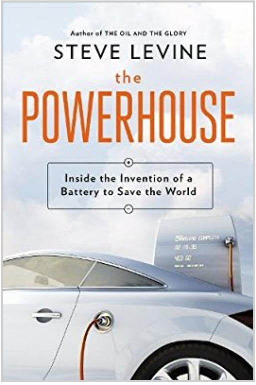

The Powerhouse: Inside the Invention of a Battery to Save the World

By Steve Levine

The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine

A Soul of the New Machine for our time, a gripping account of invention, commerce, and duplicity in the age of technology

A worldwide race is on to perfect the next engine of economic growth, the advanced lithium-ion battery. It will power the electric car, relieve global warming, and catapult the winner into a new era of economic and political mastery. Can the United States win?

Steve LeVine was granted unprecedented access to a secure federal laboratory outside Chicago, where a group of geniuses is trying to solve this next monumental task of physics. But these scientists--almost all foreign born--are not alone. With so much at stake, researchers in Japan, South Korea, and China are in the same pursuit. The drama intensifies when a Silicon Valley start-up licenses the federal laboratory's signature invention with the aim of a blockbuster sale to the world's biggest carmakers.

The Powerhouse is a real-time, two-year account of big invention, big commercialization, and big deception. It exposes the layers of aspiration and disappointment, competition and ambition behind this great turning point in the history of technology.

The Powerhouse: Inside the Invention of a Battery to Save the World

By Steve Levine

The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine

A Soul of the New Machine for our time, a gripping account of invention, commerce, and duplicity in the age of technology

A worldwide race is on to perfect the next engine of economic growth, the advanced lithium-ion battery. It will power the electric car, relieve global warming, and catapult the winner into a new era of economic and political mastery. Can the United States win?

Steve LeVine was granted unprecedented access to a secure federal laboratory outside Chicago, where a group of geniuses is trying to solve this next monumental task of physics. But these scientists--almost all foreign born--are not alone. With so much at stake, researchers in Japan, South Korea, and China are in the same pursuit. The drama intensifies when a Silicon Valley start-up licenses the federal laboratory's signature invention with the aim of a blockbuster sale to the world's biggest carmakers.

The Powerhouse is a real-time, two-year account of big invention, big commercialization, and big deception. It exposes the layers of aspiration and disappointment, competition and ambition behind this great turning point in the history of technology.

The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine Bibliography

- Sales Rank: #380964 in Books
- Published on: 2015-02-05
- Released on: 2015-02-05
- Original language: English
- Number of items: 1
- Dimensions: 9.28" h x 1.00" w x 6.30" l, 1.19 pounds
- Binding: Hardcover
- 320 pages

Editorial Review

Review

"LeVine examines the intricate dynamics of geopolitics, internal conflict and fierce industry competitiveness with equal acuity."
--Kirkus Reviews

"This globe-spanning tale involves everyone from President Obama to China's top technocrats to a collection of quirky "battery geniuses." ... I hope you'll explore the book as well as LeVine's other output. He is a Washington correspondent for Quartz with a penchant for dissecting the science side of the energy industry."
--Andrew Revkin, The New York Times

"Scientists struggling to devise a better battery aren't obvious sources of drama. Few pursuits, however, have as much potential to change the world, a point Steve LeVine makes vividly clear in his new book. ... His subjects swipe ideas from one another, fret over how much of their research to publish for fear of tipping off the competition and cast nervous glances at China."
--David R. Baker, San Francisco Chronicle

"Steve LeVine has written a fast-paced, engaging account of one of this young century's great quests: the search for a technology that will unleash a dramatic transformation of the world with blockbuster new industries and culture-changing products. It's an amazing story, gripping in its surprising narrative and crowded with fascinating characters."
--Marcus Brauchli, former Executive Editor, The Washington Post, and former Managing Editor, The Wall Street Journal

"For the better part of two years, [LeVine] was given access to [Argonne's] Battery Department, emerging with a captivating book. ... [He] tells a rollicking good tale."
--Joe Nocera, The New York Times

“With the pace...of a thriller, [LeVine]...reveals how the very human foibles of scientists and entrepreneurs, as well as fundamental physics and chemistry, stand in the way of such efforts, which, if successful, could result in a new global industry and attendant jobs.”—***Scientific American***

“‘Powerhouse’ shows readers how a scientific insight can work its way slowly into the marketplace, to the point where it becomes ubiquitous. The book is also packed with the kind of strange, unexpected history that makes good science writing so memorable.”***—San Francisco Chronicle***

“Journalist LeVine (*The Oil and the Glory*) offers an inside look at the race among industrialized nations to develop a world-changing battery technology. The story’s intensity is bolstered by the high stakes…But LeVine wisely stays focused on the competition as it unfolds, luring readers into the drama with clear explanations of the American players involved in both the public and private sectors.”***—Publishers Weekly***

“LeVine is a masterful story teller and *Powerhouse* is a thrilling read about an innovator’s quest to transform our planet and our lives. His goal, a revolutionary battery, has the potential to change everything.” **—Peter H. Diamandis, chairman of the X-Prize Foundation and author of *Abundance: The Future is Better Than You Think***

“Gripping and mind-opening. Filled with astonishing research, *The Powerhouse* reads like a thriller. It’s *fabulous*.” **—Amy Chua, Yale Law professor and author of *Battle Hymn of the Tiger Mother* and *The Triple Package***

About the Author

STEVE LEVINE is the Washington correspondent for *Quartz*, a fellow at the New America Foundation, and an adjunct professor at Georgetown University. He is the author of The Powerhouse: Inside the Invention of a Battery to Save the World, and previously The Oil and the Glory and Putin's Labyrinth. He lives in Washington, D.C.

