Institute for New Economic Thinking
Working Papers
ineteconomics.org/workingpapers

The Asian Battery Companies Charging the EV Transition

Matt Hopkins and William Lazonick[1]

Working Paper No. 253

August 28th, 2026

Abstract

Based on a program to develop a zero-emission electric vehicle (EV) launched in 1990, between 1996 and 1999 General Motors (GM) produced 1,117 EV1s, leasing them to selected customers. In October 2000, however, having ceased the production of EV1s, GM sold its EV battery joint venture with Energy Conversion Devices to Texaco. Then, from April 2003, GM began to reclaim the EV1s from their users and literally crushed them out of existence. Recognizing the opening created by GM's destruction of the EV1, in July 2003, Martin Eberhard and Marc Tarpenning founded Tesla. Ten months later, Elon Musk became Tesla's main financial backer and chairman, investing $6.35 million of the $7.5 million raised in Tesla's first round of venture funding. Flash forward 15 years to 2019, when Tesla sold 367,656 battery electric vehicles (BEVs) worldwide, with 51.5 percent delivered outside the United States, including 42,715 BEVs produced and sold in China. Tesla's success signaled that the United States was positioned to become the leader of the global EV transition. That apparent lead was short-lived. China-based BYD, which sold just 147,185 BEVs in 2019, delivered 2,256,714 BEVs in 2025, compared with Tesla's 1,636,129.

[1] Academic-Industry Research Network.

The authors gratefully acknowledge the Institute for New Economic Thinking for funding the research presented in this paper.

BYD also sold 2,288,709 plug-in hybrids (PHEVs), compared with Tesla's zero, and the Chinese company could claim global leadership in both types of EV. Moreover, inside every vehicle BYD delivered in 2025 was a BYD battery, making the company the world's second largest EV battery maker. BYD's 16.4 percent share of the global EV battery market was less than half the 39.1 percent share of China-based CATL, a pure-play battery maker, but far surpassed Korea-based LG Energy Solution, in third place with a 9.3 percent share. Japan-based Panasonic, which supplies the batteries for Tesla's EVs produced in the United States, had 3.9 percent of the global EV battery market in 2025. Asia is home to all the leading EV battery companies, while the United States can claim no major EV battery maker. This paper documents the rise to global dominance of the Asian EV battery companies, focusing on Panasonic, LG Energy Solution, BYD, and CATL. Building on the contents of this paper, we are currently deploying the "theory of innovative enterprise" to explain fully, in future papers, the sources of competitive advantage of the Asian battery makers and the reasons why the United States has fallen so far behind in the development and production of this critical technology.

https://doi.org/10.36687/inetwp253

JEL codes: B52, D21, D22, F23, F63, L1, L2, L62, L65, N85, O3, Q42

Keywords: Lithium-ion batteries, electric vehicles, global leadership, innovative enterprise, Sony, Sanyo, Matsushita, Panasonic, LG Chem, LG Energy Solution, BYD, ATL, CATL, Tesla, General Motors

The EV transition: China's race to lose

On January 4, 1990, Roger Smith, CEO of General Motors, announced at the Los Angeles auto show that his company was about to launch a program to develop a zero-emission electric vehicle (EV), known as Impact.[1] The choice of name for the sporty, two-door concept EV quickly provided late-night comedians with a gag line—Johnny Carson quipped that Ford was producing a competitor called "Whiplash".[2] On Earth Day, April 22, 1990, Smith took the even bolder step of claiming that, within the decade, GM would mass produce 25,000 Impacts per year. The California Air Resources Board (CARB) took GM's announcement seriously, using it in September 1990 to justify establishing a mandate that required leading car manufacturers to include zero-emission vehicles as at least two percent of their car units sold in the State by 1998, five percent by 2001, and ten percent by 2003.[3] GM, in other words, was spearheading an EV transition that was sure to transform both the auto industry and significantly reduce the deleterious impact of fossil fuels on the global environment.

Robert Stempel, Smith's successor as GM CEO as of August 1990, was an ardent champion of the Impact project. An engineer, he was the first genuine "car guy" to lead GM since the 1950s. In 1973-1975, Stempel had made his mark in mid-career by overseeing GM's transition to catalytic converters on all its cars, a technological advance that reduced air pollution while also requiring that the national fuel supply be transitioned to the use of unleaded gas. After a decade of losing market share to the Japanese as, under Smith, GM had wasted $90 billion on top-down automation, the new CEO understood that the company needed to secure the commitment of its shop-floor labor force to improve the quality and lower the cost of its current line of cars. Profits from these internal-combustion engine (ICE) vehicles could then provide the company with the financial commitment to invest the billions of dollars required to develop the Impact, the first step in GM's strategy to become the global leader in the EV transition that could take place in the first decades of the 21st century.

