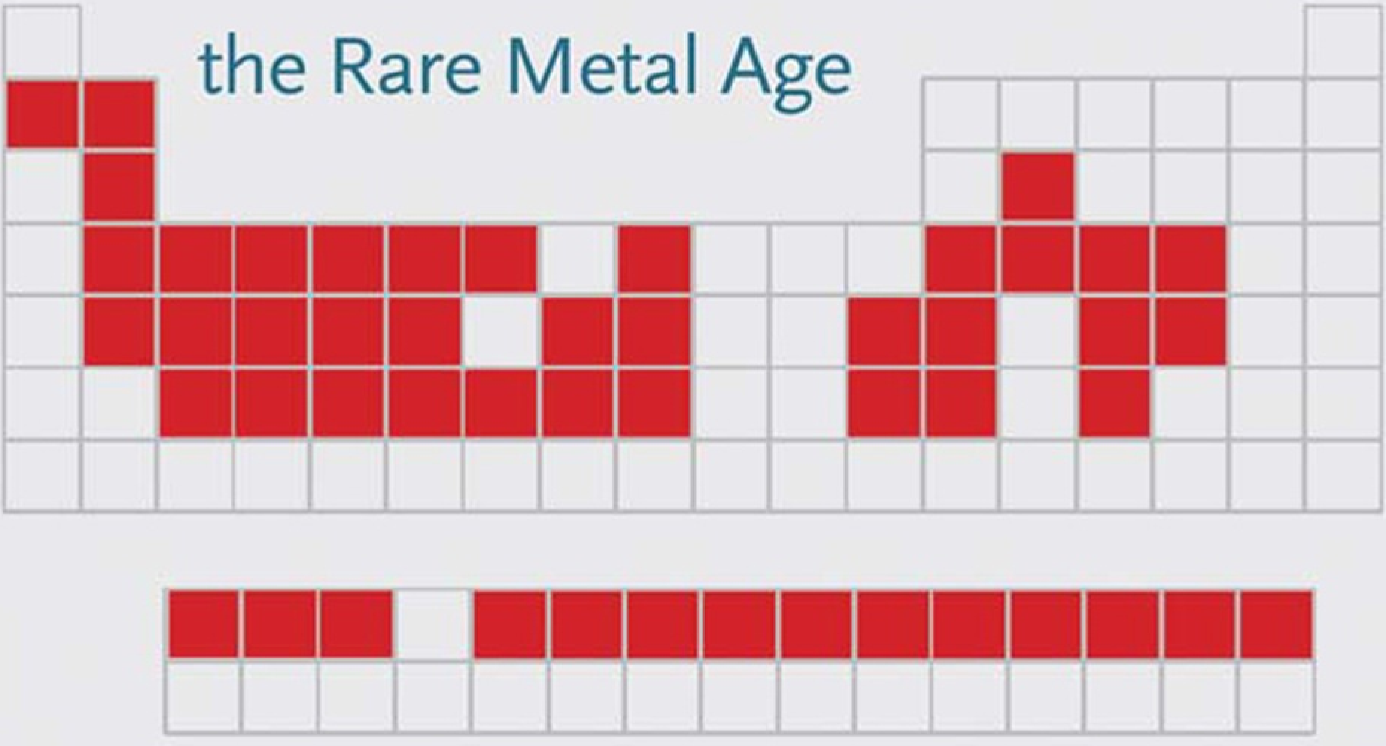
David S. Abraham

The Elements of Power

Gadgets, Guns, and the Struggle for a Sustainable Future in the Rare Metal Age



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To my father, who never read even page 1 but who was with me along the way, and to my mother, who read every page again and again, and then again.

Contents

Preface

We have quietly entered a new era, the Rare Metal Age. The products we use every day, from smartphones to cars, require a great number of hard-to-come-by metals, combined in increasingly complicated amalgamations. This book shows where the ingredients that underpin our society come from, how they get to us, and how they impact the environment. I wrote this book in the hope that you, the reader, will consider the scope of our dependence on these metals and will recognize that our technology, as well as our economic and climate security, comes at a cost. How we plan to pay will affect our future in ways many of us have not previously understood.

To develop this understanding, I've tracked the trail of these rare metals from mine to gadget and from gadget to recycled afterlife. I chatted with Japanese salarymen in smoke-filled, back-alley restaurants in Tokyo; feasted on lamb and beer with Chinese officials in Mongolian-style yurts; waded in the muck with miners off the coast of Sumatra, Indonesia; and visited factories in a formerly secret Soviet town that once refined uranium for nuclear weapons. Yet, although I traveled to some of the most rugged spots on the planet, my formal research started at a far more genteel place: Japan's Ministry of Economy, Trade and Industry in 2010.

At the time, I was a foreign researcher with the Council on Foreign Relations working from an internal cubicle on the ministry's eleventh floor. While my perch lacked a view, I had a ringside seat to one of the greatest Asian resource battles of the past generation. China cut off exports to Japan of a set of rare metals, called rare earth elements, during a territorial skirmish in the East China Sea. As I witnessed Japan's rapid capitulation to many of China's demands, I saw a new geopolitical trump card. The battle over resources, which started when the first person learned how to coax metal from stone, had expanded into a larger battle—a war over the periodic table.