PART I

THE STAKES

1

Jeff Chamberlain’s War

Wan Gang worried Jeff Chamberlain. Before returning home to Beijing, Wan, China’s minister of science, had asked to visit two places—Argonne National Laboratory, a secure federal research center outside Chicago, and a plant near Detroit where General Motors was testing the Volt, the first new electric car of its type in the world. Jabbing his finger into a book again and again, Chamberlain said that Wan was no mere sightseer. He had a mission, which was to stalk Chamberlain’s team of geniuses, the scientists he managed in the Battery Department at Argonne. They had invented the breakthrough lithium-ion battery technology behind the Volt, and Wan, Chamberlain was certain, hoped to appropriate Argonne’s work. But Chamberlain was not going to let him. A war was on, he said—a battery war. And he was right.

Wan turned up at Argonne in the summer of 2010, animated and unfailingly polite, with gentle eyes and the look of his fifty-eight years. A senior Department of Energy official climbed onto a bus alongside him and his retinue for a tour of the laboratory, and Wan posed a fusillade of questions while offering his own observations. “We are experimenting with the creation of hydrogen fuel from the gas created by waste,” he said. “It costs half the price of gasoline.” Such talk charmed the battery guys. He was himself a materials scientist, with his own record of advances, speaking openly with equals. It helped that Wan did not explicitly mention nickel manganese cobalt, or NMC, the compound at the core of the Argonne invention contained in the Volt. In addition, he had quite a personal story. Growing up in poverty in the countryside surrounding Shanghai, Wan recalled going hungry and navigating fields in a tractor, the only motor vehicle he ever drove. From there, he worked a series of research jobs and won his first break—admission to a Ph.D.

program at the Clausthal University of Technology in Germany. After he graduated, Audi hired him as an engineer and he rose to be design manager in the automaker's Stuttgart-based electric car unit, an exceedingly prestigious position. In all, he had been working at Audi for eleven years when, one day, his former academic mentor at Shanghai's Tongji University visited the plant. He suggested that Wan transform his own country, and not Germany, into an electric-car powerhouse. Wan returned to China, where another break came: President Hu Jintao requested that Wan formulate a policy on electric vehicles and make China the world's number-one producer of them. He elevated him as the country's first non–Communist Party minister since the 1950s. Now it was Wan's job to execute Hu's will. The prevailing view abroad was that, it being China, Wan would succeed. Which brought the Americans back around to their original angst after having warmed to him.

The evening before his visit to Argonne, Wan was munching shrimp hors d'oeuvres at a reception on the terrace of the Kennedy Center in Washington, D.C., when an American recognized and approached him. Wan seemed to have been waiting for just this chance conversation. He took a last bite and passed the tail to an aide. "Why don't we sit over there," he said, gesturing to the café. They exchanged talk on personal topics, and when they turned to cars Wan said he agreed that a race was under way among industrialized nations. All of them were determined to create a great new battery that in turn would propagate the large-scale manufacture of electric vehicles. They were merely using different methods to get there. Wan was too genteel to predict outright that China would win but cited markers that would signal progress. "The big thing is getting the first one percent of the market," he said, meaning 150,000 electric cars on China's roads. "That will prove the technology. From there, it won't be that hard to reach ten percent of the market three or four years after that." His initial goal was the sale of 500,000 cars, about the same aim as Barack Obama had established for the United States, and one million by 2015. It was a lot of cars. But the numbers also reflected bravado. Both countries inflated their numbers to impress and psych out rivals.

The next morning at Argonne, Wan and his hosts filed into a conference room. A senior American scientist named Al Sattelberger led off the presentation. He flashed slides on two large screens. Wan interrupted.

"You have made remarkable achievements here," he said. "So today I have many questions for you."

"That's why I'm sweating," said Sattelberger.

The room erupted in laughter. It was mostly the Americans, who *were* sweating. Argonne possessed formidable intellectual firepower and inventions, such as the American patent for its NMC breakthrough. It achieved three grand aims—allowing the Volt to travel forty miles on a single charge, to accelerate rapidly, and to do both without bursting into flames. But despite the recent accomplishment, the United States trailed far behind its rivals. After more than a decade of manufacturing, Japan and South Korea controlled two thirds of the market for consumer batteries such as AAs, AAAs, and the lithium-ion technology used in smart phones. That gave them preeminence on the proving ground where new technologies were validated or broken: the factory floor. Most winning inventions became so when the kinks were worked out through trial and error with actual consumers—what the Japanese and South Koreans had done—and otherwise might be destined for oblivion. Now, the Chinese had adopted the principle and issued an edict requiring some two dozen companies to market models within two or three years. That had led Chinese manufacturers like BYD, Chery, and Geely to introduce experimental electric vehicles. None of China's rivals, the United States included, could simply decree the manufacture of one million electric cars with the confidence that they would actually appear. China's leaders had accomplished innumerable such feats. They terrified Jeff Chamberlain.

Why Argonne Let Wan In

One might fairly ask why Wan was allowed to visit Argonne. The perverse rationale was that the United States *was* so far behind. The Americans resembled the Japanese in the 1970s and the Chinese in the 1990s—they were very much at the bottom of a learning curve others had scaled before. Given that reality, the shrewdest path was to humbly work with the best in the world, glean what you could in visits such as Wan's, then trust in intellectual brawn to push through to victory.

The global meltdown of 2008 and 2009 had put a scare into Americans, who were determined to build a fresh economy on a foundation of substance and not financial, real estate, or dot-com bubbles. Europeans were similarly fearful and determined not to be left out of such a new frontier. Asia's export-propelled economies knew they, too, had to find another way. History told Wan Gang that global financial crises breed the type of fundamental technological discoveries that move economies. He observed before him the makings of just such a breakthrough in energy technology. Like the Americans and Europeans, Wan said that powerful, affordable batteries and the cars they propelled were bound to initiate the next great economic boom. Batteries were an underappreciated technology—they were already enabling the revolution in electronic devices, he said, and now were on the cusp of much more.

