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55 Book reviews on global economy and geopolitical readings

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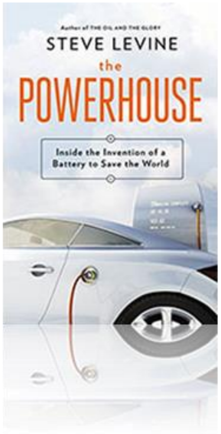
The Powerhouse: Inside the Invention of a Battery to Save the World



Levine, Steve (2015), Penguin Group, New York.

"Venture capital firms were competing fiercely for the most promising ideas. They had decided that renewable energy was the next big boom. But their eagerness seemed different from the past manias. It wasn't just about money. The fever aligned with the strain of politics, which generally vilified oil, embraced its technological rivals, and fretted about climate change. Here was a way for the venture capitalists to do well and do good."

Summary

A super-battery would transform the world. It would weaken Vladimir Putin's Russia, endanger the Saudi Arabian royal family, threaten the future of OPEC, and transform China into one of the world's cleanest industrialising nations. For the nation fortunate enough to own the patent to such a super-battery, the earning potential would be immense. And for the rest of the world, spending would decline on oil and gas, as would worries about climate change. What then is needed for such a super-battery to be made available?

To learn about batteries, Steve Levine enjoyed unprecedented access for two years to the Argonne National Laboratory in the United States. This federal research centre, located just outside of Chicago, hosts a group of scientific geniuses who are attempting to solve this monumental challenge in the world of physics. However, as Levine discovers, these researchers are not alone in wanting to find the formula. The same goal is being pursued in South Korea, Japan, China, and the UK. It is a battery war.

Steve Levine explores the intricacies of this technological race, full of hopes and frustrations, and reports on the advances announced over the last decade in terms of voltage, cost, and energy storage – some of which failed to materialise. This book will improve the reader's understanding of batteries, their problems, methods, and the technology needed to produce the long awaited super-battery. His book, however, leaves the ending open.

The author

Steve Levine has written *The Oil and the Glory* and *Putin's Labyrinth*. He is Washington correspondent for Quartz, where he writes about the geopolitics of energy and technology. Levine is also a researcher at the New America Foundation, teaches energy security at Georgetown University's School of Foreign Service, and was previously a foreign correspondent for *The Wall Street Journal* and *The New York Times*.

Key ideas and opinion

In 2010 the economic crisis led the news, and pessimism about the prospects for a revitalised economy was widespread. However, Levine noted that one industry was immune to pessimism, both in the United States and across the world: the battery industry. **Scientific researchers are confident that if the formula is found for a super-battery that doubles voltage capacity and energy storage at a competitive price, a giant new technological industry will be born, heralding the next economic boom**.

To understand this race for the super-battery, Steve Levine spent two years closely studying the American Argonne National Laboratory. This laboratory had two world-renowned battery experts and a history of great inventions – such as the US patent for nickel-manganese-cobalt cathode (NMC) technology that cut the cost of batteries while improving their autonomy, reliability, and safety. In short, **the lab at Argonne was the best place to analyse the motivation, progress, and risks in a sector with an estimated sales potential of $25 billion annually by 2020 – but which could be worth tens of billions of dollars more** if large-scale batteries are produced for storing electricity generated by wind and solar energy. Such super-batteries could also generate an annual market worth $100 billion by 2030 from the sale of electric vehicles.

Levine begins by explaining that **in the early twentieth century, electric vehicles powered by lead-acid batteries appeared to offer a better performance than cars powered by gasoline internal combustion engines. However, a number of inventions, including the electric starter, gave the advantage to gasoline internal combustion engines.** For decades, few people thought differently. The Ford Motor Company tried to relaunch the electric car in 1966, and announced a battery using liquid electrodes and a solid electrolyte. This was a new approach, using small electrodes (one sulphur and the other sodium) that could store up to 15 times more energy in the same space as lead-acid batteries. There were some issues, however: the internal combustion engine operates at an optimum temperature of 90 degrees Celsius) and so from a practical point of view, this **limited the use of the new battery** – which ran at far higher temperatures – **to stationary storage**. However, by promising clean electric vehicles, Ford had captured the imagination of a public that was becoming aware of the environmental challenges signalled by increasingly smoggy cities. Ford's announcement also attracted the attention of Argonne, which sought to be the arbiter of this emerging era, as it had previously been for the era of nuclear energy.