My interest in rare metals was initially geopolitical. I spent years examining the nexus of natural resources and geopolitics at an energy trading company, a Wall Street firm, and the natural resource division of the White House Office of Management and Budget. I also managed a nonprofit focused on water in Africa. But I looked at commodities consumed in large quantities, and I learned that the small rare metal world is far more complex and removed from the scrutiny of commodities like oil, gas, and coal.

Through my research in a dozen countries and my meetings with hundreds of miners, traders, scientists, and policymakers, I soon realized that geopolitical tensions were only one of the impediments to meeting a country's resource needs. Our rare metal supply lines—which ensure that the right metal of the right grade reaches the right location at the right time and at the right price—have become a marvel of modern efficiency. But these supply lines are precarious, and our increasing global demands will soon stress them further. Our high-tech, green society is built on a wobbly foundation.

Many have written about the economic and social effects of our international supply lines. Articles on abuse and mistreatment of workers in sweatshops and factories now abound in the press. Business journals examine which countries profit from the globalized supply chain of our electronic gadgets. Even coverage of the world's electronic waste, burned in Africa and Asia, has now entered the global discussion.

This book builds on those reports by examining the supply chain of the hidden rare metals that make modern life possible. These metals permeate our lives, allowing buildings to soar and our televisions to show vibrant colors. And because these metals are critical in green technology as well, they are the seeds of our sustainable futures, but, as a society, we know very little about them. They are buried deeply in our products and are indistinguishable to us from more well-known metals like aluminum and iron. Every age has its resources: iron provided weapons; coal, oil, and natural gas give light and power. Now ingredients like rare earth elements, indium and tungsten are critical in ways many of us have failed to grasp. Indeed, these rare metals may well be one of the most underreported areas of research today, despite, as we will see, the increasingly economic and geopolitical advantage they confer.

It's not just the metals themselves that remain mired in obscurity and secrecy; companies that use these materials often conceal their use, behind the veil of patents and trade secrets. Even those working in senior positions in many high-tech firms are not aware of the materials on which their operations are built.

Although I found unsavory aspects of the industry—illegal trade, unscrupulous mining, and environmentally noxious metal processing—most people in the business are decent. They are striving to make a comfortable life for themselves and their families. But, compared to other industries with which I'm familiar, the rare metal world has an air of secrecy, leading to a low level of trust. While the mining and trading of these metals is not a lawless realm, one would do well in this arena to abide by the Russian axiom, "trust, but verify."

For this reason, one of the greatest challenges to writing this book was the lack of reliable statistics. Verifiable facts are hard to come by and often turn out not to be facts after all, but someone's guess that was repeated enough times to etch itself into the industry as truth. Information reported in popular media can be far from accurate. Statistics on market size vary wildly between industry sources. Even government trade figures fall short; for example, China's rare earth exports to Japan and Japan's rare earth import statistics rarely align. In this situation, the absence of statistics can be as telling as the statistics themselves. Interviews with knowledgeable sources and time spent at mining sites globally were invaluable to fill in gaps in my knowledge, but they inherently carry the risk of my seeing only a certain perspective.

In my quest to get to the inner circle of truth, I have done my best to be true to the sentiment I've heard in the market and have attempted to filter the information through an unbiased lens. Figures, though, may be more estimates than actuals. And verifying black market data and activities relies heavily on the participants themselves and so data can be biased. The assumptions I make are my own. I have tried to make things simple, for example, by standardizing terms when possible; I have used metric tonnes for the weight measurement, but employed the U.S. spelling of the word “tons.” I also tried to use measurements standard for the context; metals are sold by the ounce, flask, pound, and kilogram. Statistics in the book are as current as what was available at the time of writing, but since the industry publishes statistics infrequently, they may be less current than desirable.

Throughout the book, I use the term “rare metal” to refer to a set of metals mined in small quantities, often less than thousands of tons annually. Their use is, well, rare. However, there are also those metals that are geographically rare (such as tellurium) and another group of metals called “rare earth metals,” which, although not synonymous with the term “rare metals,” are a subset of them. The challenge was to use a term that conveyed limited use of these metals in relation to the use of other metals but also to emphasize their importance.

I also use the term “minor metal,” which is an industry standard description for metals in limited production and a recently coined phrase “critical material” synonymously with “rare metal.” I take solace in the fact that the metal industry is not actually very good at labeling metals. The term “precious metal” refers to silver, but not to metals that can actually be more precious such as germanium or terbium. I also use “acids” as shorthand to refer to the complex chemicals used in metal processing, but this also includes emulsifiers, flocculants, and other agents.

The book remains a work in progress; my time with it ended in early 2015. There is much more to write about recycling, processing, and the scientific properties of rare metals. As an observer, writer, and someone who dabbled in economics, the focus of the book may be short on scientific details for some readers. To be sure, people spend their entire careers understanding the properties of just one element, the mineralogy behind one ore, and the refining process of a single metal powder.

