# LIVING IN A MATERIAL WORLD: THE SURPRISINGLY GRIPPING TALE OF SIX NATURAL RESOURCES

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Sand. Salt. Iron. Copper. Oil. Lithium. These, not petabytes or algorithms or ideas, are the building blocks of human life as we know it. At least that's what Ed Conway, author of *Material World*, tells us. And, without these basic materials, we couldn't have much of anything else, certainly not petabytes of information or algorithms for manipulating them.

Materials science is the science of finding, extracting, refining, processing, and combining these. It is thus the fount of all technology and the *sine qua non* for our standard of living.

There are only two physical "things" in the universe — matter and energy. At this particular time in history, we're focused on energy because we don't have enough of it. The world's energy output will have to triple by the end of this century to meet the demands of a still-growing population that gets wealthier (consumes more energy) every year.

But where do we get the energy? From *materials*… which are used to drill for oil and coal, mine uranium and build reactors, make solar cells and wind turbines, and transmit electric power over long distances. That's a lot of materials! Then we use more materials to build all the things that are powered by energy.

Yet materials science tends to be unloved. It's widely viewed as a prosaic discipline that keeps engineers busy while the rest of us can ignore it or take it for granted.

But, by the time you are done reading Conway's book, you will love materials science. You won't believe how important, complex, and beautiful it is. Conway is a master at taking the seemingly mundane and finding the sublime hidden in it. In that regard, he's a little like the great Michael Lewis, of whom it's been said that he could write an 800-page history of the stapler and you would read every word of it.

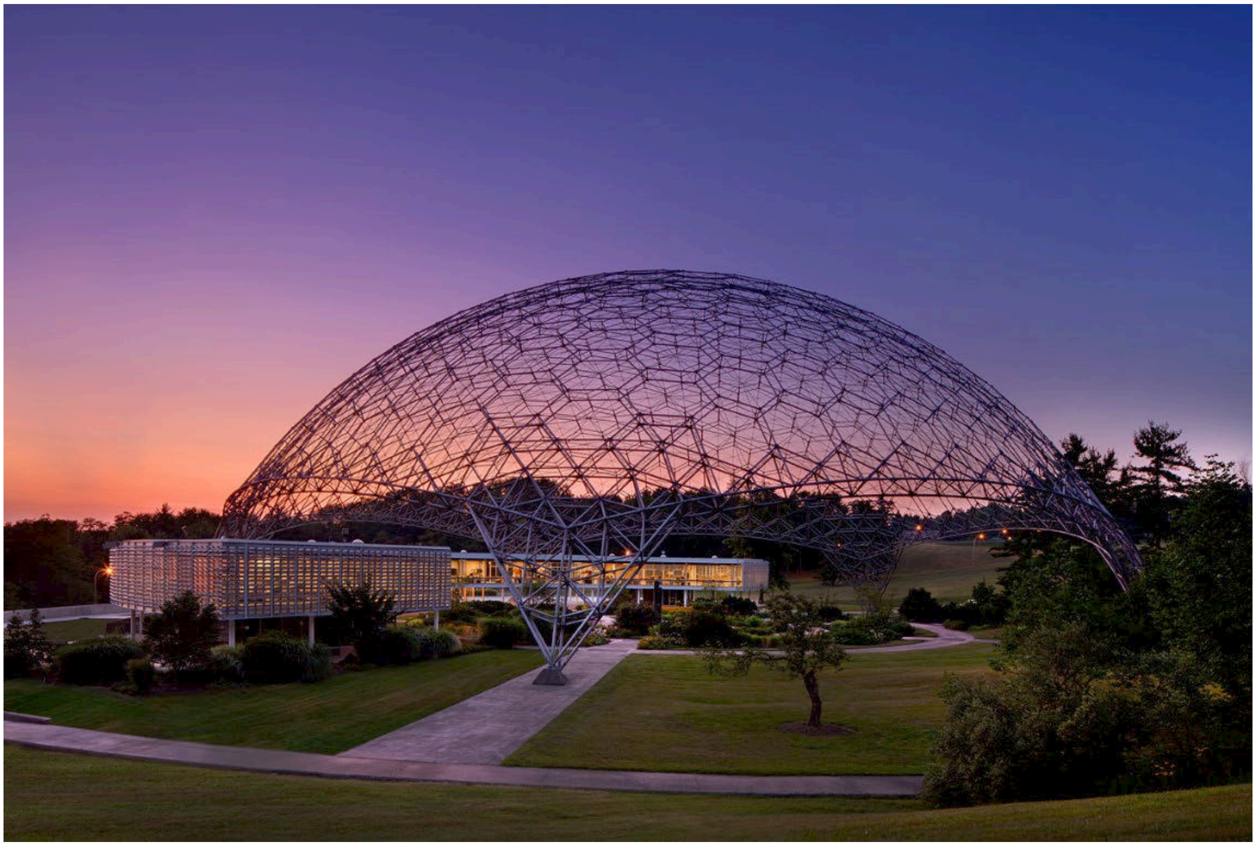
I cannot recommend this book enough.

