubes will stop making them because of lack of demand. “The future doesn’t look good,” he says. “The biggest threat to our business without a doubt is LEDs.” Wong’s business, in the city’s Mong Kok neighborhood, once included a team of assistants to keep up with demand; in the 1980s he even had a contract to make signs for the local Kentucky Fried Chicken franchises. Today there are fewer than a dozen neon masters like Wong still in business. “I don’t know any young people at all who are doing this work,” Wong says.

Aside from lighting, krypton doesn’t have any commercial uses. It emits a yellow-white color, but the gas isn’t typically used for the color. Krypton is found in airport approach lights and, less frequently, in neon signs.Photographer: Tommy Trenchard for Bloomberg Businessweek

Rubidium $84,400/kg, 99.75%-grade ampoules

## Space Commodity

Late last year a team at the U.S. National Institute for Standards and Technology in Boulder, Colo., recorded a clip of Queen and David Bowie’s *Under Pressure* using excited rubidium and cesium atoms. NIST’s Christopher Holloway says the project grew out of work on atomic sensors, whose potential applications include deep-space communications. In a paper, his team wrote of a desire to inspire others and “help create the future quantum-based workforce.” How, we wondered, might that play out…

- 2020: Atomic-music stans flood Boulder, aka Quantum Valley
- 2030: QV builds vast catalog of “rubstep” songs for aliens
- 2031: Undaunted by lack of market, VCs invest billions
- 2047: Alien contact: Rubstep broadcasts begin
- 2069: Callistock held on Jupiter’s 8th moon; profits soar
- 2099: Teen invents software to distribute rubstep for free
- 2120: Distressed-asset specialists feast on QV’s bones

Strontium $6.50/kg, 99% strontium metal f.o.b., China market

# Name and Shame

By Dina Bass

Five years ago, Microsoft Corp. founded the Microsoft Threat Intelligence Center (MSTIC, pronounced “mystic”) to track so-called advanced persistent threat groups—sophisticated bands of hackers, often linked to nation-states, that aim to steal secrets and money and to disrupt businesses and elections. MSTIC has christened more than 70 of the groups it tracks with the name of an element. For example, the Russian group responsible for the 2016 hack of the Democratic National Committee, elsewhere called Fancy Bear or APT28, is referred to by MSTIC as Strontium. Why elements? “I didn’t want anything particularly cutesy like ‘kitten,’” says John Lambert, who founded the team. And though strontium, an alkali metal, is widely used to make fireworks, the names are chosen randomly. It’s not “like all the noble gases map to Iran or anything,” Lambert says. In 2016, Microsoft sued Strontium in a U.S. court, helping it seize more than 100 website domains linked to the group.

## Strontium

- aka Fancy Bear, APT28
- Linked to: Russia
- Known attacks on: Governments, media, and NGOs in Germany, South Africa, the U.K., and the U.S.
- Recent exploit: Released doping-related International Olympic Committee emails prior to the 2018 Winter Olympics
- Elemental similarities: Tarnishes in the open

## Phosphorus

- aka APT35, Charming Kitten, Ajax Security Team
- Linked to: Iran
- Known attacks on: Political dissidents, media members, NGOs, and governments in Iran, the U.K., and the U.S.
- Recent exploit: Targeted businesses and government agencies with websites resembling Microsoft and Yahoo ones
- Elemental similarities: Can cause severe burns

## Barium

- aka Winnti, ShadowHammer, Wicked Panda
- Linked to: China
- Known attacks on: Gaming companies, airlines, and hotels in India, Ukraine, and the U.S.
- Recent exploit: Penetrated a server and inserted a backdoor into an Asus software-update program

- Elemental similarities: Produces clear view of innards

## Thallium

- aka Kimsuky, Hydra, BabyShark
- Linked to: North Korea
- Known attacks on: Governments, NGOs, and media in Japan, the U.K., and the U.S.
- Recent exploit: Sent emails tricking users into downloading software that could record login credentials
- Elemental similarities: Toxic and hard to detect