As remarked by **John Goodenough**, a scientist at the Massachusetts Institute of Technology (MIT) who would later join an inorganic chemistry team at the University of Oxford, everything suddenly changed. Batteries were no longer boring. Several factors contributed to the change: the 1973 Arab oil embargo, a widespread belief that oil reserves were running out, and scientific breakthroughs on both sides of the Atlantic. The author of *The Powerhouse* explains how Goodenough improved the **first rechargeable lithium battery that was released by Exxon Mobil in the late 70s**. To do this, he turned to another family of compounds: metal oxides (combinations of oxygen and a variety of metal elements). He believed that oxides could be charged and discharged at a higher voltage than the Exxon Mobil battery and thus produce more energy. To do this, it was necessary to obtain enough lithium to intercalate (the chemical action that generates electricity). Having determined that 50% of the lithium could be extracted at four volts from a cathode before it collapsed, he then verified that cobalt oxide was a more appropriate and stable oxide for this purpose. Goodenough had revolutionised research into electric batteries. He produced **the first lithium-ion cathode capable of powering relatively large devices**, making it far superior to any other product on the market. Its invention heralded mobile phones and computers, and resurrected research into electric vehicles.

A key role in this resurrection, according to Levine, was played by a South African marathon runner, **Mike Thackeray**, who applied for admission to Oxford for his compulsory overseas year and arrived with the aim of intercalating lithium using samples of magnetised **iron oxide** that he had brought from Pretoria. With the help of a magnetic stirrer (an automated device for mixing chemicals) Thackeray managed to combine lithium with iron oxide at room temperature. He noted that the iron oxide had fallen away from the stirrer during the process, showing that it had lost its magnetic qualities, which was encouraging for intercalation. Thackeray had demonstrated that spinels had an unexpected quality of hospitality: when lithium was introduced, the iron ions moved around to create space for it. The spinel experienced a 'phase change', absorbing the iron and transforming into a slightly different material that resembled rock salt. Just like Goodenough with his invention of lithium cobalt oxide, Thackeray had **significantly improved the energy density of carbon-zinc batteries**. He later discovered that if **manganese oxide** was used instead of iron oxide (which did not offer a sufficiently clear path for lithium), the result was a working cathode (in other words, a practical battery). The South African Inventions Development Corporation, the intellectual property branch of the South African government, became the owner of this invention.

After his period at Oxford, and a brief return to South Africa where his lithium-ion programme was closed for lack of funding, Thackeray joined the laboratory at Argonne. Alongside **Johnson**, a chemistry researcher from the University of North Carolina who had spent his entire career in Argonne, Thackeray managed in the mid-90s to create **a battery using lithium with a combination of nickel, manganese, and cobalt (the NMC battery)**. This battery was used in the **plug-in hybrid car – the Volt – launched by General Motors**. Cars equipped with the NMC battery could travel **64 kilometres on a single charge**. The introduction of manganese had made the battery **safe**, and the new battery offered the **quick acceleration** demanded by American drivers. From this invention onwards, the battle was to improve NMC technology.

In the late 90s, another figure appeared in the battle for the super-battery: **Khalil Amine**. As a student in Morocco his results in the national science exam won him a scholarship at the University of Bordeaux, where he obtained a Ph.D. in chemistry. After post-doctorate work at the University of Tokyo, Amine began working at the **Japan Storage Battery Company**, where he was made head of research and **invented a five-volt battery using nickel and manganese (whose license was sold to Sony and Samsung)**. Subsequently, Amine joined Argonne and became a central figure in the battery department, where he managed to patent a new molecule based on boron and fluorine, which when added as tiny amounts of powder to an electrolyte, absorbed excess electrons and so reduced the risk of fire.