## MATERIALS SCIENCE IS BOTH VERY OLD AND FAIRLY NEW

Materials science is as old as the first cave man or woman who found a bone and sharpened it to make an arrowhead. Yet, as a standalone scientific and engineering discipline, it's new. It grew out of metallurgy and mineralogy, which are ancient, and chemistry and physics, which are hundreds of years old, but did not take on its modern form until the last half-century.

Near where I grew up in Cleveland, there's a majestic structure, shown in Exhibit 1, that was the headquarters of the American Society for Metals. Only in 1986 was the venerable organization's name changed to ASM International, with ASM standing for "American Society for Materials." The structure now lies (without having moved) in Materials Park, Ohio. These name changes reflect the growing importance of nonmetallic or metalloid elements (silicon is one), ceramics, polymers, and biomaterials. Those, along with metals, comprise the "material world" that Conway's book lovingly explores.

### EXHIBIT 1
### THE TEMPLE WHERE MATERIALS SCIENTISTS GO TO WORSHIP



Source: ASM International.

## ABOUT THE AUTHOR AND HIS RESEARCH TECHNIQUES

The book is remarkable enough without delving into how it was researched, but an offhand comment by the British economics blogger Giles Wilkes piqued my interest: "Somehow in the course of three years' research, Ed [Conway] visited copper mines, semiconductor foundries, blast furnaces, shale wells, lithium salt flats, [and] the place where polythene was invented." For example, Conway's chapter on semiconductor chip manufacturing takes us from Santiago de Compostela, Spain where a certain type of quartz (the mineral that gives us silicon) is found, to a small town in Germany, then China, then the banks of the Columbia River in Oregon, then a mountainside in North Carolina, and finally to Taiwan, where the giant company Taiwan Semiconductor produces the chip (consisting of billions of transistors so small that four of them would fit inside a COVID-19 virus).

I don't know that Conway visited all these places, but the book reads as though he did, containing details that would be hard to obtain in any other way. And he did all this while serving as economics editor of Sky News, the British television channel. I hope they didn't give him much else to do.

*Material World* is Conway's first book in nine years. His previous books, *The Summit* (about the Bretton Woods agreement) and *50 Economics Ideas You Really Ought to Know* (a lively collection of short takes),[1] didn't really catch on, so Conway has remained, until now, a mostly hidden talent. He will be hidden no more.

Edmund Conway

Source

## SAND

Let's return to the journey of silicon from raw material to final use. This time, however, we'll start 29 million years ago, as Conway does right at the beginning of the book. (Geologists love the past — the farther back the better — and geology is a major part of materials science.) Conway tells us of a place called the Great Sand Sea, on the border of Egypt and Libya, where a meteor strike in that prehistoric time turned the local sand to an uncommonly pure form of glass. This Libyan desert glass — discovered a century ago by an Irish explorer of the Sahara who heard a crunching sound under his tires — is 98% pure silicon dioxide (also called silica), meaning that the sand from which it was formed is also 98% pure, compared with 65% to 80% for most sand.