Others focused on how a transformed battery could shake up geopolitics. An electric age would puncture the demand for oil and thus rattle petroleum powers such as Russia's Vladimir Putin, Saudi Arabia's ruling family, and the Organization of the Petroleum Exporting Countries as a whole, stripped of tens of billions of dollars in income. China could put its population in electric cars, shun gasoline propulsion, and clean up its air. Generally speaking, the world might spend less on oil and worry less about climate change.

The numbers behind all this maneuvering were large. Forecasts of the annual market for advanced batteries in 2020 were about $25 billion, half the 2012 gross revenue of Google.1 That sum would double in the likely event that oil prices settled near or in the triple digits per barrel and drove more motorists away from gasoline propulsion. Battery-enabled hybrid and electric vehicles would command sales of $78 billion by 2020.2 If large-scale batteries could economically store electricity made by windmills and solar cells, that would be tens of billions more in annual sales.

Yet those figures accounted only for the *current* decade. The general thinking was that, after 2020, the new industries would be even more gargantuan, on the scale of today's ExxonMobil, General Electric, and Toyota, the kind of rare, high-value enterprises capable of firing up an entire future economy. By 2030, advanced battery companies would swell into a $100 billion-a-year industry and the electric car business into several $100 billion-a-year behemoth corporations.3

When you sought justification for this enthusiasm, you heard a mainstream assumption that hybrid and pure electric vehicles would make up 13 to 15 percent of all cars produced around the world by 2020; a decade or two later, they would reach about 50 percent.4 These estimates did not seem unreasonable when you considered the twenty- and thirty-year-long sales trajectories of previous consumer juggernauts like laptops and cellular phones.

Regardless of the care with which they were calculated, the sums were mischievous—no one could accurately project the market for products that did not yet exist. But the leaders of most of the world's industrialized countries—Japan and South Korea, Brazil, Finland, France, Germany, Israel, Malaysia, Russia, Singapore, South Africa, and the United Kingdom, not to mention the United States and China—decided it was a race, and so it was. In the words of a French government minister, it was a "battle of the electric car."5

Because of its record for executing goals at large scale, China loomed over the contest. Yet the Argonne guys felt comfort in that China was not there yet. For one thing, it was still cranking out second-rate technology. Japanese companies, with their two-decade manufacturing lead, conversely enjoyed a commanding 43 percent of the global market for lithium-ion batteries. South Korea held another 23 percent. As for the United States, some people counted it out, but not many. Because lithium-ion had theoretical room for more or less double its current performance, and the United States had both serious scientists and a large market, it still had considerable room to try.

A senior Argonne scientist said that when Wan toured the lab, the undercurrent was, “How can we benefit from this visit?” This created a double intelligence game. Lab managers focused deliberately on the snippets of conversation in which Wan might tip his hand. Yet they could push the boundaries of politesse. During his turn at the podium, for instance, Chamberlain mentioned a clutch of German, Japanese, and South Korean companies—BASF, Panasonic, Samsung, LG Chemical—that were reconfiguring their batteries with the NMC. They were seeking twice the energy of the lithium-iron-phosphate compound favored by Chinese battery makers. Chamberlain was sure that Wan already knew this, making the remark simple candor. If Wan perceived a dig at Chinese strategy, his expression did not betray it. Having gained privileged access to the lab, he rather seemed extraordinarily attentive as he listened to Argonne’s history and inspected some of its crown jewels.

3

A Good Place to Do Science

Although venture capitalists and other titans of Silicon Valley could belittle government-run science, they spoke differently about the Department of Energy’s seventeen national laboratories. Argonne commanded particular respect because of its past. It went back to 1942, when Nobel laureate Enrico Fermi traveled to Chicago as the Manhattan Project was getting under way. Fermi set up a makeshift laboratory underneath the Stagg Field football stadium at the University of Chicago and called it the “Met Lab,” for Metallurgical Laboratory. Obsessed with secrecy, he and his collaborators kept even their wives uninformed of the big breakthrough—Fermi’s creation of the world’s first self-sustained nuclear chain reaction, which began the nuclear age. Their sole disclosure went in code to the project leader: “The Italian navigator has just landed in the New World.”

“Were the natives friendly?” came the planned reply.

“Everyone landed safe and happy.”1

Fermi then moved on to Los Alamos to help build the world’s first atomic bombs and the Met Lab went on without him.

• • •

Eighty-nine-year-old Dieter Gruen had worked at Argonne for six decades, since almost the beginning of the Stagg Field days. “That’s Glenn Seaborg,” he said in his office, pointing to a framed photo of the cocreator of plutonium. Gruen was smallish and wore a silk, herringbone blazer. When he was fourteen, Gruen and his older brother fled Nazi Germany and made it to the United States. Gruen ended up attending high school in Little Rock, Arkansas, then Northwestern University, where he studied physics. In 1944, he turned up at Stagg Field with a bachelor’s degree. He was twenty-one. World War II was at a critical stage—D-Day had just happened—and young people like him were in high demand by Manhattan Project managers. He was dispatched immediately to Oak Ridge, Tennessee, to help produce sufficient uranium-235 for shipment to the bomb makers at Los Alamos, an effort that was behind schedule.

Gruen found some thirty thousand people already at Oak Ridge. The town had been built practically overnight just for them. There was a sea of mud. Construction was everywhere. Gruen slept in a barracks known as West Village 54. Enormous machines called calutrons had been built to produce uranium-235. Oak Ridge had been chosen because it was near powerful Norris Dam, the first big project of FDR’s Tennessee Valley Authority, which could provide the immense volume of electricity that the calutrons required.