To set the stage for the organizational integration of GM's blue-collar workers into an effective strategy of manufacturing innovation, in a contract with the United Auto Workers (UAW) in September 1990, Stempel committed $4 billion to a job-guarantee program that was essential to securing the cooperation of GM's labor force in adopting Japanese manufacturing methods—which American observers had begun to call "lean" production—be it for internal-combustion-engine (ICE) vehicles in the here-and-now or EVs in the post-millennium decades.[4] During the 1980s, GM had already found proof of the importance of employment security to car innovation at both NUMMI, its California-based small-car joint venture (JV) with Toyota, and Saturn, its wholly owned Japanese-style subsidiary in Tennessee, which had started shipping its cars to customers in 1990.[5]

In the year and a half following the agreement with the UAW, however, economic recession stalled the demand for cars, leaving GM with $9.5 billion in total losses (before extraordinary items) in 1990-1992. In October 1992, Stempel was forced to resign, with a finance guy, Jack Smith, taking his place as CEO. From that point forward, GM became a company bent on "maximizing shareholder value", with only a minimal commitment to its Impact EV project.[6]

In 1993, the Impact team struck a compromise to ensure that the program would not be cancelled outright. GM's head of the Impact program, Kenneth Baker, offered GM's top managers an option to fund 50-100 hand-built Impacts and initiate a partnership with Ford and Chrysler to defray R&D costs. By forming "TeamUSA", as Baker called it, GM, Ford, and Chrysler could respond, at the lowest possible cost, to the California zero-emission mandate and potential Japanese competition.[7] Calling the TeamUSA collaboration "EV3", the Big Three established a unified front to develop EV technology while also securing subsidies from the Department of Energy that greatly reduced R&D costs that the automakers had begun to absorb. In 1991, as a precursor to gaining government support, the three companies formed the U.S. Advanced Battery Consortium (USABC), which remains in existence today.

In 1993, however, first Chrysler withdrew from TeamUSA, thus transforming the collaboration from EV3 to EV2, then Ford left, leaving GM to go it alone with the Impact. Subsequently, GM dropped Impact as the car's name, adopting instead EV1. With the caption "Teamwork in Action", the cover of GM's *1995 Annual Report* displays, front and back, a picture of about 400 GM employees semi-circled around their shiny red EV1. The message: GM was positioned to become the first major car company to mass produce a battery electric vehicle (BEV). Beginning in 1996, GM put a total of 1,117 EV1s on the road. Bearing the GM badge, the company leased the EV1s to select, often high-profile, customers through its Saturn dealerships.[8]

From April 2003, GM began to reclaim the EV1s from their users and, as graphicly documented in the 2006 film, *Who Killed the Electric Car?*,[9] GM literally crushed almost all the EV1s that it had produced from 1996 to 1999 out of existence. In fact, however, the EV1 project had already been extinguished on October 10, 2000, when, GM sold to Texaco (among the largest U.S.-based petroleum companies) its 60 percent stake in the GM Ovonic EV battery JV with Energy Conversion Devices (ECD). The JV had been supplying innovative nickel metal hydride (NiMH) batteries to the second-generation EV1 (produced in 1999). With Ovonic NiMH batteries on board, the EV1 had a range on one charge of about 200 miles, compared to the 100-mile range when equipped with lead-acid batteries that powered the first-generation EV1s. In exiting GM Ovonic, GM in effect reduced the scope of NiMH batteries to small-format uses only, which limited their use to consumer electronics and hybrid-vehicle applications rather than the large-format batteries required for BEVs.[10] Over the next two decades, lithium-ion (Li-ion) supplanted NiMH as the battery of choice in most consumer electronics and EV applications. GM's leadership in the EV transition with its 1990 Impact project, is now remembered as one of the company's most egregious failures.