My hope is that this book introduces you not only to the hidden ingredients in our high-tech, green, and military lives but also to the characters and stories behind them, and that it explains the role of rare metals, including rare earth elements, in our products and describes how future demand for these resources can shape the global economy and geopolitics. This book comes at a defining time when rare metals are increasingly critical for high-tech, green, and military applications. Yet despite their prevalence, they are not understood. Just as cars made oil a staple of modern society, many of today’s unheralded metals are likewise transformative to the products they find themselves in. This means that the rare metal market is one that demands far more scrutiny.

As you read this book I also hope you will reflect on these elements’ power and promise, and the extent to which they are already embedded in your life. I hope you will see that the ability to harness the power of rare metals to make smartphones, for example, is as impressive as the phones themselves. It’s not hyperbole to state that the fate of the planet and our ability to live a sustainable future in which technology can freely flow to the billions who do not yet have access depends on our understanding and production of rare metals and our avoidance of conflict over them.

I
Metals, Metals Everywhere

Microsoft CEO Steve Ballmer was incredulous. "There's no chance that the iPhone is going to get any significant market share. No chance," Ballmer prophesied during a CEO Forum before Steve Jobs released the iPhone in June 2007. But, by the end of the first week of sales, most storeroom shelves were bare; Apple and its AT&T partner sold hundreds of thousands of phones. The company was fast on its way to taking more than 20 percent of the smartphone market within just a few months.[1]

To those who waited in line outside Apple stores for a day or two to snap up the first phones—or paid others hundreds of dollars to wait for them—the iPhone was a revolution, the stuff of dreams. Although smartphones had been out for a few years, Jobs's phone, they believed, was set to be the smartest. Some in the media labeled it the "Jesus Phone" because of the religious fervor surrounding its launch and the blind faith that Jobs's new gadget would create not just a better phone, but a product that would reshape everything that followed it.[2]

As is now legend, the phone banished number buttons and the physical keyboard. Instead the iPhone became the first mainstream product to rely on a "multi-touch" glass screen—a highly functional screen that allows the tapping, sliding, and pinching that are now second nature for writing e-mails, determining directions, and hailing a cab. Jobs himself commented, "It works like magic."[3]

While Jobs's creative genius is beyond mythical, something greater was at play. Lost in the hubbub of new features and beyond the phone's powerful yet simple design was the most remarkable characteristic of iPhone—the reason why a powerful device can sit comfortably in the palm of your hand—it relies on nearly half the elements on the planet.[4]

These metals are the reason that devices are getting smaller and more powerful. For Jobs, the "magic" in his glass is due to a dash of the rare metal indium, which serves as the invisible link, a transparent conductor between the phone and your finger. A dusting of europium and terbium provides brilliant red and green hues on the screen, specks of tantalum regulate power within the phone, and lithium stores the power that makes the phone mobile. Rare metals are also crucial to manufacturing the iPhone's components: cerium buffs the glass smooth to the molecular level.

To be sure, the iPhone was far from the first or only product to rely on rare metals. In fact, the increasing use of rare metals correlates well with the sale of Apple and other computer products, which began some thirty years earlier. But Jobs's drive for smaller, more powerful gadgets led his company to increasingly harvest the complete palate of materials on the periodic table and deliver them to the masses. What's more, the iPhone's commercial success transformed our expectations of our gadgets. It spurred new industries, including mobile apps and tablets, making the power of rare metals indispensable not just in smartphones but in a myriad of new technologies. Jobs not only lived up to his word of reinventing the phone, he helped reinvent the world's resource supply lines. In the process, he also helped bring forth the dawn of a new era: the Rare Metal Age.

Rare metals are everywhere—really everywhere—from soaring bridges to earphone buds. They are in couches, camera lenses, computers, and cars. But they are rarely used alone or as the primary material. In essence they fill a role similar to that of yeast in pizza. While they are only used in small amounts, they're essential. Without yeast there's no pizza, and without rare metals there's no high-tech world.

We lack awareness of them because we never directly buy them as we do other commodities such as gas or corn. Rare metals are buried away in components that are essential to almost every gadget we use, like the rare earth permanent magnet. While the production of permanent magnets is approximately a mere $15 billion market today, if we were to add together the value of all industries that rely on these magnets—automobile, medical, and military—the sum would reach trillions of dollars.[5]

To paraphrase a slogan of the chemical corporation BASF, rare metals don't make the products we buy; they make the products we buy smaller, faster, and more powerful.[6] They made Jobs's iPhone thinner, more functional, and more mobile. This is because each rare metal has its own characteristics that serve very specific functions. For example, it can be malleable (indium), ductile (niobium), toxic (cadmium), radioactive (thorium), or magnetic (cobalt), or it can melt in your hand (gallium). And like characters in the X-Men comics, they all have their own superpowers. Terbium produces more vibrant light in television; dysprosium and neodymium make incredibly strong magnets possible; antimony helps resist fire.