So it went for eighteen months, until the war ended with the atomic bombing of Hiroshima and Nagasaki. The work at Oak Ridge wound down. Gruen returned to Stagg Field while beginning graduate studies at the University of Chicago—the Met had been named the country’s first national laboratory and had plenty for him to do. There was so much activity, in fact, that the Met felt cramped for space. Lab scouts began to hunt for a new home. They settled on a place called Tulgey Wood, a two-hundred-acre spit of farmland twenty-four miles southwest of the city along Route 66.

• • •

In 1936, Erwin O. Freund, a sausage titan who invented the skinless hot dog, named Tulgey Wood, his new estate, after the forest in *Alice in Wonderland*. Freund was extravagant and eccentric. He placed small, painted carvings of Tweedledee, Tweedledum, and other Lewis Carroll characters along bark trails through the property. He kept two pet chimps plus sheep and peacocks, raised championship boxers in an air-conditioned kennel, and dug limestone-lined lakes for boating in summer and ice-skating in winter. When a clothier friend gave Freund seven fallow deer—a species called *Dama dama*, which are born tan but in adulthood turn completely white—he cared for them, too.

Freund put up a fight when he learned that the Met scouts had settled on Tulgey Wood as the lab’s new home. He decided to employ “every means at my command for as long as necessary to prevent its being seized from me.”2 The government’s intent was to buy, not seize, the property, yet Freund battled to keep his estate. The dispute went on for a year, when, in 1947, Freund died of a sudden heart attack, allowing the federal acquisition to proceed.

The boxers were easy to move, but the deer would have to go to game parks. Some simply could not be captured and were left behind to wander. Over time, the scientists noticed the herd growing back, “glimpsed along the tree line through a morning fog, found on a knoll during an evening rain, or spotted in headlights near a road at night.”3 They became an enduring remnant of Erwin Freund’s grand project.

But what to officially call the Met now that it occupied a new place? Someone suggested Fermi Lab, but since such dedications ordinarily honored the deceased and the scientist was still living, the name of a local town was selected—Argonne.

The government purchased additional surrounding farmland. Argonne now covered 4,100 acres. To fill it in, workers planted about a million pine seedlings, which thrived and created a massive home for the growing deer herd. Argonne still looked like a military base, dotted with Quonset huts erected as offices. In the 1950s, red brick structures were added. They were given numbers instead of names. Building 205 was finished in 1951. The two-story structure would become home to Argonne’s Battery Department.

• • •

Many of Argonne’s first scientists commuted from Chicago aboard a shuttle bus for thirty-five cents’ fare. The lab provided the service because nearly all its staff lived in the city. Some called Hyde Park “Little Argonne” because of the number of residents employed by the lab. The ride took ninety minutes and passed streets dense with factories, warehouses, and rail yards before giving way to an expanse of farmland. It might seem long, but the driver, an amateur ventriloquist, entertained as he went. In one trick, he would startle boarding passengers with a voice that suggested someone shouting from behind to get on. But gradually the shuttle was discontinued as the scientists gave up the city and sought homes in nascent suburbs such as Aurora, Naperville, and Downers Grove. These communities, with roots stretching back to the 1830s, often resisted newcomers, and Argonne would have to vouch for their character before they could move in. Yet eventually most were accepted and some even found themselves embraced. Among the latter was Stephen Lawroski, head of the Chemicals Technology Division, whom tony Naperville dubbed "the Professor" and honored with a regular invitation to a daily breakfast club of local dignitaries at a downtown drugstore.

Dieter Gruen was awarded his doctorate in 1951. Graduates with his background had many choices. Fundamental research was under way across American industry. He interviewed at AT&T's Bell Laboratories and heard of positions at General Electric, Ford, and General Motors. Universities, too, were hiring professors and basic researchers. But Gruen remained drawn to Argonne, where he was already known and still proud to work. Argonne was already one of the world's premier research facilities. Experimentalists enjoyed a free flow of funding from Washington and tremendous liberty to research what interested them. Gruen accepted badge number 1989 and an office in Building 205.

At first, Gruen was assigned to a team building a nuclear submarine under the direction of Captain Hyman Rickover. His task was to figure out how to eliminate hafnium from zirconium, needed in combination with uranium to fuel the subs. The regime was strict. Virtually everything was top secret given that Argonne's primary function was to create sensitive nuclear technology. Gruen felt the danger. Scientists wore special yellow shoes and provided regular urine samples, both precautions against radiation contamination. An eight-foot fence surrounded the building, accessible only through a guard post. Every office contained a red wastepaper basket with bold all-capital lettering: BURN. They were for the classified papers that were no longer wanted. You weren't supposed to incinerate such documents yourself—the label was aimed at the disposal staff. But at least once, a scientist took the designation literally, setting his wastepaper basket afire and sending smoke into the hallway.

A couple of hundred people were already working in Building 205. Most of them were in their twenties and thirties, a mix of men and women, the latter mostly secretaries, and many were single. At lunch, the men bet over rounds of pinochle in the basement and through the day frequented coffee groups organized along every corridor. On weekends, the scientists visited one another's homes and numerous couples ultimately married. But generally speaking, Argonne seemed organized for the work conducted there without regard for the conditions under which it was carried out. Only rooms that absolutely required air conditioning were equipped with it, which meant that in the humid summer, moisture collected on overhead water lines and dripped onto the scientists. Some of them draped their equipment with protective plastic but they themselves still often got wet. At departmental meetings, overheated researchers regularly fell asleep.

Gruen didn't find it at all like Oak Ridge—the intensity was not there. After all, the war had ended. If you ignored the dangerous and classified projects under way, the lab seemed ordinary. Scientists worked from nine to five. In 1956, Gruen and his wife moved to Downers Grove, which had become another Little Argonne. "We didn't think anybody lived in Downers Grove except people who worked at Argonne," one of their children remarked.

Yet Gruen also noticed the envy of university friends. He had the use of rare and advanced equipment. If you were a "hotshot," which he was—he was his team's youngest senior scientist and assigned his own research group—you were smart to be at Argonne.