GM's deliberate exit from the incipient EV industry left open the opportunity for a competitor to emerge as a first-mover in mass producing an EV. On July 1, 2003, the challenge was taken up by Martin Eberhard and Marc Tarpenning, who founded Tesla as a BEV company in California. Elon Musk invested in the fledgling company in February 2004, making himself chairman of the board as of April 2004. After ousting CEO Eberhard in late 2007, Musk became Tesla CEO in early 2008. Over the next decade, Tesla emerged as the pioneer and leader in the production of BEVs, including winning permission from the Chinese government to be the first wholly owned foreign car company permitted to mass produce in the PRC, thus playing a key role in sparking the global EV transition.[11] But Tesla has not innovated in the most critical component of the EV: the rechargeable battery—which is one important reason why in 2025 Tesla's unit BEV sales were only 72.5 percent of those of the global BEV leader, China-based BYD.[12] Moreover, in 2025, in addition to 2,256,714 BEVs, BYD sold 2,288,709 plug-in hybrid electric vehicles (PHEVs), placing it well ahead of Tesla which delivered 1,654,667 BEVs and zero PHEVs.

Not only the world's largest BEV and PHEV manufacturer, in 2025 BYD was also the world's second-largest EV battery producer, with 16.4 percent of the global market, behind China-based CATL, a pure-play battery maker with 39.1 percent.[13] The next eight EV battery companies in 2025 were Korea-based LG Energy Solution (9.3 percent), China-based CALB (5.3 percent), China-based Gotion High Tech (4.5 percent), Korea-based SK On (3.7 percent), Japan-based Panasonic (3.5 percent), China-based Eve Energy (2.6 percent), Korea-based Samsung SDI (2.4 percent), and China-based Svolt (2.4 percent). In 2014, Panasonic and Tesla kicked off the current EV battery race by building the first "Gigafactory"—a direct response to the limitations posed by global Li-ion production capacity at that time, which had been built for a booming portable electronics sector. Tesla remains dependent on Asian firms for its batteries and has so far failed in its efforts to mass produce high-quality batteries on its own.[14]

This paper is the introduction to a book project undertaken by the Academic-Industry Research Network (AIRnet), funded thus far by the Institute for New Economic Thinking (INET), to analyze the role of corporate financialization in the failure of U.S. businesses to lead in EV batteries. The case of EV batteries is another example of U.S. loss of global leadership in a critical technology. Other examples include the failure of Cisco Systems[15] to become a global competitor in 5G communications and Internet of Things; the failure of Intel[16] to lead in advanced semiconductor fabrication; and the failure of Boeing[17] to produce safer, more efficient commercial planes. Our project seeks to explain why, despite the historical market, technology, and competitive advantages of companies operating in the United States, the nation lacks a major EV battery manufacturer—and why Asian companies based in Japan, South Korea, and, especially, China became world leaders.

In section two, we discuss the innovation challenges presented by EVs by focusing on Li-ion battery cells as a key EV component. We describe how dominant Li-ion cell chemistries such as NMC, NCA, and LFP present performance tradeoffs regarding range, safety, and cost, and how their mass production has driven a massive decline in battery prices. We then highlight the critical role played by the U.S. government in funding R&D for EV battery development, through agencies such as the Department of Energy (DoE) and government-business partnerships such as the USABC. Without the complementary investments of the U.S. government in technology and market development, no EV transition would be occurring today.

In section three, we describe Sony's emergence as the first-mover in rechargeable Li-ion batteries, transferring technology from the West to Japan. After explaining why Sony did not become a leader in EV batteries, we turn to the rise of four companies that did: Panasonic in Japan, LG Energy Solution (LGES) in South Korea, BYD in China and CATL in China. We apply the theory of innovative enterprise (TIE) to the construction of business histories of the four companies, focusing on the ways in which strategic control, organizational integration, and financial commitment permitted them to develop capabilities that established them as major players in consumer electronics as a precursor to capturing dominant shares of the growing global EV battery market.

In the final section, we highlight key roles of the social conditions of innovative enterprise in the emergence of the Asian companies as global leaders in the EV battery industry. We then assert, citing some of our previous publications and drawing on research-in-progress on the subject, that the pervasive scourge of corporate financialization has undermined U.S. capabilities to produce EV batteries and attempts to implement "U.S. Industrial Policy". The case of EV batteries goes well beyond the success or failure of a particular industrial sector. It is paradigmatic of the deep political, economic, and cultural problems that plague the U.S. economy and society today.

Innovation challenges

We define innovation as the production of higher-quality, lower-cost products than were previously available. In the case of rechargeable batteries, "higher-quality" refers to specific energy, specific power, duty cycle, charge rates, and safety as important factors in what may be deemed innovative. "Low-cost" batteries result from scale and, for a given battery chemistry, sufficient resource availability. As the highest-cost component of a modern EV with the greatest impact on the EV's range, safety, duty cycle, and convenience, automakers have a strong interest in investing in innovative batteries as a key source of competitive advantage.