Steve Levine indicates that after this invention little happened at Argonne until **Jeff Chamberlain,** a post-doctorate researcher from Georgia Tech, joined the intellectual property division in 2006. With Chamberlain on board, Argonne sought to grant licences to companies, thereby extracting revenue from the NMC battery market and ensuring payments were made for using the technology – even in the 'patent-free' environment that prevailed in Asia. Argonne also managed to ensure that everyone eagerly awaited the arrival of **NMC 2.0**, the advanced cathode it was developing. The new cathode involved jolting the NMC battery with a little more than 4.5 volts of electricity, and its production would **double the speed of a car battery and halve its cost**.

Levine explains how at around this time, **Envia**, a Silicon Valley start-up company, requested an NMC license to explore several new developments. In the summer of 2007, Envia co-founder Sujeet Kumar, a graduate in engineering from the Varanasi Technological Institute with a PhD from the University of Rochester, started raising $3.2 million to license and validate the idea of NMC 2.0 (a clear indication that NMC 2.0 could be close). Envia announced in 2011 that it had developed a **cathode that reduced the cost of the battery to $250 per kilowatt-hour – less than half the current market price**. Moreover, it announced that its next product, due nine months later, would further reduce the cost to $200. By comparison, the US Department of Energy was simultaneously challenging researchers to reduce the price to $300 per kilowatt-hour by 2014 or 2015, with the goal of achieving $125 by 2022. Therefore, for Steve Levine it was unsurprising that Envia's announcement attracted the attention of several Asian companies interested in starting informal bidding for the start-up.

Envia also attracted the attention of General Motors (GM). Levine reports that a man heading up the negotiations at **GM, Jon Lauckner, aimed to achieve the largest possible technological leap for the next generation of Volt cars** – due for launch in 2016. A much better battery was needed for the new car, a battery that would cost thousands of dollars less, and take the car much greater distances. Lauckner took an unprecedented decision (given that GM traditionally worked with large established providers) and **chose the start-up Envia to produce the most crucial component of the new generation Volt**. The idea was to work step-by-step for 18 months on Kumar's cathode. Lauckner proposed that GM Ventures invest $17 million in the start-up. GM would contribute $7 million and the remaining $10 million would come from two Japanese companies, Asahi Kasei and Asahi Glass (both large suppliers of battery materials). The goal of Envia (which was almost insolvent at the time of the agreement) was to win the contract with GM and then sell the company at the most profitable moment – hopefully for one billion dollars. The only remaining obstacle was for Lauckner to overcome reluctance within GM, which just two years earlier had declared bankruptcy and needed a $49 billion state bailout to survive.

Levine stresses that Chamberlain and **the Argonne team, whose goal was to build a super-battery that would enable America to gain independence from oil**, were feeling increasingly anxious and under pressure. Unlike other contemporary universities that were traditionally entrepreneurial, it was not in the DNA of Argonne to turn ideas into competitive companies. Argonne decided to change this history by bidding for a tender published on the website of the US Department of Energy in February 2012 to manage a new innovation hub for energy storage called 'Battery Hub'. In order to win the competition, Argonne had to convincingly explain how it would invent a battery that could finally rival the energy density of gasoline. To do this, Argonne had gathered the best battery scientists in the nation, from Berkeley, MIT, Stanford, A123 (the lithium-ion company), and Johnson Controls (one of the leading global producers of lead-acid batteries).

However, matters became more complicated for Argonne when it received an email from one of the researchers at an American company called Waltham indicating that the voltage jolt that boosted the power of NMC 2.0 also seemed to change its thermodynamics. It seemed that **a scaled-up NMC 2.0 battery could not provide the same power for cars as it had indicated when a coin-sized version was tested by Argonne**. Levine explains that this meant redirecting the efforts of the Argonne battery department towards resolving this problem – a task that would cost some $4 million annually, and could take up to three to four years. Envia was working on the NMC battery invented by Argonne and responded to this bad news with mixed feelings. It reacted cautiously because the start-up did not want to see the deal it was about to sign with GM fall through. However, individuals at the company felt some excitement because **the answer to the problem could be in the coating compounds**, and Envia was in a position to produce a solution before the competition. This mixed feeling was widely shared in the industry.