Why should we care how pure a sand dune is? Many uses of sand, such as for precision lenses and optical fiber, require nearly pure silica, and ingenious processes for purifying silica were invented long before anyone wanted to make a microchip. (Optical fiber is important — "the internet is made of glass," writes Conway.) But the purity standards for silicon used in today's chips sound like science fiction — it must be 99.99999999% ("ten nines") pure. That means that if more than *one in ten billion* of the atoms in the chip are not silicon, the electrons wending their way across the chip's etched surface will lose their bearings and your computer, phone, rocket ship, self-driving car, or microsurgical device repairing your heart will not work.

The process for getting from, say, 98% pure silica to "nine nines" is more science fiction, this time too detailed to summarize here. So I'll skip to the scary part: some of the steps on the path from sand to today's super-duper chips rely on materials that, as far as we know, exist in *only one place in the world*.

That place is Spruce Pine, near Asheville on the aforementioned North Carolina mountainside. There, two mines produce *all* of the silicon used in making the crucibles in which other batches of silicon, the ones destined to become chips, is purified. (In case you're confused, yes — silicon is purified in devices made of silicon. Don't ask.)

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[1] Full text online here.

A cloak-and-dagger atmosphere surrounds the mines, of course. And industry insiders worry that the mines are vulnerable. Conway writes:

> What if, say, the single road that winds down the mountain...to the rest of the world was destroyed in a landslide?... [O]ne veteran of the sector [said], "If you flew over the two mines in a crop duster loaded with a very particular powder, you could end the world's production of semiconductors and solar panels within six months." (p. 107)

We'd eventually find other sources and substitute materials, and the world would not end. But the short-run economic consequences would not be pretty.

And, just as I'm writing this, I read:

> A fireball illuminates the skies over Spruce Pine, NC on Aug. 30....According to the space agency, the event began about 45 miles above Piney Flats, Tennessee and moved south and eastward at an astonishing 31,300 miles per hour... [T]he asteroidal fragment weighed around 1,000 pounds and was about 2 feet in diameter... "The breakup produced an energy of 10 tons of TNT...," the agency said.

No real danger this time unless a fragment hit you in the head, but...close call.

## SALT

Everybody knows you can't live without salt. But there is a lot of salt in the world — in some places too much. After all, we're spending a bundle on desalination, making salt water into fresh water at a high cost in energy as well as money. "Water, water, every where / nor any drop to drink."[2]

Conway turns this perception on its ear. Salt has been so scarce in many places, and so desperately needed, that it has precipitated wars, motivated dangerous expeditions, and caused words like "salary" (salt allowance) to stand for sustenance itself. In England, archaeological remnants of the salt trade go back further than any other traces of business activity. Dating from a thousand years before Stonehenge (!), the salterns (salt factories) of southwest England form what he calls a "missing link between the agricultural revolution and everything that followed." The British of 6000 years ago were mass-producing products, "not for their own consumption but to trade or sell to others...Squint a bit," he writes, "and you can see the very origins of what some might call intellectual property, tech transfer, and...capitalism." (pp. 129-130)

Even mountain goats go to extreme measures in search of salt, risking their lives. (See Exhibit 2.) They can't live without it, and neither can we.

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[2] Coleridge, Samuel Taylor. 1798. Rime of the Ancient Mariner (but you knew that).

## EXHIBIT 2

## FOR SOME, GETTING ENOUGH SALT TO SURVIVE IS A ROCKY ROAD

Source

### A WORLD MADE HEALTHIER THROUGH SALT

Back to the present day. (Salt has become, in Conway's words, "the bedrock for the chemicals and pharmaceutical industry." He uses this observation as a launching point for an appreciation of what the DuPont company memorably called Better Living Through Chemistry. "While we celebrate the pioneers of steelmaking and steam power," Conway writes, "we have mostly forgotten the earliest giants of industrial chemistry, like [Nicolas] Leblanc or Ernest Solvay... [W]e have whitewashed most of our chemical heritage." I, for one, have forgotten them if I ever knew about them.