Among the elements in the periodic table, roughly two-thirds are metals or metalloids, elements like silicon that share some characteristics of metals and nonmetals, and are most valuable because of their semiconducting properties. Of these, mines produce millions of tons each year of the best-known metals, like copper and zinc, which are called "base metals." Others, like gold and silver, have retained value for centuries, hence their name "precious metals."

Rare metals are in an umbrella category for almost all other metals. Their defining feature is that they're consumed in small quantities, hence "rare" when compared to base metals. On average, the world consumes individual rare metals in the hundreds or thousands of tons annually—the annual production of each can fit into just a few rail cars. By comparison, miners produce about 1.4 million tons of copper annually. According to data from the U.S. Geological Survey, if you add up the annual consumption of all materials that are considered rare, the amount would be substantially less than the quantity of copper consumed every year. The label "rare" does not mean that these metals are all geologically scarce. Indeed, some are plentiful. Others are abundant but seldom found in concentrations high enough to be mined profitably. To complicate labeling matters further, some in the industry call them “advanced” or “technology” metals because of their prevalence in electronic applications. Others call them “strategic” or “critical” because of their irreplaceability in their applications. Those who trade these materials alternatively call them “minor.” Throughout the book I use these previous words interchangeably. (I also use the term “materials” instead of “metals” because in many cases it’s not the pure metal that’s traded, but a less-refined derivative of it.)[7]

Rare metals also encompasses rare earth elements, a set of seventeen atomically similar metals, which gained international attention in 2010, when fears of Chinese monopolistic control of production and export restrictions drove prices up nearly tenfold. Rare earth elements are a mere subset of rare metals but they share many of the same market dynamics. For example, many rare metals, like rare earths, must undergo challenging refining techniques. They are also traded in backroom deals rather than on open exchanges like other commodities such as oil.

If naming them is a challenge, classifying which metals are “rare” is even more problematic. Even the Minor Metals Trade Association, the organization that trades these metals, lacks a standard definition. By its count, members now trade forty-nine rare metals as in Figure 1, up from eight just three decades ago when manufacturers bought only a handful of them. (Many insiders can’t even agree as to what is a rare metal and quibble about whether a specific metal should be labeled as such.)

But don’t let the lack of an encompassing term or the small production levels fool you into underestimating their economic and geopolitical importance. These tiny quantities of metal have fostered incredible technological change. Rare metals are the base of our modern high-tech, green, and military industries. Rare metals are no less transformative than oil or coal. They will increasingly deserve the same attention we afford fossil fuels, meaning those who control and manage their production and trade will increasingly reap outsized economic and geopolitical fortune. And yet, unlike oil or coal, they are often more limited in supply and far more complex to produce, and they originate from just a few places on earth. Many have such unique properties and uses that they cannot be switched out for cheaper or more abundant alternatives. Our reliance on rare metals is not just an abstract geopolitical issue or a topic of concern only to material scientists. It is a potential source of conflict. But it was not always this way.

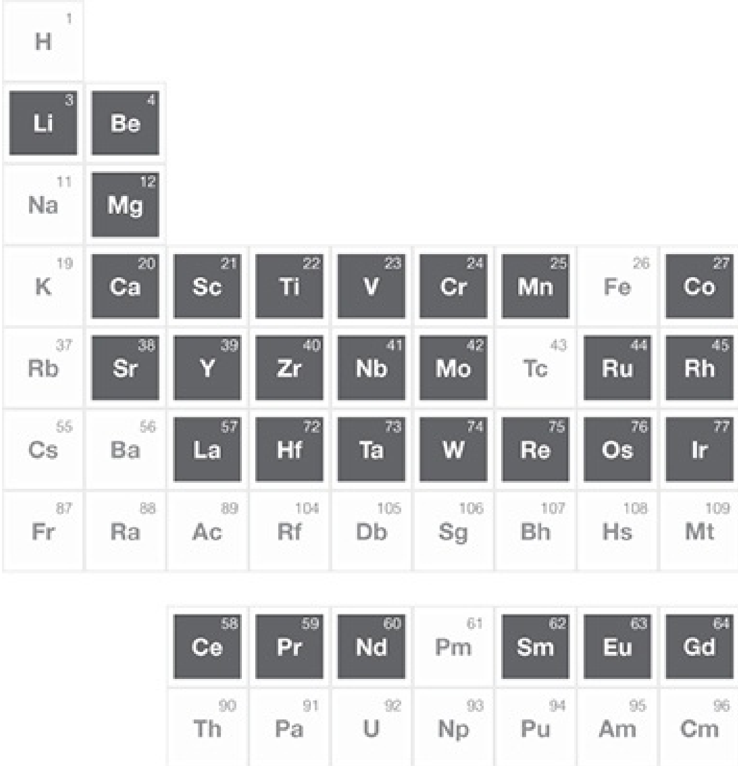
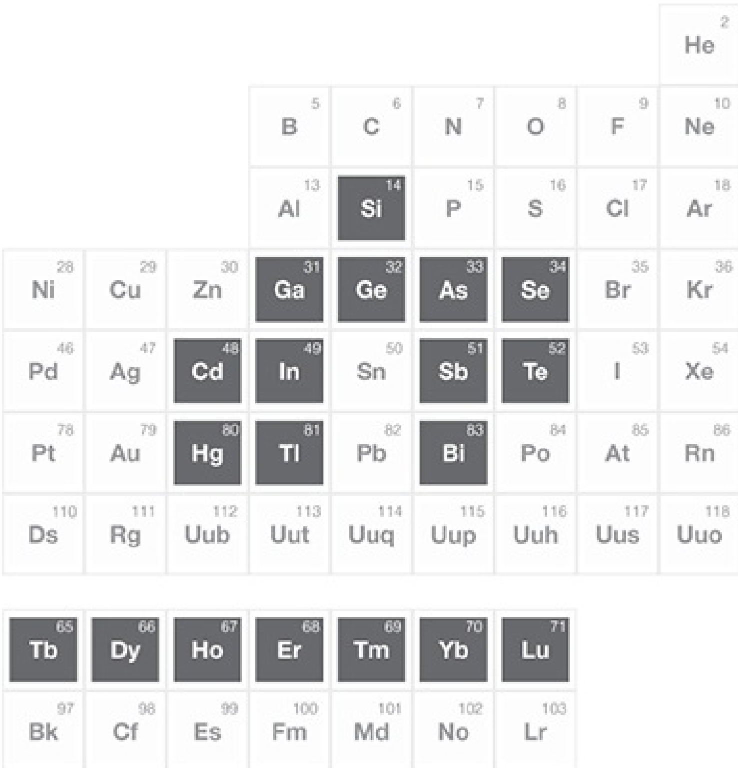