This setback to the future prospects of NMC 2.0, along with disappointing worldwide sales figures for electric vehicles, seemed to indicate that the race for the super-battery had ended. Steve Levine notes that in 2011 GM only sold 7,671 Volts in America, compared to a forecast of 10,000. In China, the results were even worse, with sales of just 8,159 electric vehicles nationwide. ExxonMobil, meanwhile, had just published an energy forecast predicting that oil and gas would supply 60% of global energy by 2040, up from 55% in 2010. Although the report predicted that almost half of the global car fleet would be electrified by 2040, it considered that the market for fully electric vehicles would remain paralysed. The report based it forecast on the limited progress that was being made on reducing the performance gap with combustion engines.

However, Steve Levine notes that **Kumar, the co-founder of Envia, remained convinced that he would find the formula and that the road ahead involved improvements to the anode and not the cathode**. The anode was the starting point for lithium. Kumar's team discovered that the best anode was made of **silicon monoxide particles embedded into carbon**. They therefore built pores into this silicon-carbon combination measuring between 50 nanometres and 5 microns in diameter, and then filled them with electrolytes. Carbon in the shape of fibres or nano-sized tubes was also mixed into the anode, thus creating an electrically conductive network. The silicone's expansion was thus redirected and absorbed. The results were satisfactory and provided a density of 400 watt-hours per kilogram.

These results were received with excitement by **Arun Majumdar**, director of the Advanced Research Projects Agency for Energy (**ARPA-E**), which was founded in the US in 2009 with the aim of identifying pioneering research. **If this battery could be scaled up for use in vehicles, it would be possible to drive from New York to Washington on a single charge and at half the price of current technology** (around $30,000). This announcement was well received by companies, investors, and the media at an ARPA-E conference on new energy technologies. Envia was described by a reporter as the 'Golden Child of the Summit'. Levine explains how this announcement was, at best, confusing for Argonne and other industry competitors. **How could Envia (a laboratory with three dozen researchers running on a fairly tight budget) manage to achieve greater progress than everyone else**, including the inventors of NMC 2.0? Despite this shock, Levine claims that the main concern for Argonne remained winning the Battery Hub contract.

After the conference, Kumar received offers from Korea's Samsung, the Japanese-American company Dow Kokam, and GM. **After negotiations with Envia, GM agreed to provide $8 million a year for a minimum of four years to achieve the launch of an electric car in 2016 that would travel 322 km** on a single charge, and a battery that operates at 350 watt-hours per kilogram. **However, Envia was soon receiving complaints from GM engineers that it was impossible to reproduce the results**. Envia's inability to demonstrate the results was compounded by an announcement that a company called Shin-Etsu had created the anode that Envia was working on (Kumar had considered Envia to be the rightful owner of the anode because of the various treatments, coatings, and nanomaterial processing that Envia had added in order for the anode to work). Although Envia attempted to bring relations with GM back on track, **the contract was terminated after the second quarterly revision of the results**. The promise remained unfulfilled.

Argonne, however, managed to win the **Battery Hub** contract. In its presentation, the team noted that the main obstacle to achieving the super-battery was the methodological approach whereby scientists focus on publishing and engineers focus on results – causing gaps to open between teams working on the anode, cathode, and electrolyte. **Argonne, says Levine, had learnt the need to integrate engineering and manufacturing. The lab now used a trial and error approach**. The objective was to achieve a gradual improvement of 5% in battery performance, which was too slow to achieve the objectives of the private companies involved – but still represented considerable progress. Moreover, given the track record of the laboratory, success was quite likely. Shortly after winning the Battery Hub contract, the **Argonne team received a visit from President Obama** – who praised Thackeray and his team for their perseverance in energy research. **America began to believe that it could still win the race**.