From salt, or with the help of salt, we obtain chlorine, which purifies our water; sodium bicarbonate, used for kidney dialysis; "cheap soaps and sanitary items" that reduce infection even more than antibiotics do; and myriad pharmaceuticals that keep us alive in the event of illness. "Look at the map of the world's pharmaceuticals and chemicals companies," Conway notes, "and you see that we are still following ancient salt routes." Who knew?

### A MULTITUDE OF SALTS

Over the last 250 years, a "salt" has come to mean any chemical compound made up of positively and negatively charged ions, and (typically) forming a crystalline structure. Sodium chloride (table salt) is only one of a huge number of salts. Common salts include sodium bicarbonate (baking soda), calcium sulfate (plaster of Paris), and iron salts such as ferrous sulfate (used to treat anemia). More exotic salts are used in industrial processes, medical treatments, and explosives.

But the most interesting salt product, discovered near Salzburg ("salt city"), Austria in 1818 but not commercially available until recently, is polyhalite. In Greek the word means "many salts," but the name is misleading. The deeply buried, 260 million year old mineral is not a mixture of several salts, but a single compound involving potassium, calcium, magnesium, and sulfur. And it just happens that this weird, rock-hard stuff, which breaks drill bits with regularity, is a near-miraculous fertilizer.

At a time of increasing concern about the energy requirements of nitrogen-based fertilizer extracted from the air using the Haber-Bosch process, polyhalite is a potential godsend. And, because it is simply dug out of the Earth, ground into grains, and sprinkled on crops, it can be sold as organic![3] (It does not contain any organic compounds.)

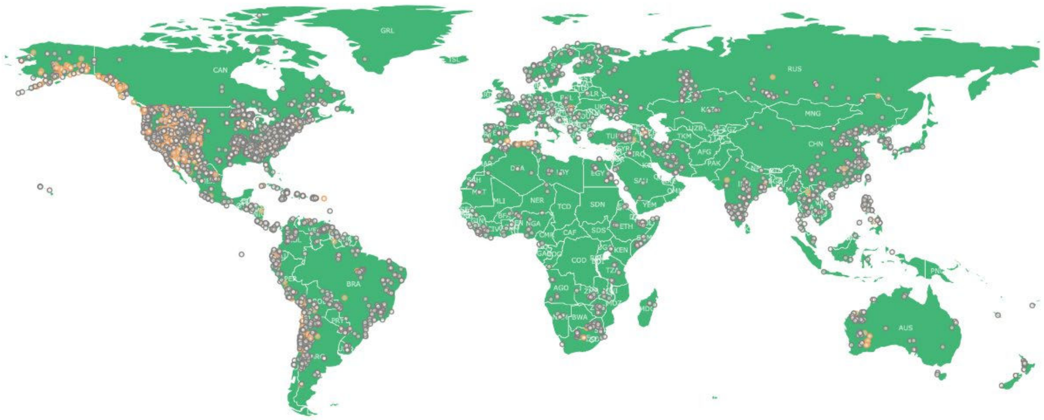
Nitrogen will still be needed, and at present polyhalite is only being mined in England. There's not enough of it to revolutionize agriculture a second time, the way the Haber-Bosch process did a century ago, but it's within the realm of possibility.

## IRON

Iron is the least mysterious of Conway's six materials. It has fewer magical-seeming properties than sand and salt. Iron ore is found practically everywhere, as shown in Exhibit 3. (Central Africa and central Asia are the exceptions; note how poor those areas are compared with most of the world). Because iron has a relatively low melting point of 2500° F., the technology for smelting it developed early, about 1200 B.C. (but not as early as for copper, which we'll get to).