4

“Discouraged Weariness in the Eyes”

At times, the ferment of the 1960s seemed aimed at Argonne. Seeing their nuclear research stigmatized and budgets reduced, some people thought that Argonne’s existence was threatened. After a while, the lab director noticed “discouraged weariness in the eyes” of the scientists. Recalling his own time in Exxon’s research lab a few years back, the director reckoned that much of the gloom sprang not from the national politics but Argonne’s atmosphere—scientists were likelier to produce first-rate work if they were surrounded by first-rate facilities. He asked his wife to help. Before long, she had workers retiling and painting Building 205. They added lights in the public areas and gussied up the hitherto pale green offices with pinks, golds, and blues. The overall effect was a softer ambience, “a brand new building,” especially with the finishing touch of a jazz and blues concert series.

One researcher carried a loaded derringer into the lab, explaining that he attended classes in a dodgy neighborhood and needed the protection. He was fired when the pistol discharged as he changed clothes, wounding him. “No further gunplay in the locker room,” the division director said. At the annual Turkey Raffle in the basement auditorium, Sandy Preto, a lab researcher who moonlighted as a belly dancer at a nearby club, surprised colleagues with a performance.1

Throughout, the lab’s hazards remained unignorable. One day, a new scientist named Paul Nelson assisted a senior researcher who was heating and freezing molten zinc mixed with a few tenths of a gram of plutonium. For protection, they wore gas masks, but the concoction accidentally spilled and burned straight through some hot stainless steel. Nelson “thought about my children and decided it was time to leave.” Colleagues subjected him to good-natured ribbing for fleeing a harmless bit of combustion. They were somewhat less casual a few years later when an experiment with uranium and plutonium oxide blew out the glass panels of a working lab, created a bulge in the concrete walls, and scattered radioactivity.2 Researchers had accidentally installed the safety meter backward, leading to a buildup of hydrogen and oxygen. Cleaning crews removed the contamination while the researchers sat out some time on medical watch.

Some things went unchanged—gazing from his window one day, Nelson counted eighty-three white deer—but Argonne was aging. In the 1970s, a former senior manager remarked that the lab “isn’t exactly the Club Med type of atmosphere that one would expect to engender romantic relationships.”3 When high emotions did arise, they seemed to pit the various arms of science against one another. The engineers called the chemists “pharmacists,” who assailed the former as “pipefitters.” The physicists had a similarly low opinion of materials scientists. But the physicists cast themselves favorably as “part of the big science world [that] thought big.” Unlike the energy storage scientists, who insisted on going home for dinner at six, the physicists frequently worked around the clock, through weekends and on holidays if necessary, to repair, say, a failed particle accelerator.4

There was truth in what the physicists said—Argonne’s battery guys by and large were not the type who stuck out.

• • •

That was new, because for much of the eighteenth and nineteenth centuries, batteries and the electricity held within them were treated as an almost unfathomable force by poets, philosophers, and scientists. Those who had unleashed the epoch were accorded tremendous deference. Alessandro Volta invented the first battery and thus launched the electric age in 1799. It was a feat rooted in a debate with fellow Italian Luigi Galvani, who claimed that frogs possessed an internal store of electricity. Volta theorized that the electricity observed by Galvani originated in metals used as part of the experiment, rather than in the frogs themselves. Volta created his battery while carrying out experiments to disprove Galvani. Benjamin Franklin, a contemporary, had already coined the word to describe a rudimentary electric device he built out of glass panes, lead plates, and wires. But Franklin's was a battery in name only, while Volta's was a true electric storage unit. After Volta's brainchild, scientists kept hooking up batteries to corpses to see if they could be coaxed back to life. Many wondered whether electricity could cure cancer or if it was the source of life itself. What if souls were electric impulses?

To make a battery, you start with two components called electrodes. One is negatively charged, and is called the anode. The other, positively charged electrode is called the cathode. When the battery produces electricity—when it discharges—positively charged lithium atoms, known as ions, shuttle from the negative to the positive electrode (thus giving the battery its name, lithium-ion). But to get there, the ions need a facilitator—something through which to travel—and that is a substance called electrolyte. If you can reverse the process—if you can force the ions now to shuttle back to the negative electrode—you recharge the battery. When you do that again and again, shuttling the ions back and forth between the electrodes, you have what is called a rechargeable battery. But that is a quality that only certain batteries possess.

The battery's very simplicity—its remarkably small number of parts—has both helped and hindered the efforts of scientists to improve on Volta's creation. They had only the cathode, the anode, and the electrolyte to think about, and, to fashion them, a lot of potentially suitable elements on the entire periodic table. Yet this went both ways—there was no way to bypass those three parts and, as it soon became apparent, only so many of the elements that were truly attractive in a battery. In 1859, a French physicist named Gaston Planté invented the rechargeable lead-acid battery. Planté's battery used a cathode made of lead oxide and an anode of electron-heavy metallic lead. When his battery discharged electricity, the electrodes reacted with a sulfuric acid electrolyte, creating lead sulfate and producing electric current. But Planté's structure went back to the very beginning—it was Volta's pile, merely turned on its side, with plates stacked next to rather than atop one another. The Energizer, commercialized in 1980, was a remarkably close descendant of Planté's invention. In more than a century, the science hadn't changed.

In the early part of the twentieth century, electric cars powered by lead-acid batteries seemed superior to rivals featuring the gasoline-powered internal combustion engine. But a series of inventions, including the electric starter (which eclipsed the awkward rotary hand crank), finally gave the advantage to the internal combustion engine propelled by gasoline and contained explosions rather than a flow of electricity. For four decades, few seemed to think that things should be different.