Today's EVs use Li-ion cells that are comprised of anodes, cathodes, a separator, and an electrolyte, packaged using cylindrical, prismatic, or pouch form factors. Cylindrical or "jelly roll" batteries are the most recognizable form factor, packaging battery components into tubular metal cases of various sizes, with a 16850 Li-ion battery resembling, for example, the common "AA" single-use battery. The prismatic form factor stacks the battery components into rigid rectangular cases of various sizes, which may also be metal, resembling the lead-acid battery in a typical automobile. Pouch batteries also stack the key components together, but within a laminate bag (or "pouch") that is more flexible, lighter in weight, and potentially more space efficient.

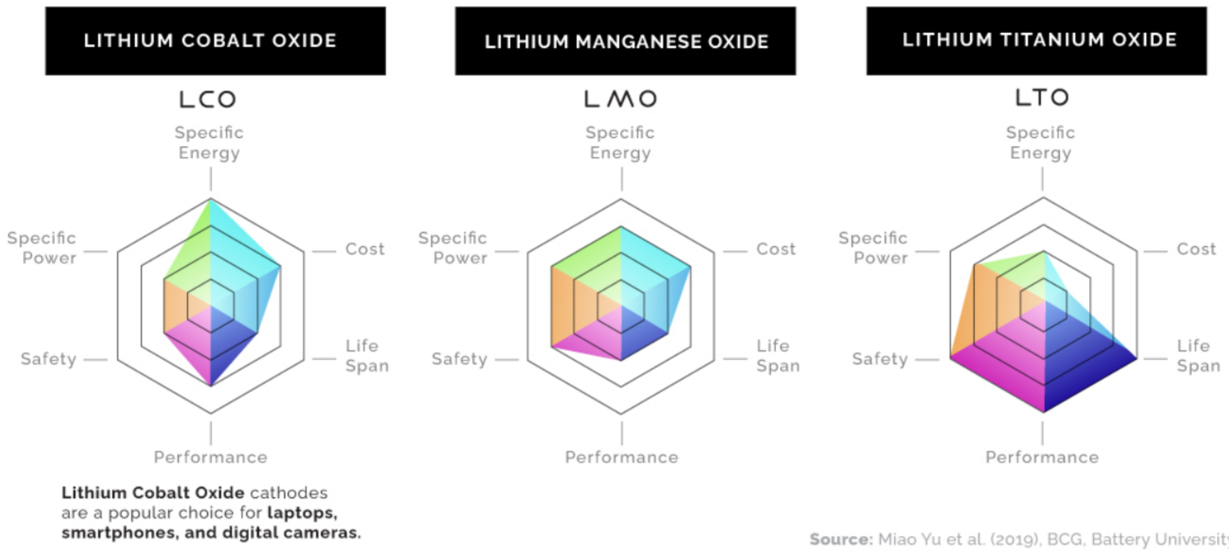
Li-ion battery anodes are typically carbon-based materials such as graphite. Cathodes, on the other hand, are distinguished by a variety of material combinations. Current dominant cathodes for EV batteries are lithium nickel manganese cobalt oxide (NCM), lithium nickel cobalt aluminum oxide (NCA), and lithium iron phosphate (LFP). Each commercially successful Li-ion battery chemistry thus far has underpinned progress in the global EV transition. Each chemistry, however, makes tradeoffs in terms of performance (range, charging rates, discharging rates, duty cycle), safety, and cost. Figure 1 illustrates these differences as a performance envelope.

Between 2020 and 2025, the EV transition was accelerating, with sales of EVs increasing from about 3.0 million to 20.7 million, equal in 2025 to about 23 percent of the global auto market.[18] China-based BYD surpassed U.S.-based Tesla as the #1 EV producer in 2025, with 2.3 million BEV sales versus Tesla's 1.7 million, and, with PHEVs included, 4.6 million EV sales overall, equal to about 22 percent of the global EV market. As a vertically integrated automobile company, BYD manufactures its own batteries, which have helped position LFP as a dominant chemistry. Tesla has relied, as have other automakers, on securing access to battery technologies through a growing number of strategic alliances or supplier relationships with Asian companies. Tesla initially partnered with Japan's Panasonic to supply Li-ion cells for EVs produced for U.S. and European markets. Upon setting up manufacturing in Shanghai, China in 2019, Tesla selected