Figure 1. Minor Metals Trade Association's list of minor metals. Courtesy of Minor Metals Trade Association (MMTA).



Only some 150 years ago, nearly all of the materials in a person's home originated from a nearby forest or quarry. By the 1960s, with more developed supply lines and an increased demand for consumer appliances, the average American home used around twenty elements. Since then, material scientists have led a quiet revolution transforming the products we use and the materials that allow them to work. In the 1990s Intel used only fifteen elements to build its computer chips. Now the company demands close to sixty elements.[8]

The transformations in the products we use appear subtle to the untrained eye. Modern lights, for example, emanate a hue slightly different from that of their predecessors. But these slight changes in tone mask a profound change in resources. Whereas Edison's lightbulb contained a simple metal filament, the resources in today's LED lights are more akin to computer hardware, powered by gallium, indium, and rare earth elements.[9] This new set of elements and the applications that sprang from them, makes the products of today far more sleek than those of a generation ago. In the 1980s, when Maya Lin, the designer of the Vietnam Memorial in Washington, DC, asked Steve Jobs why he made clunky computers instead of thinner ones, he responded that he was waiting for the technology to build them.[10] What he really waited for was the time when material scientists would unlock the properties of rare metals and bring forth the flat screen.

Today, our daily individual purchasing decisions and the technology we use have significant ramifications on our rare metal supplies. Unfortunately, we have thought little about that connection between ourselves and these resources. While rare metals have been around since the beginnings of time, most were just discovered in the past few hundred years, and some just in the past century. Today, companies are using elements that scientists dismissed as mere impurities decades ago. Over the past thirty-five years, mining companies have produced four times more of many, if not all, rare metals than they produced from the dawn of civilization until 1980.[11]

It is the properties of rare metals like neodymium and dysprosium in the hardware of our gadgets that form the bedrock of new services that have revolutionized our lives. The media shower praise on the Silicon Valley innovators but the credit for our tech existence must be shared. What makes technologies from Google to Alibaba work is the proliferation of rare metal–laden technologies in our pockets. That so many people have smartphones generates new markets. But without decades of work by nameless mining engineers, metallurgists, and material scientists, Uber and Facebook would never have become household names. (Therefore, it's hardly ironic that, in the 1980s, Jobs bought the house of a mining and metallurgical engineer who had earned his wealth more than fifty years before him.[12])

These rare metal digital technologies have transformed not only the ways we travel, communicate, and shop but also our expectations. We have come to demand that technologies will become cheaper, more accessible, and more advanced each year—and that they do far more than many once thought possible. Although the multiple functions of our new gadgets appear to come with the opportunity to use fewer raw materials—after all, the iPhone is a computer, book, and music player—the reality is we use far more total resources. We don't realize this dynamic because we pay little attention to the increasing complexity inside our gadgets. Nor do we understand the tenuous supply lines that support our habits. Many of us simply wait for the next version of the iPhone and line up to buy it. Few understand the wondrous properties of rare metals that have made small, powerful devices inexpensive enough that billions of people can afford them. Rare metals now underpin our lifestyle. Indeed entire industries, like apps, and the foundation of many economies, are built on them.