Yttrium $32/kg, metal, Shanghai market

## Ore Spot

At least eight elements, all rare earths, can trace their discovery to this mine in Ytterby, Sweden, photographed in 1910. Four are named for the site: yttrium, terbium, erbium, and ytterbium. The others are gadolinium, holmium, scandium, and thulium.
Courtesy Tekniska Museet

Zirconium $13/kg, unwrought import, China market

## The Bombmaking Vintner of Colchagua

By Daniela Guzmán
Carlos Cardoen sold weapons to Saddam Hussein, then became a renowned winemaker in Chile. The U.S. wants him extradited.
The 4th Tactical Fighter Wing ordnance disposal team detonates a cluster bomb during Operation Desert Storm in Iraq.Courtesy NARA

There are certain elements a good winemaker should know. Soil rich in iron, for example, gives merlots and malbecs notes of tobacco, graphite, and mushroom. Calcium and magnesium give pinots the tang of earth, anise, and spices. But there's another element that Carlos Cardoen, a winemaker in Chile's bucolic Colchagua Valley, is familiar with for very different reasons.

Cardoen with Hussein.Courtesy U.S. Department of Commerce

A civil engineer with a doctorate in metals science, Cardoen started an explosives company in the 1970s meant to serve the mining industry. With regional tensions rising, Chile's then dictator, Augusto Pinochet, asked him to start making bombs and land mines. Cardoen's business soon expanded internationally, and Iraqi leader Saddam Hussein became a fan of his zirconium-laced cluster bombs, designed to blow up and burn a target on impact.

Launched from air or ground, cluster munitions can be bomblets, chemicals, or biological weapons. They can kill indiscriminately across a wide swath of territory, and left undetonated they're dangerous long after a conflict ends. The Convention on Cluster Munitions, ratified by 120 countries including Chile, prohibits their use, but they were common during Iraq's wars, responsible for thousands of civilian deaths.

In 1993 the U.S. government charged Cardoen with improperly exporting zirconium, effectively confining him to Chile. He continued building his commercial empire there, spanning mining, agriculture, tourism, renewable energy, and, of course, wine. In so doing, he cultivated relationships with politicians and businesspeople of all stripes. Many Chileans hailed him as a hero and visionary after he helped rebuild communities devastated by a massive earthquake in 2010. His once sleepy hometown of Santa Cruz became an international tourist destination, with a luxury hotel, a personally curated history museum, and the winery, renowned for rich and diverse soil that produces grapes such as carménère, cabernet sauvignon, and tempranillo. The wines are branded with names drawn from Chile's indigenous peoples: Aymara, Mapuche, Rapa Nui.

That it's an idyll for oenophiles is fortunate for Cardoen, now 77, who was placed under house arrest in April after an extradition request by the U.S. He declined to comment on the case, but his longtime lawyer, Juan Pablo Hermosilla, calls it "fragile," saying the U.S. made the extradition request "simply to keep the red alert valid until he dies." Hermosilla speculates that Interpol, in renewing the notice last year, told the U.S. it needed to do something to pursue the case—"what they should have done 26 years ago." He adds, "It shows bad faith. They always knew where Carlos was."

Some Chileans who've been avidly following the saga, however, hope it will close an open wound from the Pinochet era. Rodrigo Avilez, a 47-year-old accountant who grew up under the regime, says the case has brought back bad memories. "Justice is delayed," he says, "but justice arrives eventually."

