

## Why the Periodic Table of Elements Is More Important Than Ever

*Mendeleev's 150-year-old periodic table has become the menu for a world hungry for material benefits.*

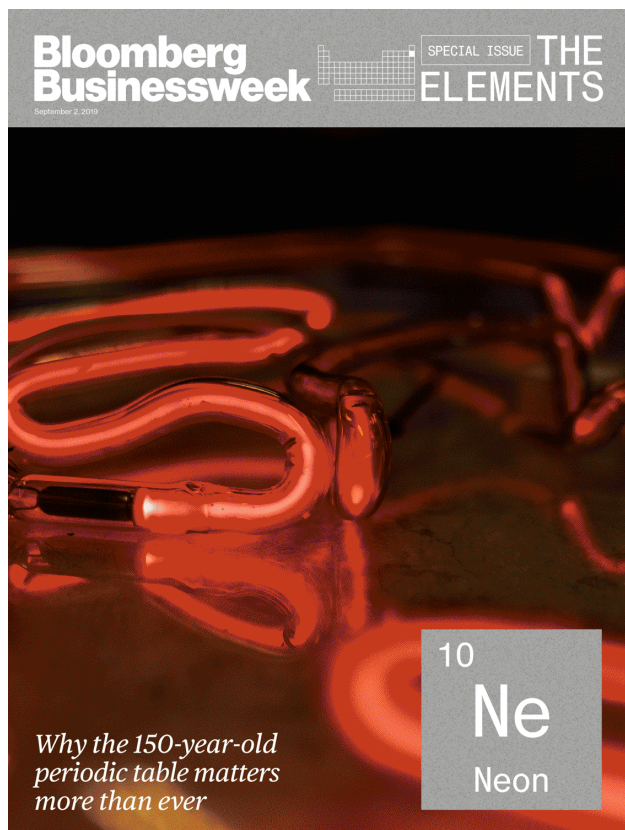
1 H Hydrogen																	2 He Helium									
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon									
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon									
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton									
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon									
55 Cs Cesium	56 Ba Barium											81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon									
87 Fr Francium	88 Ra Radium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury								118 Og Oganesson								
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*Illustration: 731 By Peter Coy August 27, 2019, 9:01 PM PDT Corrected August 28, 2019, 12:06 PM PDT*

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.

True, technology has made the economy more virtual, but it’s also vastly increased the capability and sophistication of material objects. Much of the enhanced efficacy of jet engines, computer chips, and medicines comes down to what they’re made of: the elements. Need a superstrong magnet for a hard disk drive? Try [neodymium](#). A material to absorb neutrons in a submarine’s nuclear reactor? Hafnium. A spark-proof wrench? Beryllium. A contrast agent for magnetic resonance imaging? Gadolinium. Even Fuller’s ephemeral world of software and ideas lives on very real computers, servers, and fiber-optic networks, which are built from Mendeleev’s famous table.



*Featured in Bloomberg Businessweek, Sept. 2, 2019. [Subscribe now](#). Photographers: Tommy Trenchard (neon), Shawn Records (sodium), Christie Hemm Klok (berkelium), Carlotta Cardana (gold), and Kili Yuyan (neodymium) for Bloomberg Businessweek*

Over the past century and a half, but particularly since World War II, scientists and engineers have learned to treat the periodic table like a banquet table—a bountiful spread from which to pluck what they need. There's [scandium](#) in bicycle frames, tin (stannous fluoride) in toothpaste, tungsten in catheters, and [arsenic](#) in some computer chips. We are well past the Stone Age, the Bronze Age, and the Iron Age, and into the Everything Age, because almost every entry on the periodic table is being put to some kind of use in today's economy (excluding [synthetic elements](#) that are costly to make and highly radioactive, such as einsteinium).



*Produced in 1984, the Motorola DynaTAC 8000x was the first mobile cellular phone.*

*Photographer: Chris Willson/Alamy*

Cellphones exemplify the complexification. The first ones in the 1980s “were the size of a shoebox and consisted of 25 to 30 elements,” Larry Meinert, U.S. Geological Survey deputy associate director for energy and minerals, said in 2017. “Today, they fit in your pocket or on your wrist and are made from about [75 different elements](#), almost three-quarters of the periodic table.” That may include tantalum from Rwanda, potassium from Belarus, [silver from Mexico](#), tin from Myanmar, carbon from India, and germanium from China.

Nuclear medicine is another example, highlighted in a 2013 [article](#) in the journal *Resources, Conservation & Recycling* by Thomas Graedel and Aaron Greenfield of Yale's

Center for Industrial Ecology. In 1936 doctors used isotopes of phosphorus and [sodium](#) to treat leukemia. In 1939 they pioneered an isotope of iodine for thyroid imaging and treatment. In 1957, xenon for lung ventilation studies. Around 1964, technetium for skeleton and heart muscle imaging. And so on up to 2008, when an isotope of [lutetium](#) came into use for prostate cancer applications.

In exploiting more of the elements available to us, we're following the course of our evolution as a species. Over millions of years, our body has evolved to take advantage of 30 or more members of the periodic table, stuff from the environment that's now incorporated in ourselves. Most of what we are—96%—is carbon, oxygen, hydrogen, and nitrogen. But our bodies also use, and are composed of, calcium, chlorine, magnesium, phosphorus, potassium, sodium, and sulfur, plus trace amounts of boron, chromium, cobalt, copper, [fluorine](#), iodine, iron, manganese, molybdenum, selenium, silicon, tin, vanadium, and zinc, among others.