In 1966, Ford Motor tried to bring back the electric car. It announced a battery that used *liquid* electrodes and a *solid* electrolyte, the opposite of Planté's configuration. It was a new way of thinking, with electrodes—one sulfur and the other sodium—that were light and could store fifteen times more energy than lead-acid in the same space.

There were disadvantages, of course. The Ford battery did not operate at room temperature but at about 300 degrees Celsius. The internal combustion engine operates at an optimal temperature of about 90 degrees Celsius. Driving around with much hotter, explosive molten metals under your hood was risky. Realistically speaking, that would confine the battery's practical use to stationary storage, such as at electric power stations. Yet at first, both Ford and the public disregarded prudence. With its promise of clean-operating electric cars, Ford captured the imagination of a 1960s population suddenly conscious of the smog engulfing its cities.

Popular Science described an initial stage at which electric Fords using lead-acid batteries could travel forty miles at a top speed of forty miles an hour. As the new sulfur-sodium batteries came into use, cars would travel two hundred miles at highway speeds, Ford claimed. You would recharge for an hour, and then drive another two hundred miles. A pair of rival reporters who were briefed along with the *Popular Science* man were less impressed—despite Ford's claims, one remarked within earshot of the *Popular Science* man that electrics would "never" be ready for use.

The *Popular Science* writer went on:

They walked out to their cars, started, and drove away, leaving two trains of unburned hydrocarbons, carbon monoxide, and other pollution to add to the growing murkiness of the Detroit atmosphere. [The other reporter's remark] was a good crack. But it was wrong. When a development is needed badly enough, it comes. Without some drastic change, American cities will eventually become uninhabitable. The electric automobile can stop the trend toward poisoned air. Its details are yet to be decided. But it will come. And it won't be long.5

For a few years, the excitement around Ford's breakthrough resembled the commercially inventive nineteenth century all over again. Around the world, researchers sought to emulate and, if they could, best Ford. As it had been on nuclear energy, Argonne sought to be the arbiter of the new age. In the late 1960s, an aggressive electrochemist named Elton Cairns became head of a new Argonne research unit—a Battery Department. Cairns initiated a comprehensive study of high-temperature batteries like Ford's. Someone suggested a hybrid electric bus assisted by a methane-propelled phosphoric acid fuel cell, and it was examined as well. Welcoming suggestions, the lab director insisted only that any invention be aimed at rapid introduction to the market. To be sure that would happen, he invited companies to embed scientists at Argonne for periods of a few months to a year, and many did so.

John Goodenough, a scientist at the Massachusetts Institute of Technology, said that everything suddenly changed. Batteries were no longer boring. Goodenough attributed the frenzy to a combination of the 1973 Arab oil embargo, a general belief that the world was running out of petroleum, and rousing scientific advances on both sides of the Atlantic. Pivoting off the Ford work, a young British chemist named Stan Whittingham, working as a postdoctoral assistant at Stanford University, discovered that he could electrochemically shuttle lithium atoms from one electrode to the other at room temperature with inordinate damage to neither. To explain this action, which created rechargeability, Whittingham borrowed the term *intercalation* from chemistry, and it stuck. Exxon, the oil giant, wishing to compete with Bell Labs—"to be perceived as *the* lab of the energy business"—offered to hire Whittingham at a significant salary.6 He accepted and set out to make a battery from his findings.

Whittingham was drawn to lithium, silvery white and malleable, because it is the lightest metal on the periodic table. But it reacts with air and, in certain circumstances, catches fire. Scientists therefore handle pure lithium metal only in a laboratory setting in which all moisture has been removed from the air. Whittingham could make lithium metal practical only if he could combine it with another metal into an alloy—which is what he did, coupling it with aluminum to create a small and powerful anode. In 1977, Exxon released Whittingham's device as a promotional product, a coin-size battery that fit in the back of a solar watch. It was the first rechargeable lithium battery. But when Whittingham tried to make them larger, his batteries kept igniting in the Exxon lab. Despite the presence of aluminum, the lithium metal was still too reactive.

Then Goodenough, the MIT scientist, proceeded to outdo all that Ford, Argonne, and Whittingham had accomplished. By the time he was finished, he would either himself produce, or be part of the invention of, almost every major advance in modern batteries.

Professor Goodenough

John Goodenough grew up in a sprawling home near New Haven, Connecticut, where his father, Erwin, was a scholar on the history of religion at Yale. His parents' relationship "was a disaster," he said, friction that extended into aloofness toward their children; Goodenough and his mother, Helen, especially "never bonded." When he was twelve, John and his older brother, Walt, were sent to board on scholarships at Groton and he rarely heard from his parents again. John's mother wrote just once as he grew to adulthood. In a slender, self-published autobiography, Goodenough cited many influences: siblings, a dog named Mack, a family maid, long-ago neighbors. But in this regard he conspicuously ignored his parents and never mentioned them by name. Theirs was a solely biological place in his life.

Goodenough's boyhood did not suggest the warm, amusing, and self-assured adult to come. Suffering from dyslexia at a time when it was poorly understood and went untreated, Goodenough could not read at Groton, understand his lessons, or keep up in the chapel. Instead, he occupied himself in explorations of the woods, its animals and plants. Somehow everything came together. He went on to thrive at Yale, from which he graduated summa cum laude in mathematics, then by happenstance fell into science: after World War II, Goodenough, by then a twenty-four-year-old Army captain posted in the Azores Archipelago off the coast of Portugal, received a telex ordering him to Washington, D.C.—educators had stumbled on unspent budget money and advocated using it to send twenty-one returning Army officers through graduate studies in physics and math. Goodenough had taken almost no science as an undergrad but, for reasons obscured by time, a Yale math professor had added his name to the group. So he found himself at the University of Chicago, studying physics under professors Edward Teller, Enrico Fermi, and others. As Goodenough registered for preliminary undergraduate classes, necessary to catch up with the others, a professor remarked, "I don't understand you veterans. Don't you know that anyone who has ever done anything significant in physics has already done it by the time he was your age?"