Niobium $75.75/kg, 98% China spot

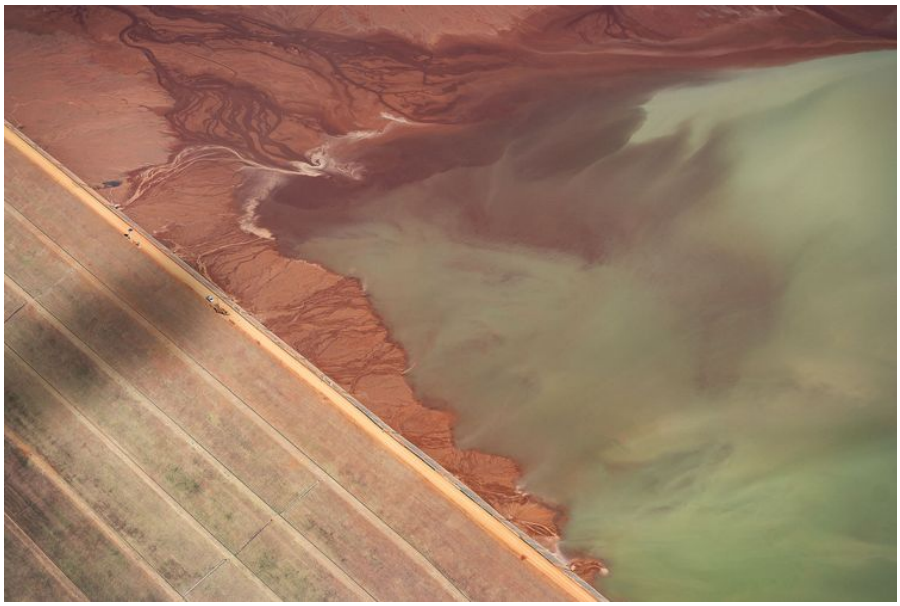
## 'I Dream … That One Day, We'll Also Have a Niobium Valley'

Photographs by Júlia Pontés

Last year, Brazil produced almost nine-tenths of the world's niobium, used primarily in steel alloys for airplanes, cars, and electronics. The country's president, Jair Bolsonaro, who's long touted the metal's economic potential, described his "Niobium Valley" dream in a 2016 promotional video. Photographer Júlia Pontés—who took these shots of a niobium mining operation owned by Companhia Brasileira de Metalurgia e Mineração and Chinese partners in Araxá, in the state of Minas Gerais—researches and documents the vast scale of such projects so people can see the effects of mineral exploration and consumption. A Niobium Valley "could be great only if it primarily aimed," she says, at "benefit for the community." Extraction industries, she's found, have returned limited benefits to Araxá's people. *—Jeremy Keehn*

Pit at a CBMM niobium mining operation in Araxá, Brazil.Photographer: Júlia Pontés for Bloomberg Businessweek

Minerals gathered for processing.Photographer: Júlia Pontés for Bloomberg Businessweek



Tailings dam.Photographer: Júlia Pontés for Bloomberg Businessweek

Niobium processing plant.Photographer: Júlia Pontés for Bloomberg Businessweek

Molybdenum $24.89/kg, London Metal Exchange cash spot
Technetium Price not available

## Moly Cow

By Drake Bennett

A NorthStar machine for producing technetium-99m from molybdenum-99.Courtesy NorthStar

These periodic table neighbors are also kin. Molybdenum-99, an unstable isotope with one neutron more than Mo-98 (the element's most common naturally occurring form), produces the even more unstable technetium-99m. Tc-99m, as it decays, helps doctors see into the human body, emitting gamma rays that

are picked up by specialized cameras in cardiac scans, bone scans, and other imaging procedures.

Traditionally, this unusual supply chain has required irradiating highly enriched uranium—the stuff of nuclear weapons—in reactors overseas, then shipping back the fast-decaying Mo-99. Last year, NorthStar Medical Radioisotopes LLC got permission from the FDA to make it a new way. Discs of stable molybdenum are irradiated in a nuclear reactor in Columbia, Mo., creating Mo-99 that's then shipped in tungsten-shielded containers to specialized pharmacies. There, NorthStar machines—earlier devices were dubbed "moly cows"—harvest the Tc-99m.

When a hospital orders a scan, the pharmacy prepares a lead-jacketed syringe with Tc-99m and a cocktail of molecules that will bond to the organ of interest. The isotope's six-hour half-life ensures that it's gone from the body in days.

Ruthenium $8,819/kg, Johnson Matthey spot
Rhodium $139,509/kg, Johnson Matthey spot
Palladium $47,320/kg, dollar spot

## Elements That Go Boom and Bust

By Eddie van der Walt
Commodities used in small quantities by giant industries have a tendency to undergo spectacular rallies and crashes, especially if they're produced as byproducts of another material. Their supply doesn't correspond directly with changes in demand and so doesn't respond directly to big changes in technology, consumer appetites, or trade relationships. The result is periods of over- or underproduction, with shifting costs to match.