Look at the influence of Jobs's phone: iPhone sales are now so large that analysts state that they increase the GDP of the United States and Taiwan, where many of the parts are made, as much as half of a percent. And they have resurrected Apple's fortunes. By 2012, sales of the iPhone totaled more than half the company's revenue. Add in its sibling, the iPad, and around three-quarters of the company's revenue springs from the iPhone technology. The invention transformed Apple from the eighty-fifth biggest company in the world, to the largest, the very largest, in just five years, overtaking ExxonMobil. Apple's ascendancy over Exxon reflects a new reality: the world is fast becoming as dependent on rare metals as it is on oil.[13]

Society was once bifurcated: the wealthiest 20 percent historically consumed more than 80 percent of the resources. Or as the anthropologist Jared Diamond put it in 2008, each person living in a developed country consumed thirty-two times more material than one in a developing country.[14] When most of the world lived in developing countries, seemingly endless resources flowed to wealthiest ones. But that is changing—not because the wealthy are consuming less, but because everyone is consuming more. This is in part because wealthy countries have adapted to a high-tech, yet disposable lifestyle. They have paved the way for the entire world to live similarly without considering the global resource implications.

When research took me to Jakarta, Indonesia, I was struck by the number of cranes dangling over towering, hollow concrete shells. These budding high-rises peered over slightly shorter ones constructed just a few years before. These new buildings will provide homes for increasingly wealthy, upwardly mobile Indonesians who are striving to live the technological-advanced dream, with all its attendant accoutrements. The people of Indonesia will be no different from the billions of others in the developing world, from South America to China, who are heading toward the same resource-intense existence. This means the global demand for metals, especially rare ones, will increase as countries follow a well-worn economic path. As people move from farms to better-paying jobs in cities, which necessitates the building of bridges, subways, and more power plants to supply electricity to charge people's smartphones and laptops, metal demand skyrockets.

How much more is needed? No one is sure. But the growth of steel consumption may be a relevant proxy. In South Korea, steel demand per person grew more than fivefold as the income of individual Koreans increased from $2,000 to $20,000. Likewise in China, the country consumed about one kilogram of steel per person when 30 percent of the population lived in cities, but jumped to more than five kilograms per person when 50 percent lived in urban areas, much of this for infrastructure. Because China plans for 70 percent of its people to live in cities by 2030, this means China will need even more steel. While this infrastructure needs more rare metals, the wealthier city can afford more gadgets which will compound demand for rare metals.[15]

Based on our current rate of rare metal resource production and our consumption patterns, we won't have the dysprosium necessary to build magnetic resonant imaging (MRI) machines; yttrium critical for military radar; or the tungsten for oil exploration drill bits. New high-tech inventions will only add urgency to expand our limited supply chains, meaning the future supply of materials for our gadgets is at stake. Numerous recent government and think tank studies highlight the risk of shortages over the next decade and some even longer. The American Chemical Society finds that over the next century, forty-four of the ninety-four naturally occurring elements face supply risks. While production levels of many elements will rise to meet demand, their report highlights a real concern.[16]

The future of our high-tech goods may lie not in the limitations of our minds, but in our ability to secure the ingredients to produce them. In previous eras, such as the Iron Age and the Bronze Age, the discovery of new elements brought forth seemingly unending numbers of new inventions. Now the combinations may truly be unending. We are now witnessing a fundamental shift in our resource demands. At no point in human history have we used *more* elements, in *more* combinations, and in increasingly refined amounts. Our ingenuity will soon outpace our material supplies.

This situation comes at a defining moment when the world is struggling to reduce its reliance on fossil fuels. Fortunately, rare metals are key ingredients in green technologies such as electric cars, wind turbines, and solar panels. They help to convert free natural resources like the sun and wind into the power that fuels our lives. But without increasing today's limited supplies, we have no chance of developing the alternative green technologies we need to slow climate change.

Our demands are now pushing against the bounds of what we can sustainably produce. Fluctuations in the complex supply line will affect society in unpredictable ways. New supplies of dysprosium could speed the development of highly efficient wind turbines, and conversely, a lack of it could drive up the cost of hybrid vehicles. It's no understatement to say that our use of rare metals will determine the fate of the planet.

Back in the Iron Age, a new set of strong iron weapons enabled those who mastered the art of turning stone into metal to conquer their neighbors. Today, although the weapons have changed, the situation is much the same: those who can master the elements make stronger foes. The difference is that whereas throughout history people have relied on metals to make weapons such as swords stronger and harder, today rare metals make weaponry smarter. Consider, for example, new missile weapon systems like Israel's Iron Dome, which gives a glimpse of what may be possible over time.

When a rocket flies toward an Israeli town, the system's computers and sensors decide within milliseconds when and where to launch a precision-guided missile to intercept it. By 2014, the Iron Dome had reportedly knocked out upward of 85 percent of the rockets headed toward Israeli cities, saving an untold number of lives and altering the nature of warfare.[17]

A few decades ago, a system like the Iron Dome, as well as any precision-guided missiles systems and even drones, were the stuff of science fiction. Today's technology relies on advances in radar, computers, and guidance systems. And at the core of each component lies rare metals. While the exact components of the Iron Dome are classified, the system, as any such sophisticated system today, must make abundant use of rare metals. Its computer screens use indium; rare earths are in the fin actuators that guide the missiles; and microchips full of rare metals drive their computers. These metals underpin complex weapons systems and ultimately a country's national defense.