### EXHIBIT 3

### THE STARTLINGLY WIDE DISTRIBUTION OF IRON ORE DEPOSITS



Source

The ancients didn't know *why* adding different amounts of carbon to molten iron produces a variety of useful alloys collectively called steel, but they knew how to do it anyway. We do know why, as Conway explains:

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[3] At least in the U.K., where Conway lives. I don't know about other countries.

> [A]…small disparity in carbon content makes such a big difference [because]…, in steel, those carbon atoms nestle neatly between the iron atoms creating a strong, immovable lattice. Too much carbon and the structure of the lattice is imperfect, so the metal can easily shatter (cast iron). Too little and the iron atoms can slide over each other without much resistance (wrought iron).

Yet the ancients, and their successors up until only a couple hundred years ago, knew nothing about atoms, much less the crystalline structures they form under various conditions. (Democritus famously conjectured that atoms exist, but he knew nothing about them beyond that.)

As is often the case, then, technology led science rather than the reverse; artisans and inventors make something useful, and then scientists try to figure out why it works. The crystalline structure of metals at the atomic level wasn't worked out until the twentieth century, more than 3000 years after the Iron Age began. That's a long wait!

For structural and toolmaking purposes, steel was far superior to iron. Thus, when the Industrial Revolution dawned in northwestern Europe in the 1700s, an ideal material for making machines already existed, although the demands of the machine age required higher grades of steel than had been previously available. Steelmaking and machine-making technologies thus grew in tandem, with better steel making it possible to build better machines, and new designs and uses for machines making it necessary to forge better steel.

Conway takes us on his usual Indiana Jones-like tour of the mines, mills, and factories he visited while researching the section on iron and steel, but I don't have the space to describe it any further. Just buy the book and read it.

The Material World we now live in is built around bones of iron. The flesh (and often the skin) is concrete, the brain is silicon, and the blood is oil. The nerves are copper, to which we turn next.

## COPPER

Before the Iron Age, before the Bronze Age, was a period that archaeologists sometimes call the Copper Age. It sounds fancier in Greek —"Chalcolithic," meaning copper and stone, and was transitional between the neolithic or late Stone Age and the more familiar Bronze Age, when written history begins. The first stirrings of the Copper Age were nine thousand years ago, when copper was first smelted and made into tools and weapons.

### THE REAL COPPER AGE IS NOW

Yet, Conway tells us, the real Copper Age is only two centuries old and still lies mostly in the future. The reason is twofold: copper is a superb electrical conductor, a fact that has been relevant only in modern times; and, even more importantly, Michael Faraday discovered in 1831 that by moving copper through a magnetic field, one could generate electricity. This is called electromagnetic induction.

Today’s movement to electrify everything, in the hope of limiting global warming, relies almost entirely on this principle. Almost every kilowatt of electrical energy produced on the Earth — solar panels being the major exception — is generated through electromagnetic induction. That is how coal, oil, gas, nuclear, hydroelectric, wind, and geothermal energy are all converted to electrical energy — each of these sources of raw power drives a generator, which produces electric current in the same way that Faraday did two centuries ago.

We are thus uncommonly dependent on a supply of copper and are quickly becoming even more so.

Where does copper come from? As with silicon chips, the answer is complex. A given ingot of copper is likely to have started its journey in the world’s largest copper mine, in northern Chile near the abandoned desert town of Chuquicamata — but, says Conway, the ingot

> [is] a cocktail of atoms from all over the world: a bit from Chile, a bit from Australia, some from Indonesia, some from the…Congo, some recycled from copper mined long ago somewhere else altogether. (pp. 267-68)

“Each slab,” he concludes, “is a physical manifestation of globalization.”

This victory for technology and global trade came at a price. Chuquicamata is abandoned because the mine by-products were toxic. Some died and many more were sickened. In addition, a little-remembered war was fought in the late 1800s between Chile, Bolivia, and Peru over resources in this region. (Chile won, and Bolivia lost its coastline.) The war is often blamed on nitrates, used for fertilizer, but copper was also a factor — and would become much more important in the region in the next century when the Haber-Bosch process made the search for naturally occurring nitrates less urgent.