One such set is the platinum group metals, which include ruthenium, rhodium, palladium, and iridium. Dug up as byproducts of platinum in South Africa and nickel in Russia, they're coveted for their catalytic properties, notably used in cars to turn toxic material into less harmful gases.

## Ruthenium

Around 2005, Toshiba, Western Digital, Seagate Technology and other companies started using more ruthenium to increase storage capacity on hard disk drives. The price soared almost 1,500% in two years, but "thrifting"—using less metal to achieve the same results—wiped out the rise by 2009. In 2016 the cloud-storage boom pushed prices higher again, but it's now hit a plateau as solid-state PC hard drives, which don't use ruthenium, gain in popularity.

Data: Compiled by Bloomberg

## Rhodium

Rhodium was once a favorite of carmakers, who put it in catalytic converters. But around 2003 they found themselves bidding against Sony Corp. and other manufacturers of flatscreen TVs. The price soared 2,000% in five years, only to crash by 90% when car companies started using less and the global financial crisis struck. There was a short-lived recovery in 2009-10, driven by speculators. Lately, they're betting that auto executives, despite being burned before, will get back in the game.

Data: Compiled by Bloomberg

## Palladium

With palladium significantly cheaper than platinum in the 1990s, automakers started shifting to it for gasoline engines. Supply disruptions in Russia around 2000 led to an acute shortage and a price spike, followed by depressed prices as Soviet-era stockpiles were sold off. Automotive demand grew, and, starting in 2012, the world produced less than it consumed for seven straight years. There was a 60% rise in futures in the past year, the largest among 35 key commodities Bloomberg tracks.

Data: Compiled by Bloomberg

## What If You Eat It?

A silver pellet.Photo: SPL/Science Source

- *Who eats silver?*
  Colloidal silver—small particles suspended in liquid—was sometimes promoted as a cure-all for hundreds of ailments. But the FDA warned in 1999 that it isn't safe or effective.

- *What does it taste like?*
  People describe it as being like "water with a faint metallic taste."

- *What does it do?*
  Overexposure causes a condition called argyria, which turns the skin a bluish purple. *—Silvia Killingsworth*

Cadmium $2.90/kg, metal, U.S. market

## Of Crabs and Lichen

A selected list of products that made news in 2019 for containing elevated levels of cadmium, a pervasive environmental contaminant that can, with prolonged exposure, cause bone and kidney damage, as well as some cancers:

- Plush pencil cases and cartoon-character backpacks sold on Amazon by third-party vendors; Amazon removed them, issued refunds, and agreed to stronger monitoring protocols

Blue crab.Photographer: Prarinya Thonghyad/Alamy

- Giant mud and blue swimmer crabs harvested from Lake Macquarie, Australia
- Faux-pearl buttons found on River Island check-pattern dresses and sleeveless blouses; the label recalled the garments
- Decorative enamels used on a variety of beer, wine, and liquor bottles in the U.K.
- Diatomaceous earth (a soft sedimentary rock) used for filtration in some wine and beer production
- *Xanthoparmelia scabrosa* (aka “sexy pavement lichen”), available on Alibaba as a purported performance enhancer for men

*Xanthoparmelia scabrosa*.Courtesy D.M.Wright/Lichen Herbarium

Indium $310/kg, free-market price
Tin $16.18/kg, London Metal Exchange cash spot

## How Tin Made the World

By Matthieu Aikins

A bronze ingot from Cyprus.Courtesy Metropolitan Museum of Art

In 1982 a sunken merchant ship from the 14th century B.C. was discovered off the coast of Uluburun, Turkey. Made of cedar and oak, and almost 50 feet long, it was remarkable for the breadth of its cargo. Aboard were goods from at least nine cultures: glass, ebony, elephant ivory, hippopotamus teeth, pine nuts, safflower, pottery, 10 tons of copper—and one ton of tin.

The shipwreck demonstrated that trade routes across continents were already flourishing during the Bronze Age, linking cultures thousands of miles apart. Tin was one of the catalysts. The era draws its name from the fourth millennium B.C. discovery by smiths in Mesopotamia and the Iranian Plateau that alloying copper with a second metal made it stronger, easier to cast, and more resistant to corrosion. The earliest bronzes were made with arsenic, but tin’s superior properties—it didn’t give off toxic fumes when heated, for example—eventually made it the favored alloy.