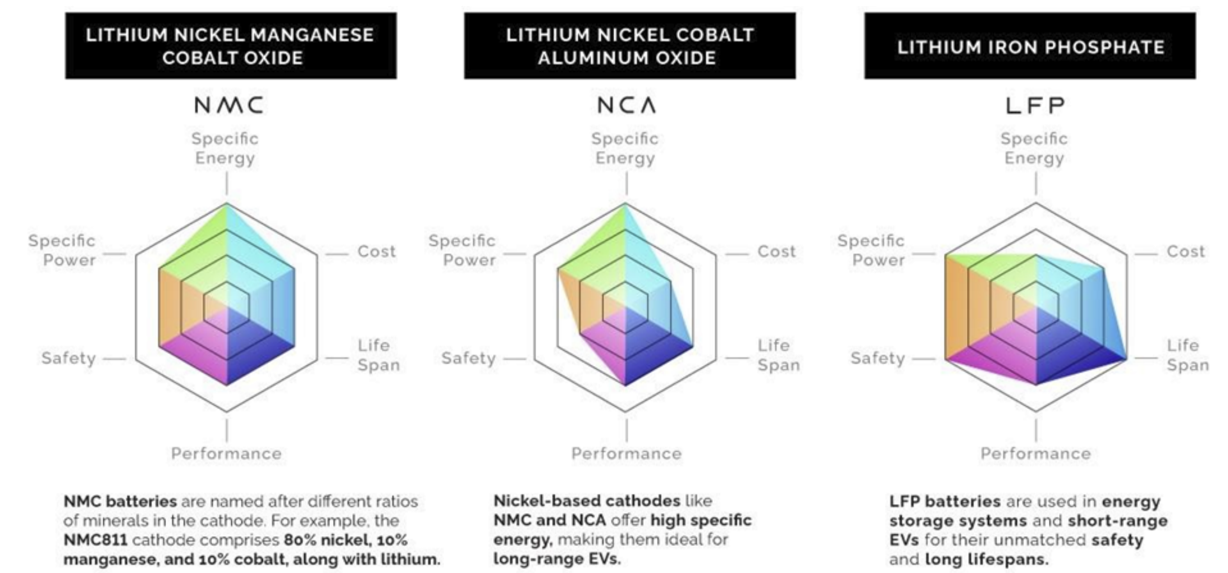
CATL and, more recently, BYD to supply batteries for the EVs that it produces in China or at its new gigafactory in Germany. As Tesla and other "Western" automakers have outsourced battery cells, battery producers have greatly expanded supply, with the cost of batteries plummeting.