## THE ECONOMICS OF COPPER

As one of the materials we will rely on more and more as we electrify the world, you might think that copper has gotten super-expensive. But, over the very long term, it has barely kept up with inflation! Exhibit 4 shows that, in real terms (today’s money), copper started the twentieth century at $10,000 per metric ton and is trading very close to that price now ($8,972 to be exact).[4] It was cheap at various times in between, including early in this century, which is where the impression of rapidly rising copper prices comes from.

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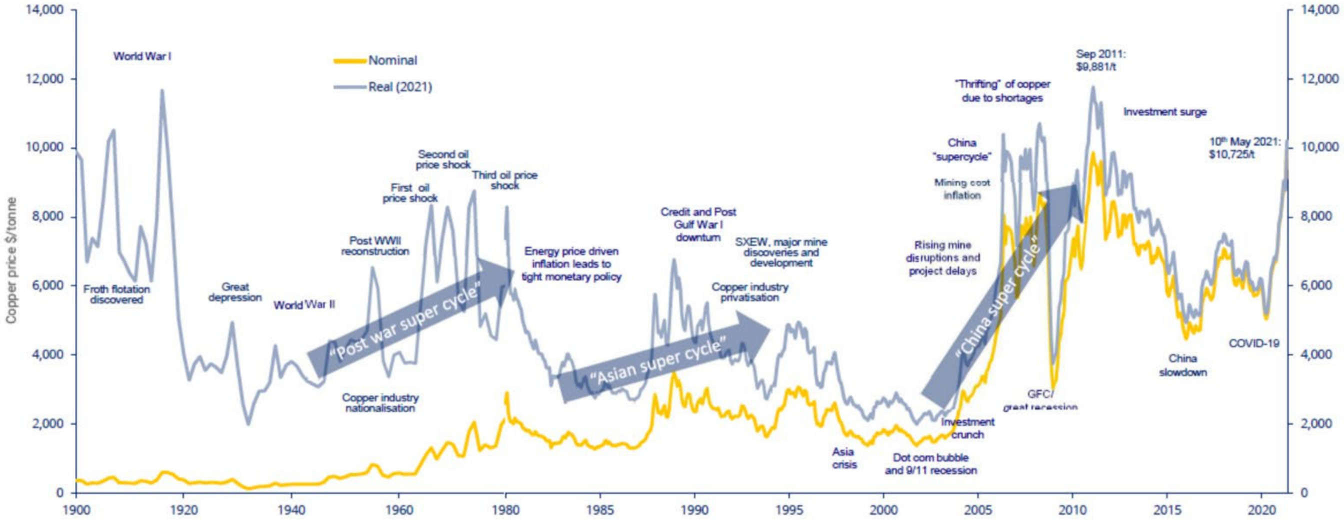
[4] Data as of September 9, 2024.

## EXHIBIT 4
## REAL AND NOMINAL PRICE OF COPPER, PER METRIC TON, 1900-2024



Source. Underlying source: US Federal Reserve, Roskill

The lesson for investors is that, when the expected demand for a commodity or other product or service seems to be unlimited, that does not mean you can easily make money. High prices stimulate the search for new supply as well as the discovery of substitutes such as aluminum and graphene.[5] Human ingenuity and the pursuit of profit solve most supply problems — eventually.

## OIL

I could write endlessly about oil, but I won't because Daniel Yergin has done a much better job of it and I recommend his work (although I've only read a little). Instead, I'll cut to the chase and summarize Conway's views on the oil issue that dwarfs all others: climate change.

Conway begins with the "good stuff" (his words) that oil has done. Since the mid-1800s when large petroleum reserves were discovered in Pennsylvania and in the Middle East, the world economy has boomed on a massive scale, something that had never happened before in the roughly 4000 years that petroleum was known to exist. The fruits of the Industrial Revolution began to benefit almost everyone as oil-powered railroads, then automobiles and airplanes, caused transportation costs to plunge, and oil-fueled electric generating plants made labor (especially household labor) radically easier and enabled us to communicate instantly and almost costlessly.