The strongest bronzes were only about 10% tin, but the element soon became one of the ancient world’s most precious substances. Bronze tools built the first cities, and bronze weapons destroyed them. During the first battle recorded in detail, at Megiddo (in present-day Israel) circa 1500 B.C., Pharaoh Thutmose III crushed a rebellious Canaanite army using bronze weaponry. In the Iliad, Achilles’ armor is forged from copper and tin by Hephaestus, Greek god of smiths. Classical astrologers associated tin with Jupiter, the mightiest of planets.

But tin is rare—30 times less abundant than copper in the Earth’s crust—and unevenly distributed. Where

did ancient tin come from? There are no records of major deposits in the northeastern Mediterranean nor in Ancient Egypt. Sumerian texts speak of tin from the east, but there's no record of its being mined in the Indus Valley Civilization, in present-day Pakistan, either. Even well after the Bronze Age, Herodotus' Histories spoke of India's abundant gold, Arabia's incense and spice, even Ethiopia's ebony. Yet he could only allude to "Tin Islands, where our tin is brought from," and about which he knew nothing more.

By the first century A.D., some of the picture was being filled out. The Roman Empire had discovered mines in present-day Cornwall and on the Iberian Peninsula that had likely supplied much of Europe and the Mediterranean. Texts and archaeological digs suggest that tin traveled from Afghanistan west to Mesopotamia and southeast to the Indus Valley. But little more was known until recent decades, when scientific techniques began to trace ancient trade networks with greater certainty.

By analyzing the proportion of different lead isotopes in ore samples taken from sites known to have been exploited in antiquity, researchers have developed "fingerprints" they can match to the metal in some artifacts. The technique, known as lead isotope analysis, has been around since the 1960s, but it's been challenging to apply to tin because there are very few Bronze Age samples, and cassiterite, the metal's primary ore, doesn't generally contain much lead.

Data: Berger et al 2019

Recent advances in lead isotope analysis, however, combined with the study of antimony, indium, silver, and other elements, have let researchers link mid-16th century B.C. tin ingots found in Crete with tin deposits in Afghanistan and Tajikistan, and 13th to 14th century ingots from present-day Israel to Cornwall and the Iberian Peninsula. Researchers publishing in the journal PLOS One this year traced the east-to-west shift in tin supply routes to the decline of the Minoan civilization and the rise of the Mycenaeans, who laid the foundations for Classical Greece.

As for the Uluburun shipwreck, the same researchers lamented that its tin ingots were too corroded for reliable analysis. The best they could say, based on the samples' low concentration of indium, was that the tin likely didn't come from Cornwall. With improvements in the science, the picture may fill out more—for now all that's certain is that traders valued it enough to bring it a long way before it met its watery end.

Antimony $8.60/kg, metal

## Explosive Liquid Droplets

By Dimitra Kessenides

Three large fireworks demonstrate the brocade effect and, below that, the glitter effect.Courtesy Thomas H. Handel

Those three words, from a seminal 1978 paper by Nevada biology professor and amateur pyrotechnician Robert Winokur, describe the liquid molten pellets packed with antimony trisulfide that create a glitter effect when ignited. "As the pellets fall through the air, chemistry goes on," says Winokur, now retired. "Then an

array of combustion products are produced by the burning pellet.” There isn’t one magical recipe for the best glitter effect, Winokur says—a typical formula consists of 10% antimony trisulfide, which “increases the delay between the formation of the droplet and the flash reaction.” These days, he adds, a similar effect can be achieved using cheaper, more sulfurous mixes.

Glitter-effect diagrams.Courtesy Robert Winokur

Tellurium $50.50/kg, 99% metal, Rotterdam market

## What If You Eat It?

Tellurium.Photographer: Bjorn Wylezich/Alamy

- *Who eats tellurium?*
  Very few people; it’s more of an occupational hazard for people working in silver refineries.

- *What does it taste like?*
  If touched or consumed, the metalloid will instantly metabolize into a compound with a strong garlic smell that can hang around for weeks.