Figure 1: Types of Lithium-ion cathodes

Cathodes dominant in consumer electronics



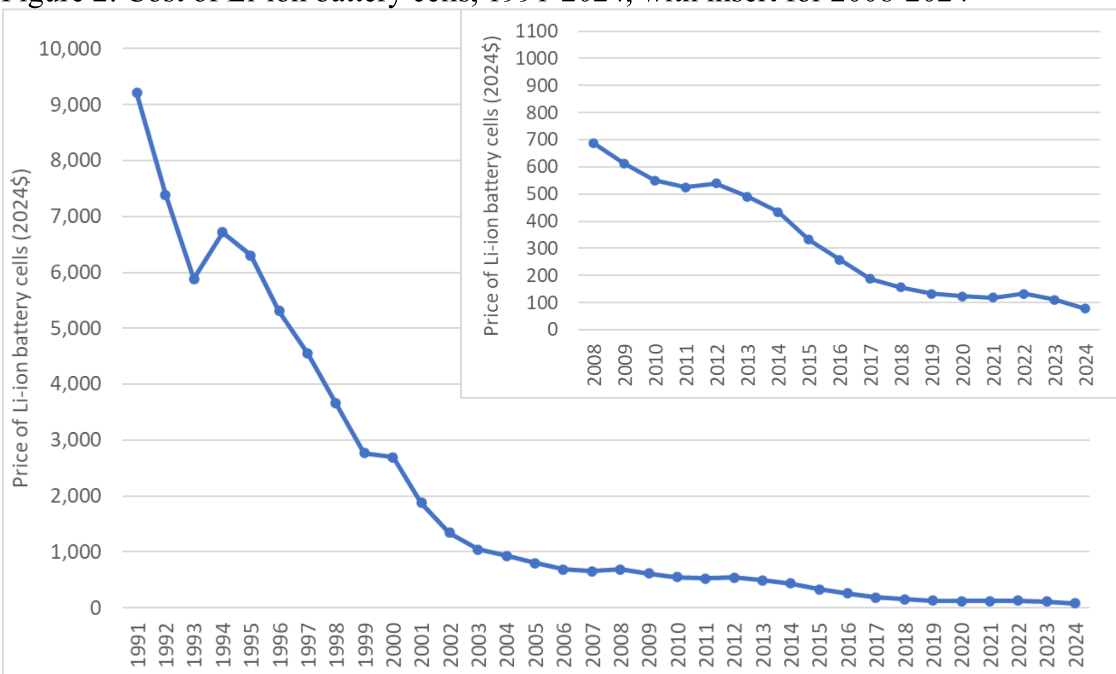
Cathodes dominant in EVs



Adapted from: Govind Bhutada, Christina Kostandi, and Clayton Wadsworth, "The Six Major Types of Lithium-ion Batteries: A Visual Comparison," *Visual Capitalist*, April 18, 2023.

As Li-ion batteries were produced for a booming portable electronics revolution, roughly, between 1991-2007, the cost of battery cells fell by an order of magnitude. Figure 2 illustrates the dramatic decline in Li-ion battery prices more generally over the last 34 years. As the new era of Li-ion powered EVs began, with Tesla and BYD acting as first-movers from about 2008, it set the stage for prices of Li-ion battery cells to fall by another order of magnitude, as BEV and PHEV production accelerated. As battery producers gained experience, some diversified into electric grid energy storage—greatly expanding the potential extent of the market for Li-ion batteries, while creating opportunities for new innovative chemistries, like Sodium-ion batteries, to gain a foothold. Battery innovation, in other words, is foundational for not only a broader transformation of transportation technologies, but also transitioning electric grids toward expanded utilization of zero-emission sources of renewable energy.

Figure 2: Cost of Li-ion battery cells, 1991-2024, with insert for 2008-2024



Source: "Price of lithium-ion battery cells," *Our World in Data*, November 19, 2025.

The stunning success of the rechargeable Li-ion battery led to recognition in 2019 of the pioneering research of three scientists, sharing in a Nobel prize for fundamental contributions that "laid the foundation of a wireless, fossil fuel-free society, and are of the greatest benefit to humankind."[19] Two of the researchers, Stanley Whittingham and Akira Yoshino, made their key discoveries in the corporate labs of chemical companies; respectively, U.S.-based Exxon (now Exxon Mobil) and Japan-based Asahi Kasei. Whittingham was awarded the prize for establishing the "intercalation" principle of the batteries in the early 1970s—in essence demonstrating their ability to be rechargeable. Yoshino discovered a viable carbon anode for the battery. The third researcher, John B. Goodenough, identified viable cathodes over the course of a long career within university labs—first at Oxford University in the United Kingdom and then in the United States at the University of Texas, Austin.

Each of their contributions made it possible for Sony, the Japanese consumer-electronics giant, to produce the first commercially available rechargeable Li-ion batteries in 1991.[20] Although Sony claimed to have discovered a viable chemistry through its own trial-and-error efforts carried out in the 1980s,[21] it nevertheless had to license its right to produce the first lithium cobalt oxide (LCO) batteries from the Atomic Energy Research Establishment (AERE) of the U.K., which had purchased the rights to the cathode in turn from a disinterested University of Oxford and a bamboozled John Goodenough (who, given his contributions to the science of lithium batteries probably should have died fabulously rich rather than merely fabulously renowned).

Rechargeable Li-ion batteries are superior to the lead acid, nickel cadmium, and nickel metal hydride batteries that preceded them, capable of storing and delivering more power per unit weight. As such, the devices into which they have been integrated can be smaller, lighter, more powerful, and longer lasting. By the 1990s, Sony, Matsushita (which changed the corporation's name to Panasonic in 2008),[22] LG Chem[23], ATL,[24] and BYD were able to pluck the world's best battery chemistries off the proverbial shelf, the critical R&D having been completed in university, government, and corporate labs, in some cases decades earlier.

The foundational research carried out by the Nobel laureates Whittingham and Goodenough was supported in part by the U.S. government,[25] which has for decades allocated billions of dollars to the development of batteries, powertrains, and a market for EVs, using a variety of policy tools. Among them are pollution emission standards set by the Clean Air Act of 1970 and the establishment of the Corporate Average Fuel Economy (CAFE) standard in 1975, which have functioned as "sticks"—setting emission and fuel economy targets that require investment by automakers in improved vehicle technologies.