But it turned out that Goodenough had an intuition for physics. After obtaining his doctorate in 1952, he went to work at MIT's Lincoln Laboratory, which the U.S. Air Force had funded the year before to create the country's first air defense system. His team was told to invent a system of computer memory, a vital component of the envisioned air defense, which was to be called SAGE. At the time, computers comprised enough vacuum tubes to fill "the space of a large dance hall," in Goodenough's words, and had infernally slow memories.1 Some thought the task impossible because of the physical limits of the ceramic material with which the team was working. Three years later, the lab unveiled an invention that they called "64 x 64 bit magnetic memory," a triumph that, in addition to helping to enable SAGE, became the foundation of later computer memory systems. For Goodenough, more advances followed, including the "Goodenough-Kanamori rules," which became a standard for how metal oxide materials behave at the atomic scale, another building block of future computers.

Politics intruded—a U.S. senator named Mike Mansfield pushed through a law requiring that any research financed by the Air Force have an Air Force application. By now, Goodenough was fixated on finding a scientific answer to the OPEC-led energy crisis, which seemed to be the largest problem facing the country. But he was told to try something else—given the Mansfield law, the subject was the responsibility not of the Air Force but of the national labs.

For Goodenough, it was time to move on. A friend sent word of an opportunity across the Atlantic. Oxford University required a professor to teach and manage its inorganic chemistry lab. Goodenough was surprised to be selected given that he was not a chemist and in fact had completed just two college-level chemistry courses. He was lucky a second time to be chosen for a job for which he was underqualified, on paper.

• • •

Goodenough was a tough professor. An early student of his at Oxford recalled a physics course that started with 165 students. After a stern Goodenough lecture, she was one of just 8 to return for the second class.2 Goodenough was equally exacting in the lab. After MIT, he was on the hunt for big advances in solid state chemistry, a field known for creating the kinds of materials that go commercial. Among the first on his list of targets was Stan Whittingham's recently published breakthrough on the lithium battery.

For six decades, zinc carbon had been the standard battery chemistry for consumer electronics, having eclipsed lead oxide, which was too bulky and heavy for small devices. Whittingham's brainchild was a leap ahead of zinc carbon—powerful and lightweight, it could power portable consumer electronics such as tape recorders. If it worked. But basic physics got in the way. The same electrochemical reactions that enabled lithium batteries also made them want to explode: the voltage would run away with itself, a cell would ignite, and before you knew it the battery was spitting out flames. But you seemed no better off if you played it safe and used other elements—you'd find that they slowly fell apart on repeated charge and discharge.

Goodenough thought he could create a more powerful battery than Whittingham's. Much of invention, he said, involves shifting your mind-set, something many scientists either refused or simply could not do. The Exxon man's battery relied on a sulfide electrode; Goodenough turned to another family of compounds—metal oxides, a combination of oxygen and a variety of metal elements. In his judgment, oxides could be charged and discharged at a higher voltage than Whittingham's creation, and thus produce more energy. But there was also the matter of getting sufficient lithium to intercalate, the action that created electricity—pulling lithium from a cathode, in this case made of metal oxide, and sending it into a shuttling motion between the electrodes. The more lithium that could be shuttled, the more energy the battery would produce. But it seemed axiomatic that you could not remove all the lithium, because that would leave the cathode virtually hollowed out, and it would fall in on itself. So could any of the oxides manage to hold up under this abuse? And if so, which one, and what was the magic proportion of lithium that could be pulled out?

Goodenough directed two postdoctoral assistants to methodically work their way through structures containing a group of oxides; he asked them to find out at what voltage lithium could be extracted from the oxides, which he expected to be much higher than the 2.2 volts Whittingham was using, and to determine how much lithium could be intercalated in and out of the atomic structure before it collapsed. Their answer was half—about 50 percent of the lithium could be pulled from the cathode at 4 volts before it crumpled, which was plenty for a powerful, rechargeable battery. Of the oxides they tested, the postdocs found that cobalt was the best and most stable for this purpose.

In 1980, four years after Goodenough arrived at Oxford, lithium-cobalt-oxide was a breakthrough even bigger than Ford's sodium-sulfur configuration. It was the first lithium-ion cathode with the capacity to power both compact and relatively large devices, a quality that made it far superior to anything on the market. Goodenough's invention changed what was possible: it enabled the age of modern mobile phones and laptop computers. It also opened a path to the investigation of a potential resurrection of electric vehicles.

Over the years, Goodenough would attract a constellation of bright people to his lab, researchers who often had their best professional years with him. It was not that Goodenough himself did any of the hands-on experimentation—the postdoctoral assistants and researchers he attracted were actually at the bench. Goodenough could be stern, but the atmosphere of big expectation he created drove them to do exceptional work. And he talked them through their projects. One of these researchers was a young South African who arrived in 1981 with a curious idea about gemstones.

6

The Double Marathoner

The Comrades Marathon extends to the South African port of Durban from Pietermaritzburg, twenty-eight miles inland and three thousand feet lower in altitude. The first time that Mike Thackeray ran the race, in 1968, he finished in ten hours and three minutes, just under the eleven-hour cutoff for the slowest participants. Determined to do better, he ran it again. And again. In 1976, entering the race for the fourteenth time, Thackeray took fourth place with a time of 6:32. His discipline had paid off.

Thackeray was the lead inventor of Argonne's NMC technology, a descendant of the lithium-cobalt-oxide cathode pioneered by Goodenough and the formulation that had beguiled Wan Gang. Thackeray's office was situated within the main Battery Department suite, two doors down from his boss Chamberlain. Long halls lined with linoleum and pale green brick walls gave Building 205 a lingering feel of the 1950s. A handwritten sign taped to a coffee brewer requested that drinkers leave behind thirty cents a cup.