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[5] Graphene is a form of carbon, so it has the added advantage of being a permanent store of carbon removed from the atmosphere or captured at the point of emission.

The “bad stuff,” of course, is the environmental harm done by carbon emissions. Conway states that we are

> …[b]reaking a geological cycle that goes back more than 100 million years…[by] sending the carbon dioxide that was sequestered long ago into…underground reservoirs back into the atmosphere, precipitating a new age of global warming.

Conway notes — and I agree — that we are “utterly dependent” on oil for making literally billions of lives not only livable but *possible*. These additional lives exist because of the huge expansion in the food supply that occurred as oil made mechanized agriculture and synthetic fertilizers practical. Oil and gas, he writes, are tricky to replace because they are “an almost perfect energy source and a near irreplaceable feedstock into nearly every manufactured product.”

Then, noting that drastically reducing carbon emissions will be “very difficult,” he avers that “[i]t is possible.” And, as he turns his discussion from “black gold” (oil) to “a powdery white gold which promises to power the twenty-first century,” I likewise turn to that white substance with miraculous new uses, lithium.

## LITHIUM

The only one of Conway’s basic materials that was not known to the ancients, lithium was discovered in 1817 and was first used in batteries less than a century later by none other than Thomas Edison. It had uses in industry, medicine, and nuclear weaponry, but its sudden and recent importance in modern society arises from the effort to limit climate change. Rechargeable (lithium-ion) batteries are now needed on a massive scale, both for electric cars and to store energy from non-continuous power sources (wind and solar) for use when the wind is not blowing or the sun is not shining. If we can find enough lithium and if the Electrification of Everything goes as planned, we will be living not so much in a Material World as in a Lithium World…

…at least for a while. Before you go out and buy lithium mining stocks, you should know that scientists and engineers are working hard to develop substitutes, and progress is being made.

Much of the world’s lithium is concentrated in the same part of western South America as the copper I discussed earlier. According to the U.S. Geological Survey, one-quarter of the world’s known lithium resources are in Bolivia, and much of the rest is in Argentina, Chile, Australia, and China. The United States doesn’t have much. Fortunately, much of the world’s lithium is obtained from brine (water containing various salts), a process that is relatively easy, rather than mined out of the ground, which is hard.

Conway visited the world’s largest facility for extracting lithium from brine, which is in Chile near the Bolivian border. (Chile has an advanced economy by South American standards;

Bolivia, much less so.[6]) After describing the unbelievably dry and isolated location where the lithium is found, he reflects on the geopolitics of lithium:

> In much the same way as we talk today about petrostates like Saudi or Russia, the battery age is giving birth to a new era of *electrostates*: countries like Chile, Argentina, Australia and, of course, China, which will dominate the extraction and refining of these materials.

Rightly, lithium should be making Chile and Bolivia rich, but it is not — the "resource curse" seems to apply. Countries with abundant natural resources have always struggled to get ahead, possibly because extractive industries use a lot of low-paid workers while the tax revenue from resource extraction discourages governments from building a more diversified economy. With silicon, the big winners are engineers in Taiwan and California, not the owners of sand; likewise, with lithium, designers and manufacturers of high-tech batteries are prospering while those who extract the raw resources just get by.

An unexpected afterthought: Just as I'm writing this, a large lithium brine deposit has been discovered in northeast Texas. "It could rival South America's…Lithium Triangle," reports *Russell Gold in Texas Monthly*. So maybe the next electrostate will be the United States — it's far too early to know.

## ADVICE FOR INVESTORS AND CONCLUSION

Why should investors care about all this detailed knowledge of the basic materials industry? Because many of the companies in which we invest make money by mastering this kind of specialized knowledge. Unless we are experienced security analysts, we tend to think only about the last company in the supply chain — NVIDIA, for example, which makes chips for AI applications, or Tesla, a leading user of lithium batteries. But, mostly behind the scenes, the companies and people who discover new sources of raw materials and find better ways to make them useful are the heroes of our evolving Material World.