In response to the oil embargo of 1973, Congress passed the Electric and Hybrid Vehicle Research, Development, and Demonstration Act, providing $160 million (about $1.2 billion in 2025 dollars) to facilitate development of electric vehicles and hybrids. The Department of Energy (DoE), formed in 1977, has provided $13.1 billion ($20.0 billion in 2025 dollars) in R&D funding for vehicle technologies since 1978.[26]

A large portion of the R&D funding supported business-government partnerships for innovative battery production. In January 1990, as we noted above, GM unveiled a prototype EV called the "Impact", at the time signaling its intention to begin an EV transition. In September 1990, responding to GM's proclamation that a mass-production EV was now imminent, California required that a condition for each of seven major automakers to sell cars in California was that two percent of their sales had to be zero-emission vehicles (ZEV) by 1998, escalating to ten percent by 2003.

In 1991, GM, Ford, and Chrysler set up the U.S. Advanced Battery Consortium (USABC) to fund R&D for innovative EV batteries. Following the Energy Policy Act of 1992, the USABC became a business-government partnership, the DoE contributing half the group's annual budget, with seed funding in its first year of $94.5 million.[27] From 1991 through 2013, the DoE's $971 million investment in battery R&D directly supported the commercialization of hybrids and EVs using advanced NiMH and Li-ion batteries.[28] Under the 2009 American Recovery and Reinvestment Act (ARRA), the DoE set up ARPA-e, modeled after DARPA, to fund radical energy innovations. Since its inception in 2009, ARPA-e has allocated $5.2 billion in R&D funding ($6.5 billion 2025 dollars), of which over $1 billion has supported advanced electric-vehicle powertrain and battery research as well as commercial scale-up activities.

The 1992 Energy Policy Act provided a ten-percent tax credit toward the purchase of an EV (capped at $4,000) to facilitate the formation of a market for EVs. The 2009 ARRA revised the EV tax credit to provide a maximum of $7,500 (or 30 percent of the purchase price), but only for the first 200,000 units of a model sold by an EV manufacturer (whereupon a phaseout began). Under the Inflation Reduction Act (IRA) of 2022, consumers could also receive up to $4,000 on used EVs priced up to $25,000. The $7,500 and $4,000 credits are contingent on household income and EV price caps, with qualifying EVs also subject to new domestic content requirements.

The ARRA and IRA both subsidized battery manufacturing. Under the ARRA, the advanced technology vehicles manufacturing loan program provided $465 million to Tesla and $1.4 billion to Nissan to support EV production. Another $2.4 billion was provided to Li-ion battery startup A123 Systems and Johnson Controls to support domestic battery manufacturing. The IRA provides a maximum $45/kWh credit for battery cells and battery packs made in the U.S., with a ten percent credit for battery mineral processing, and a 30 percent credit for investment in battery manufacturing, recycling, and processing centers (as well as energy storage systems). The manufacturing credits are a key reason why the U.S. has, since 2022, recorded $141 billion in battery-related project investments, led by several major automakers and foreign battery companies with which they have partnered.[29]

Notwithstanding government efforts since the 1970s to invest in battery R&D and to institute policies that promote investment in vehicle electrification as a strategy for energy "independence" or pollution mitigation, the U.S. finds itself in "catch-up mode". The production of high-quality, low-cost rechargeable batteries is critical to the success of the EV transition. Yet the U.S. has failed to spawn a company with the capability to supply batteries for the 1.3-1.5 million EVs (BEVs and PHEVs) sold in the U.S. in 2025, let alone enough to electrify, hypothetically, the other 15 million ICE vehicles sold in the U.S. market that same year.[30] In their efforts to secure access to state-of-the-art batteries, the U.S.'s major automakers have instead turned to global battery leaders LGES, SK On, Panasonic, and CATL, seeking to establish U.S.-based manufacturing of battery cells via entry into JVs or licensing agreements with foreign partners.[31]

Companies based in the U.S. and abroad face two key barriers as they seek to gain strategic control over present and future innovations in battery technology. The first is political. Following the re-election of Donald Trump in 2024, policies intended to promote EV sales and the "onshoring" of EV-battery production were either cancelled or revised, causing companies to put clean-tech investments, including battery production plans, on hold.[32] The $7,500 tax credit for new EV purchases and $4,000 tax credit for used EV purchases introduced by the IRA were canceled in September 2025 after passage of the Trump Administration's One Big Beautiful Bill Act. Subsidies that reward manufacturers for domestic production of rechargeable batteries were largely left alone, but the administration can deny "prohibited foreign entities" from access to the credits. At present, "foreign entities" with ties to China, Russia, Iran, or North Korea are precluded from access to U.S. subsidies. The value of any subsidy is, however, dependent on robust and growing EV sales, which have been dampened by the loss of available tax credits.[33]