Two portraits decorated the walls in Thackeray's office—an 1861 etching of the nineteenth-century physicist Michael Faraday and a sketch of the astronomer William Herschel, who in 1781 discovered Uranus. Thackeray received them as gifts in his youth in South Africa. His mind returned often to his native land, which seemed to speak the most for his soul. Few knew it, he would say, but for a short time almost four decades before, South Africa was one of the great centers of battery thinking.

In Pretoria in the late 1970s, Thackeray, in shaggy, blondish hair and long sideburns, did his Ph.D. under a crystallographer named Johan Coetzer. One day, Coetzer walked into the lab and announced a new project. They were going to "do some stuff in the energy field." The Yom Kippur War between Israel and its Arab neighbors had triggered an energy crisis and the Western world was seeking a way around Middle East oil. Coetzer thought one answer was the advancement of batteries and he told Thackeray that that was where they would focus their work. The effort was challenged from the beginning because of South Africa's system of apartheid, to which the world had responded with economic sanctions. No one outside the country would collaborate with them. To avert international trouble, they had to cloak their work in secrecy and communicate using code words. The smokescreen did not seem to matter much since neither Coetzer nor Thackeray knew anything about energy storage. But their fresh eyes turned out to be advantageous. Approaching the field laterally, "uncontaminated by how other scientists were looking at the world," as Thackeray put it, they found insights into high-temperature batteries, the breakthrough reported by Ford and Stanford. The early result was the Zebra, South Africa's own molten battery. Corporate funding quickly followed, a respectable achievement when you recalled their modest start.

Considering the Zebra, Thackeray thought there still must be a way to do better and at the same time move ahead of John Goodenough's blockbuster advance in 1980. The Zebra and other molten batteries, operating at 300 degrees Celsius, were unsafe, inside a car anyway. As for Goodenough's room-temperature formulation of lithium-cobalt-oxide, it was an improvement but still expensive if you thought of using it in electronic devices.

In physics, there is a structure called *spinel*. These structures have considerable advantages. They are abundant and therefore cheap. They have an appealing three-dimensional structure resembling a crystal. And spinels are inherently stout—sturdier, for instance, than the layered structure of Goodenough's lithium-cobalt-oxide electrode. Goodenough had been instructing his lab assistants to put half the lithium in motion between the cathode and the anode; but Thackeray wondered whether *all* the lithium could be pulled in and out of a spinel cathode. If he could do so without the cathode's collapsing, spinel would be less expensive and potentially much more powerful than the lithium-cobalt-oxide.

The particular spinel that interested Thackeray was iron oxide. Ordinarily, we know iron oxide as rust—it is what happens when you leave your bicycle out in the rain. But for battery scientists, iron oxide is also a spinel, lending it special characteristics. In South Africa, Thackeray had already successfully shuttled lithium in and out of iron oxide working at the same high temperatures as the Ford researchers. He had a hunch that iron oxide might also cooperate at room temperature, which would make it much more practical.

Users Review

From reader reviews:

Teressa Fernandez:

Why don't make it to be your habit? Right now, try to prepare your time to do the important action, like looking for your favorite e-book and reading a reserve. Beside you can solve your long lasting problem; you can add your knowledge by the book entitled The Powerhouse: Inside the Invention of a Battery to Save the World. Try to the actual book The Powerhouse: Inside the Invention of a Battery to Save the World as your close friend. It means that it can to get your friend when you sense alone and beside regarding course make you smarter than in the past. Yeah, it is very fortuned for yourself. The book makes you a lot more confidence because you can know every little thing by the book. So , let's make new experience in addition to knowledge with this book.

Randy Gable:

This The Powerhouse: Inside the Invention of a Battery to Save the World book is not ordinary book, you have it then the world is in your hands. The benefit you receive by reading this book will be information inside this reserve incredible fresh, you will get facts which is getting deeper you actually read a lot of information you will get. That The Powerhouse: Inside the Invention of a Battery to Save the World without we understand teach the one who reading it become critical in thinking and analyzing. Don't be worry The Powerhouse: Inside the Invention of a Battery to Save the World can bring whenever you are and not make your bag space or bookshelves' turn into full because you can have it in your lovely laptop even telephone. This The Powerhouse: Inside the Invention of a Battery to Save the World having great arrangement in word along with layout, so you will not sense uninterested in reading.

Shane Hern:

The guide with title The Powerhouse: Inside the Invention of a Battery to Save the World includes a lot of information that you can study it. You can get a lot of gain after read this book. This particular book exist new information the information that exist in this reserve represented the condition of the world right now. That is important to yo7u to learn how the improvement of the world. This specific book will bring you with new era of the the positive effect. You can read the e-book on the smart phone, so you can read the item anywhere you want.

Gene Conley:

The Powerhouse: Inside the Invention of a Battery to Save the World can be one of your beginning books that are good idea. Many of us recommend that straight away because this book has good vocabulary that could increase your knowledge in vocab, easy to understand, bit entertaining but nonetheless delivering the information. The copy writer giving his/her effort to set every word into satisfaction arrangement in writing The Powerhouse: Inside the Invention of a Battery to Save the World yet doesn't forget the main level, giving the reader the hottest along with based confirm resource data that maybe you can be among it. This great information can drawn you into completely new stage of crucial imagining.

Download and Read Online The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine #7CRMKS3EOBP

Read The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine for online ebook

The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine Free PDF d0wnl0ad, audio books, books to read, good books to read, cheap books, good books, online books, books online, book reviews epub, read books online, books to read online, online library, greatbooks to read, PDF best books to read, top books to read The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine books to read online.

Online The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine ebook PDF download

The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine Doc

The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine Mobipocket

The Powerhouse: Inside the Invention of a Battery to Save the World By Steve Levine EPub