For years, companies and countries took their rare metal supply lines for granted, unaware of the material makeup of their products. In fact, in 2011, Congress forced the U.S. military to research its supply chains because the Pentagon was having difficulty determining which advanced metals it needed.[18] As the materials that make up product components have become more varied and complex, those who rely on sophisticated hardware can no longer afford to remain in the dark.

Now, corporate and government leaders are realizing how important rare metals are. Indeed, efforts to secure rare metals have sparked a war over the periodic table. In offices from Tokyo to DC, in research and development labs from Cambridge, Massachusetts, to Baotou, China, and in strategic command centers the world over, new policies and the launching of research programs are ensuring that nations have access. The struggle for minor metals isn't imminent; it's already here and is shaping the relationship between countries as conflicts over other resources did in the past.

Just as the Cold War split the world along ideological lines, this new struggle will create fissures between those who have access to rare metal resources and those who do not. Because whole industries are built on just a few rare metals, disruptions to their supply can have profound global implications and give countries tremendous leverage. Billion-dollar companies are often beholden to just one country such as Congo or Kazakhstan—or even one particular mine—for a vital advanced metal. For most companies it's "difficult, if not impossible, to trace the minerals' origins," as the computer manufacturer Dell notes. Such lack of transparency is hardly a fail-safe situation when companies often need hundreds or thousands of components or more.[19]

This book is the first of its kind to explain what rare metals are, where they come from, and how they are used. We will meet miners, investors, and material scientists as we explore these metals and the seemingly unlimited opportunities they offer us. You will understand minor metals' complex supply web that begins on a hillside in Chile or on the edges of a Congo jungle, where people toil with simple shovels and picks, and ends on your desktop, in your pocket, or on a military base.

We will see the increasing importance of rare metals through the past century. Just as dependence on oil forced many countries into uneasy relationships with oil-rich regimes, now metal-rich countries like Russia and China have a new hold on trading partners. And some have begun to flex their muscles as China did in 2010, when it restricted the export of rare earth elements to Japan. In fact, the role of China and its control over rare metals is an important theme that plays throughout this book.

We will track the journey of these materials from rock to metal and come to understand how rare metal supply lines, which may appear similar to those of iron or oil, are far more complex. They are often dominated by a few entrenched suppliers and can take more than a decade to establish. This means that although higher prices will often bring on new supply, the principles of supply and demand do not work in a timely fashion. Inventions of new high-tech products can create resource demands far more quickly than suppliers can increase supplies, leading to price spikes.

What’s more, because the cost of starting new projects is exorbitant, junior mining companies often spend more time looking for financial resources than for mineral ones. But those are just the first obstacles. Receiving regulatory approvals, creating the refining techniques to coax the metal from the minerals, and predicting demand can vex even the savviest mining company executive.

When companies can overcome those hurdles and produce rare metals, their material enters a channel of small trading shops where secrecy reigns and a reliable delivery is prized. A transparent market benefits those who produce the metals and those who buy them because it establishes clear prices, but it hurts the trading business. Traders’ profit comes not only from the metals they peddle but also from their monopoly of information. There are profits in obscurity.

The future market looks bright for these traders, as we will see, because high-tech goods are getting cheaper, green products are more in demand, and countries are spending more on defense. The proliferation of cheaper rare metal–laden technology is colliding head-on with the increasing purchasing power of people in even the poorest communities. This can create surreal scenes—in places that have no clean water or paved roads, people have phones and TVs—but it also sows the seeds of a high-tech lifestyle in new lands.[20]

As demand for these rare metals grows, it is important to understand the environmental and geopolitical effects of increased production. Whereas the total environmental impact of producing rare metals is small in comparison to producing traditional commodities, the impact per kilogram (or pound) is far greater because of the quantity of chemicals and energy needed to refine the metals. And with little oversight of operations in some countries, the production of rare metals can be ruinous to the surrounding communities. Despite the environmental challenges, it’s a risk that countries like China take because rare metal production will confer economic and geopolitical benefits that were previously reserved for more traditional commodities. As we will see, some countries, such as Japan and Germany, are realigning their relationships to ensure a reliable supply of rare metals.

The challenge is to produce and use rare metals efficiently while at the same time developing a sustainable supply chain. It is something we can do only if we both understand our use and dedicate ourselves to thinking about solutions, as this book does in its final pages. Otherwise we will repeat past mistakes: we once averted our eyes from the challenges of relying on fossil fuels, and now we are at risk of ignoring the dangers of relying too much on too little. And there are glimpses of the challenges that lie ahead, especially when the world relies on very rare metals from very remote places.