- *What does it do?*
  Tellurium exposure can cause weight loss or drowsiness, and severe poisoning can slow breathing and stop circulation. *—Silvia Killingsworth*

Composition

## Laser

Lasers are both potent and mundane, high-energy beams that can be used to operate on eyes, precision-cut metal for appliances, and scan bar codes at the corner store. “Light amplification by stimulated emission of radiation” neatly describes how the technology works: Energy is applied to a medium—such as a crystal wafer, liquid solution, or gas—whose particles become stimulated and emit light. Mirrors capture and amplify that light into an intense beam. *—E. Tammy Kim*

Photographer: Daniel Shea for Bloomberg Businessweek. Product courtesy Trumpf Lasers

Iodine

## Salting the Earth

Data: Iodine Global Network

Even as noniodized sea salts are gaining popularity in the U.S., iodization has been a public-health success story globally—ensuring proper body and brain development and preventing issues such as goiters and hypothyroidism. The Iodine Global Network, an alliance of governments, nongovernmental organizations, and industry partners, estimates that a $1 donation provides enough iodized salt to sustain 100 participants in its programs. *—Jeremy Keehn*

Xenon $25/liter, 200-liter cylinder

## More Hong Kong Lights

By Tommy Trenchard
Brian Kwok, an assistant professor of design at Hong Kong Polytechnic University, has spent the past six years documenting and working to preserve what remains of the city's neon lights. He says the government should safeguard the more iconic signs, much as it does other parts of the city's artistic and cultural heritage. He's helped develop an interactive map of Hong Kong's last neon signs and gives walking tours and museum talks to raise awareness of the works. "If nobody documents them, we'll be losing an important part of our visual culture," he says. "But we have to do it fast—it's a race against time."
Xenon emits a bright lavender light. Although rarely used on its own, it's sometimes combined with other noble gases to create a variety of colored lights. The gas also is used to make strobe lights and flash lighting for cameras.Photographer: Tommy Trenchard for Bloomberg Businessweek

Cesium $78,700/kg, 99.98% metal basis

## Chernobyl in the Food Chain

By Aine Quinn
Some of the particles released by the 1986 explosion of Reactor 4 at Chernobyl are no longer radioactive, but one isotope, cesium-137, still is. Winds deposited the material on dry ground nearby in Ukraine, Belarus, and Russia after the accident; a toxic cloud carried more as far away as Ireland. Mixed with rain, it soaked into the ground: "The highest depositions occurred where you had the highest rainfall," says Nick Beresford, a professor at the Centre for Ecology & Hydrology in Lancaster, U.K. Plants and fungi take up cesium from the soil, and if animals eat them, their meat can be contaminated. Consuming a lot of this meat can cause a moderately higher incidence of cancer, though Jim Smith, a University of Portsmouth professor who's doing crop experiments near the plant, is quick to note that cesium is "not a massive risk" for the people affected, compared with other environmental hazards.

## Norway

Photo: Alamy

Scientists monitor about 90,000 sheep in more than 30 municipalities during the summer season, taking

weekly milk samples from ewes to measure radioactivity. If levels are too high, says Runhild Gjelsvik, a scientist at the Norwegian Radiation and Nuclear Safety Authority, flocks are brought down from the hills and given uncontaminated feed until they can be safely slaughtered. Cesium-137 levels in sheep have dropped steeply since 1986, but they rose last year thanks to an abundance of wild mushrooms.

## Sweden

Photo: Alamy

Hunters can pay up to 800 kronor ($83) to have boars they shot in riskier areas checked before butchering, according to Per Zakariasson from the Swedish Association for Hunting and Wildlife Management. Last year a wild boar in Uppsala County was found to contain more than twice the legal radioactive cesium limit for boar meat. “The anxiety of the people is a problem. It’s a problem when good, fine meat is thrown away,” Zakariasson says. Authorities have also been monitoring radiation levels in reindeer herded by the indigenous Sami people, who eat a lot of the meat.

## Ukraine and Belarus

Photo: Alamy

In the so-called exclusion zones of Ukraine and Belarus, agriculture and forestry remain officially banned, though Smith says recent research shows contamination levels are very diverse. Greenpeace researchers recently found radioactivity levels in milk from some private households and farms in a resettlement area 200 kilometers from the Chernobyl plant were up to six times higher than Ukraine’s legal limit. In 2017, France rejected a shipment of mushrooms from Belarus that showed traces of radioactivity connected to Chernobyl.