By the time I finished the book, I wanted to become a materials scientist. I've had a similar reaction to other great books on topics that I previously had only peripheral interest in — Stephen Jay Gould's masterpieces on biology, John McPhee's on geology, and others. *Material World* is in that category, and my recommendation to read it is a particularly strong one.

The most important message of Conway's book is that technological progress depends not just on innovation but on "the availability of the right kind[s] of [materials] in the right kinds of quantities." And, I'd add, in the right place or a way of getting them to the right place, combined with the knowledge, tools, and — surprise! — additional materials needed to refine, combine, and shape them into the desired forms. We rarely think of basic materials as occupying such a central place in making the world better, but there they are.

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[6] In 2023, Chile's PPP-adjusted GDP per capita was $33,285 (World Bank estimate); Bolivia's was $10,727.

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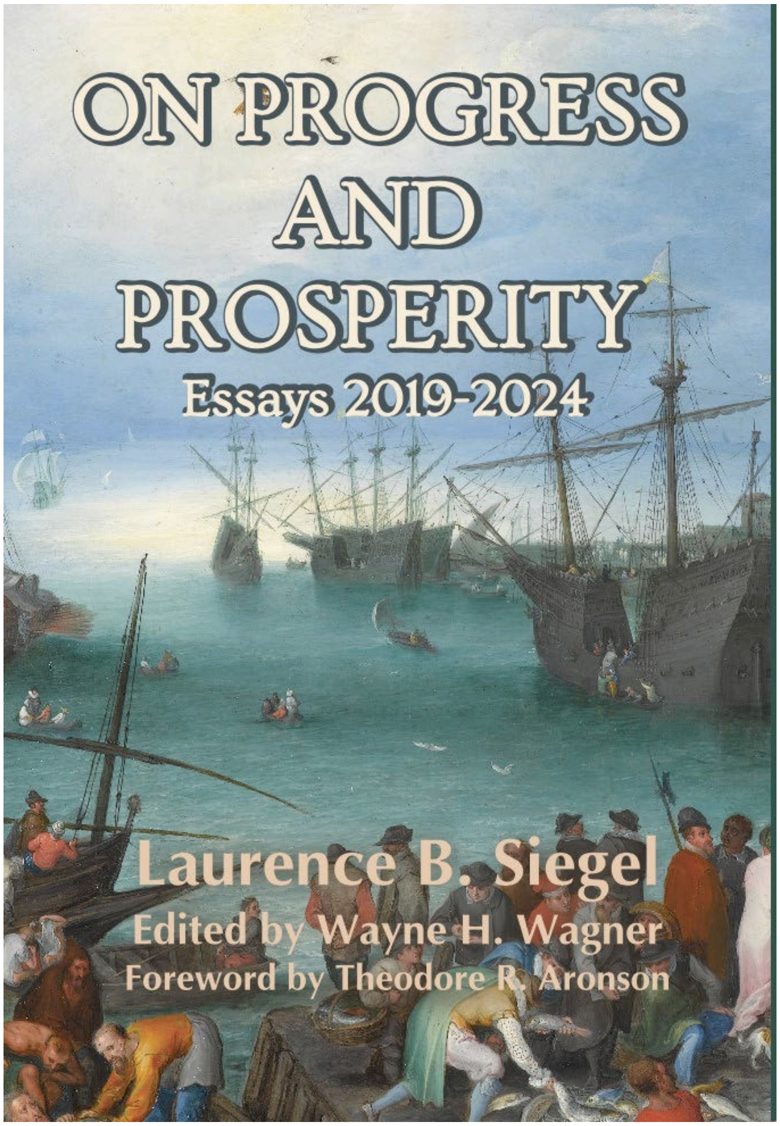
**COMING SOON**



*It will be on Amazon as a hardcover book and a Kindle ebook!*