II
National Struggles
Mineral Veins and Battle Lines

During his thirty-one years as Zaire's president, Mobutu Sese Seko plundered the country's resources. He amassed billions of dollars to fund a lavish lifestyle and to dole out to supporters. In 1978, almost thirteen years after coming to power, when Soviet-backed rebels from Angola seized the Katanga region, known for its rich cobalt deposits, and challenged his control, Mobutu was quick to send in the military.

The ensuing battle choked off cobalt supplies to much of the world. The price of the rare metal—essential for permanent magnets in electric motors and heat-resistant alloys in jet engines—spiked to more than $60 per pound from $10 per pound in less than a year. Manufacturers scrambled for supplies. With the price so high, in fact, producers found it profitable to transport the silver-blue metal by air from the metal processors, when traditionally they had shipped it by boat.[1]

Rumors spread about greater geopolitical battles at play beyond the jungles of Africa. A few months before the rebels seized Katanga, the Soviet Union bought massive quantities of cobalt from Congo for its military-industrial needs. This move surprised many metal traders and simultaneously raised fears in government circles, especially in the United States, which relied on Zaire for 40 percent of its cobalt. Other rumors swelled that the Soviets wanted to take over the global cobalt market, hoarding supplies and crippling U.S. industries. A few years later, the secretary of state, Alexander Haig, said he thought the Soviet Union had started a resource war, and Zaire was the first battle.[2]

Some industries, such as paint manufacturing which used cobalt for pigment, shifted away from using it because substitutes were easy to find. Others tried to reengineer their products to eliminate cobalt, a strategy that often meant using less effective materials and led to higher prices for inferior products. The shortage spooked military planners and aviation executives since they had no substitute for cobalt alloys in new jet engines and other military applications.[3] But it may have been cobalt's use in permanent magnets that created some of the greatest challenges.

First used in the 1960s, cobalt permanent magnets quickly found their way into military applications such as microwave communication systems.[4] Over the next decade, they made their way into small motors because they were tiny and could be formed into a variety of shapes. Permanent magnets are useful to system designers because they sustain a strong fixed charge over an indefinite period of time while expending no energy in the process. At the time, no one knew whether cobalt magnets could be replaced, and if so, with what.

The fact that war disrupted mineral trade is neither surprising nor new. But it was new that a small insurgency, in a far-off land wreaked havoc upon the world's largest companies by cutting off most of their supply of a seemingly trivial metal. The cobalt fight highlighted the tenuousness of vital military supply lines, which had come to rely on rare metals. Fortunately for those who relied on cobalt, Mobutu regained control of the mines, and simultaneously a global recession reduced demand for cobalt and reduced its price. But the conflict had started a scramble to replace cobalt.[5]

The widespread use of a rare metal whose production comes from an unstable source, as in the case of Zaire, may seem shortsighted, but what is myopic to the diplomat can be genius to the material scientist. The decisions about which ingredients to use in our devices come down to which materials can solve technical challenges, not which metals are in abundant supply.

This was the case when Masato Sagawa began work as a junior research scientist at the Japanese electronics giant Fujitsu, about five years before the Congo conflict. Although he had never taken much interest in magnets during his doctoral studies, let alone cobalt, his task at Fujitsu was to strengthen a samarium-cobalt magnet that kept chipping. Over the course of the project, the young scientist grew enamored with magnets, staying late at the lab to better understand their composition.

He knew cobalt alone couldn't create a permanent magnet, but mixing it with the rare earth element samarium could. Samarium helps form a unique crystalline atomic structure that assists in aligning smaller magnetic fields of individual atoms. This creates a strong, permanent magnet.

Sagawa thought that he could apply the same theory to make a permanent magnet out of iron and a more abundant rare earth, neodymium. This new magnet wouldn't face the price and supply limitations of cobalt and samarium. He believed it might even be stronger than existing magnets because iron had a more powerful magnetic disposition than cobalt.[6] Sagawa started working on his neodymium-iron magnet in 1976, spending weekends and nights at work and rarely seeing his newborn child. But by January 1978, he still had no success and the obstacles appeared formidable.

Masaaki Hamano, a leading permanent magnet researcher of the day, commented during a conference Sagawa attended that the iron–rare earth magnet, like the one Sagawa was working on, was impossible because the distance between the iron atoms was too small to allow for proper spacing to form a magnet.[7] But this presumed impossibility inspired Sagawa's solution—he would create more space between the iron atoms by adding boron to the rare earth–iron mix. With its smaller atomic size, boron increased the molecular distance between atoms by shoehorning itself in the spaces between them.[8]

As the war raged in the Congo, the newly inspired Sagawa continued his efforts while unbeknownst to him, materials scientists in corporate and military labs were blazing a similar trail to reduce the world's reliance on Zaire's cobalt.[9] But Sagawa's concern at the time was more parochial: not competition, but temperature.

Magnets are finicky—if they get too warm, beyond what is known as the Curie temperature, they lose their magnetism. Sagawa's magnets were losing their magnetic properties at such a low temperature that it would preclude their use in (hot) motors.