Barium $62.55/kg, barium sulfate

## Swallow Study

By Silvia Killingsworth

A colored barium-swallow X-ray of a 65-year-old’s abdomen shows a gastric ulcer at lower center.Photo: Zephyr/Science Source

Should you find yourself in need of a live video X-ray of your upper gastrointestinal tract, you have my sympathies. Bracco Diagnostics Inc. manufactures a product called Varibar, a liquid suspension of barium sulfate that comes in an array of flavors and consistencies: thin liquid, nectar, honey, thin honey, and pudding. None can quite mask the reality of ingesting a chalky, room-temperature drink the consistency of a watery milkshake, but taste isn’t the point. Barium on its own can be toxic to humans, but in this form, it’s insoluble and serves as a contrast agent. It shows up white on the X-ray, allowing a doctor to visualize your

digestive tract as you swallow. Just try to keep it down.

Lanthanum $5.03/kg, metal, Shanghai market
Cerium $4.89/kg, metal, Shanghai market
Praseodymium $98.40/kg, metal, Shanghai market
Neodymium $56/kg, metal, Shanghai market
Promethium Price not available
Samarium $1.77/kg, 99.9% samarium oxide, China market
Europium $32.56/kg, 99% europium oxide, China market
Gadolinium $26.97/kg, 99.99% gadolinium oxide, China market
Terbium $744/kg, metal, Shanghai market
Dysprosium $326/kg, metal, Shanghai market
Holmium $55.57/kg, 99.5% holmium oxide, China market
Erbium $24.85/kg, 99% erbium oxide, China market

## Greenland's Rare-Earth Minerals Make It Trump's Treasure Island

Photographs by Kiliii Yüyan / Text by David Stringer
The country's hostile wilderness becomes a new front in the trade war. Read Story
Video: Kiliii Yuyan for Bloomberg Businessweek

Thulium $12,000/kg, 99.95% pure sample on Amazon.com

## (Mostly) Useless

By Samanth Subramanian

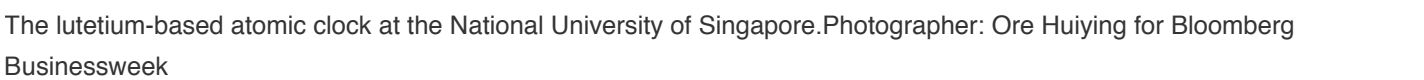
- What's it look like?It's silvery and shining if preserved in an ampoule of an inert gas such as argon.
- Why's it (mostly) useless?Thulium occurs at 0.5 parts per million in the Earth's crust, and it's difficult and expensive to extract.
- What's it used for?Arc lights use thulium to provide soft green light. Euro banknotes contain traces of thulium and other elements that fluoresce under ultraviolet light, for security. Max Whitby, founder of Red Green & Blue Co. in London, which sells periodic tables that hold element samples, says he once heard of toothpaste containing thulium, but he hasn't been able to track down the brand.
- Can I get some?Why yes. A 99.95%-pure gram sample costs $12 on Amazon. A Sunmaster Full Nova 315-watt lamp, which includes not just thulium but dysprosium in its arc element, costs $109.85. A €10 banknote costs €10.

Ytterbium $15.50/kg, 99.99% ytterbium oxide, China market
Lutetium $609/kg, 99.9% lutetium oxide, China market

## The Race to Build the World's Most Precise Clock

By Adam Minter

Lutetium and ytterbium are vying to become the beating heart of science and the global economy. Read Story



The lutetium-based atomic clock at the National University of Singapore.Photographer: Ore Huiying for Bloomberg Businessweek

Hafnium $775/kg, hafnium, unwrought

Tantalum $245/kg, 99.95% tantalum metal f.o.b., China market

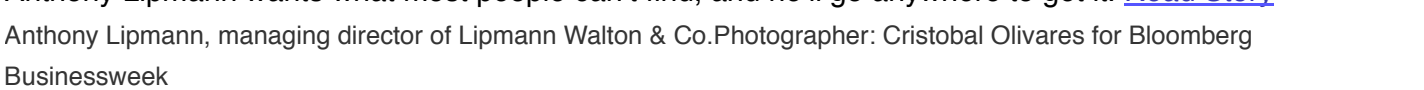
Tungsten $200/MTU (metric ton unit), 88.5% tungsten APT, Rotterdam