As our first factory, our bodies are a good role model for product engineers and materials scientists. One lesson is that quantities matter. Cobalt, for example, is part of vitamin B12, which is essential to protein formation and DNA regulation. But in excess, it's a poison. Another lesson is that there's still a lot to learn. Biologists are trying to figure out the usefulness, if any, of a couple of dozen other elements that are found in the body in even smaller quantities.



*Mendeleev Photo: Heritage Image Partnership Ltd /Alamy*

Before “better living through chemistry” became a slacker reference to recreational drug use, it was a slogan of DuPont, an earnest invocation of putting the periodic table to good use. There was a lot to be proud of. Modern chemists are a big step up from medieval alchemists, who futilely tried to transmute lead into gold. Mendeleev’s creation of the periodic table helped usher in a golden age of chemistry, in which Germany was an early leader. In 1910, German Carl Bosch scaled up his countryman Fritz Haber’s process for reacting nitrogen from the air with hydrogen to make ammonia, the main ingredient in fertilizer. Crop yields soared, making it possible to [feed more people](#) even with fewer people working on farms. If you work in an office today rather than on a farm, thank Haber, Bosch, and the fixation of nitrogen. (On the downside, Haber also weaponized chlorine as a poison gas in World War I.)





*Dr. Earth Nitrogen Fertilizer. Source: Dr. Earth*

As the nitrogen story goes to show, it's not only hard-to-find elements that have been put to new uses. Silicon Valley was built on a foundation of common silicon, the second-most abundant element in Earth's crust after oxygen. Another common element—hydrogen, the most abundant in the universe—could one day save the planet by [arresting climate change](#). Right now hydrogen is mostly produced from natural gas, along with some coal, in processes that each year emit as much carbon as the combined emissions of the U.K. and Indonesia, according to the International Energy Agency. But hydrogen can also be derived from plain water with a jolt of electric current, producing nothing but oxygen as a byproduct. That hydrogen can later be recombined with oxygen in a fuel cell to produce power for a spaceship or car. The only thing that comes out of the tailpipe is water.

Hydrogen, in other words, can function as the ultimate clean energy carrier. The key for the environment is to find cheaper and cleaner ways to generate the electricity that electrolyzes water. Solar power seems like a good candidate. Hydrogen is also the main actor in another planet-saving technology, the nuclear fusion

reactor, which (someday) will fuse hydrogen atoms into [helium](#) and emit clean energy.

## Where Elements Are Found

Data: Arizona State University, "The Composition of the Earth" (W. McDonough), NASA, Geological Survey of Norway

The modern drive for elements has brought new pitfalls, such as new forms of scarcity. Wood, the substrate of an earlier era, may not be a miracle material, but at least it's [easy to get](#). Today's technology is vulnerable to disruptions of supply chains that extend to the corners of the Earth. China is the dominant supplier of [rare-earth metals](#), a group of 17 elements used in advanced magnets, batteries, and other devices. A single Virginia-class attack submarine in the U.S. Navy uses almost 5 tons of them.

If the free market is working efficiently, impending shortages of elements should be corrected by rising prices, which discourage consumption while encouraging more production or the development of substitutes. As the market saying goes, the cure for high prices is high prices. Biologist Paul Ehrlich, author of *The Population Bomb*, famously lost a bet to economist Julian Simon when he predicted in 1980 that the prices of chromium, copper, nickel, tin, and tungsten would rise over the following decade. All five got cheaper.

But there are reasons not to trust the market entirely. One is national security. If war threatened to break out between the U.S. and China or Russia, no price would be high enough to entice those foes to supply the U.S. war machine with raw materials. War is often the result when a country can't get the natural resources it needs. Resource-poor Japan occupied Manchuria before World War II to get its iron ore. Germany, lacking in just about every resource but coal, sought Lebensraum—literally, "living room"—to grab cobalt, copper, iron ore, petroleum, rubber, tungsten, and bauxite for aluminum. The Axis powers eventually lost in

part because the Allies cut off their access to those critical raw materials.



*Native gold. Photo: SPL/Science Source*

Saleem Ali, an environmental planning professor at the University of Delaware, argues for an international treaty to prevent a repetition of “old colonial scrambles for wealth,” which he points out have occurred not only with minerals but also with sugar, spice, and vanilla.

Market forces can also respond too slowly. Yale’s Graedel, a professor emeritus of industrial ecology, estimates that it takes 15 to 30 years to bring a new mine into commercial production. Expedited permitting would help with that, he says, as long as it doesn’t open the door to abuses by mining companies. Ironically, the green economy depends on many elements whose production is anything but green. Without strong global standards, the free market could push

production to the countries that do the least to protect the environment.



*Carbon powder. Photographer: Charles D. Winters/Science Source*

Both economics and geopolitics will drive the world toward greater reuse of elements. Recycling will be built into the design of products. That will favor the elements that are most adaptable. “Carbon, which can be as soft as graphite or as hard as diamond, may be the material of choice,” Jamais Cascio, a research fellow at the [Institute for the Future](#), a think tank in Palo Alto, Calif., wrote in 2012. “Instead of worrying about minimizing carbon outputs, we may find ourselves working to maximize carbon inputs,” he added.

The value of the world’s output keeps going up in terms of dollars per ton—more value for less mass. But Buckminster Fuller was wrong. Technological progress isn’t ephemeralization. It’s invention—and there’s no clearer example of invention than the exploitation of Mendeleev’s table of elements.

*This story is from Bloomberg Businessweek’s special issue [The Elements](#).*

(Corrects the most abundant element in Earth’s crust in 10th paragraph.)