Rhenium $2,844/kg, Engelhard spot

The Metals Hunter Scavenging the Globe for Nature's Rarest Elements

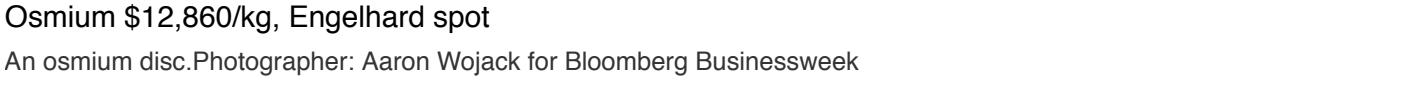
By Eddie van der Walt, Mark Burton, and Laura Millan Lombraña

Anthony Lipmann wants what most people can't find, and he'll go anywhere to get it. Read Story



Anthony Lipmann, managing director of Lipmann Walton & Co.Photographer: Cristobal Olivares for Bloomberg Businessweek

Osmium $12,860/kg, Engelhard spot



An osmium disc.Photographer: Aaron Wojack for Bloomberg Businessweek

## Disco-Dancing German's Secret Lab Could Disrupt the Diamond Industry

By Austin Carr

Ingo Wolf is trying to spark demand for one of the rarest elements on the planet. Read Story

Iridium $47,583/kg, Johnson Matthey spot

Platinum $27,521/kg, Johnson Matthey spot

## More Elements That Go Boom and Bust

By Eddie van der Walt

## Iridium

The market for iridium—primarily used in sparkplugs and in crucibles for growing crystals to make light-emitting diodes (LEDs)—is much smaller than those for other platinum-group metals; only 7 tons were consumed in 2018, vs. 214 tons of palladium. But iridium still sees jumps—its price rose 150% from 2010 to early 2011, as use in phones and other tech soared. The price slumped starting in 2013 as recycling met demand from phone manufacturers, then climbed again with rising use in the clean production of other

chemicals.

Data: Compiled by Bloomberg

## Platinum

Platinum's mid-2000s price spike resulted from a shortage caused by increased use in catalytic converters for gasoline and diesel engines. As it reached record highs in early 2008, the financial crisis struck, carmakers reduced their use, and speculators sold off holdings. Shortages returned and prices went up again for a few years until around 2012, when demand for platinum jewelry declined. In 2015, the Volkswagen AG emissions-testing scandal further hurt the weak market for diesel cars, creating more surpluses and lower prices again.

Data: Compiled by Bloomberg

## Some That Glitters Is Recycled

Photos and text by Carlotta Cardana

In a twist on the old saying "One man's trash is another man's treasure," the organizing committee of the 2020 Summer Olympics has harnessed the recycling fervor of Japan's citizenry to source precious metals for the medals that will be awarded at next year's games. A two-year collection drive that wrapped in March netted almost 79,000 tons of consumer electronics. The labor-intensive process of mining metals from the discarded gadgets has yielded 32 kilograms of gold, 3,500kg of silver, and 2,200kg of copper and zinc—enough to produce more than 5,000 medals.


Unveiled in July, the gold medal designed for the Tokyo Games contains just 6 grams of the precious metal—the minimum required under guidelines issued by the International Olympic Committee. The rest is silver.Courtesy Tokyo 2020


Yellow collection boxes, like this one at a government building in Tokyo, were installed at post offices and on street corners across Japan.Photographer: Carlotta Cardana for Bloomberg Businessweek

More than 6.2 million handsets were donated to the Medal Project.Photographer: Carlotta Cardana for Bloomberg Businessweek

Employees at a facility in Kawasaki owned by Field Environmental Service Inc., one of 50 companies contracted to process the e-waste. A handset’s circuit board contains tiny quantities of precious metals.Photographer: Carlotta Cardana for Bloomberg Businessweek