The second barrier is ideological. As important as industrial policy has been to U.S. companies seeking to compete in clean technologies, the actions of the last two presidential administrations have been far less decisive than the innovation strategies of U.S.-based businesses over the last several decades. As we argue in our book-in-progress on corporate financialization in the United States, the U.S. companies that might have played bigger roles in establishing a lithium-battery supply chain instead adopted the fallacious ideology that "maximizing shareholder value" is the foundation of the most efficient economy. As a result, there are no major EV battery producers in the United States.

The Asian competitors

The pioneers: Sony and Asahi Kasei

Sony's entry into batteries began in 1975, when it commenced a 50:50 JV with U.S.-based Union Carbide, at that time the world leader in consumer batteries. Union Carbide gained access to the Japanese market, boosted by the brand recognition of Sony, which distributed Union Carbide's battery cells under the "SonyEveready" trademark. Sony expanded its role in the JV by establishing a battery manufacturing facility in Koriyama, Japan in 1977, where it began making silver oxide coin batteries, to which it added alkaline coin batteries in 1979 and lithium coin batteries in 1982.[34] In 1979, Sony launched a revolution in portable electronics by releasing its innovative "Walkman" portable cassette player, which epitomized the company's success in developing and miniaturizing complex consumer electronics devices. However, the appetite for batteries in devices such as the Walkman was a prompt for battery makers like Sony to create non-toxic (mercury-free) alkaline batteries or rechargeable alternatives that would allow a shift away from nickel cadmium batteries, particularly as the Japanese public became concerned about their impacts on health and the environment.[35]

In the 1980s, according to Sony's corporate history, it began to push Union Carbide's management to invest in rechargeable Li-ion battery technology, not only to reduce battery waste but to enable development of more innovative portable electronics products. In late 1985, however, following a tragic industrial accident in 1984 at one of its plants in Bhopal, India, Union Carbide became embroiled in a hostile takeover bid by Samuel Heyman's GAF conglomerate.[36] This attack led directly to the sale of Union Carbide's consumer products division, which included its world-leading battery business. Keizaburo Tozawa, an architect of the SonyEveready JV, who became Sony's chairman in 1984, flew to the U.S. after the news to negotiate a buyout. In March 1986, Sony completed the purchase for $12 million, agreeing to drop the SonyEveready brand and manufacture batteries under "Sony Energytec" going forward.[37]

Under Tozawa, Sony committed to developing its own rechargeable Li-ion battery, pursuing development via six independent R&D groups, while benefitting from a shared R&D effort into which it entered with Japan's Asahi Kasei. Akira Yoshino, an employee of Asahi Kasei and future Nobel Prize winner, discovered that using petroleum coke (soft carbon) as an anode and Goodenough's LCO as a cathode produced a viable rechargeable Li-ion battery. To maximize secrecy, Isao Kuribayashi and Akira Yoshino flew to New York seeking pilot battery production plant equipment. From there they went to Boston to have prototype samples produced by Battery Engineering, Inc. in "a converted truck garage next door to an auto body shop".[38] Led by Nikola Marincic, a chemical engineer who had worked for GTE and Duracell, Battery Engineering could produce specialized batteries on-site with a staff of four PhDs and several assemblers. By late 1986, Asahi Kasei had working prototypes of size C "jellyroll" Li-ion batteries produced by

Battery Engineering that had been lab tested as well as cleared by the U.S. Department of Transportation for air transport.

As a chemical firm with no electronics segment that might consume its internal production, Asahi Kasei showed its prototypes to Sony in January 1987, hoping to make it a large customer. Over subsequent months the companies set up cooperative R&D activities, with each company's employees allowed to move freely to and from each other's labs. Notwithstanding their collaborations, Sony claimed in its official history that it had made the critical breakthrough by means of its own dogged in-house battery R&D efforts, which yielded a virtually identical battery chemistry to that developed by Asahi Kasei.[39]

Sony then succeeded in beating Asahi Kasei to market, commercializing the first rechargeable Li-ion batteries in 1991, after purchasing a license to produce the LCO cathode from the U.K.'s AERE, and combining it with a license for Asahi Kasei's carbon anode. Without an exclusive license from either grantor, Sony possessed no control over the intellectual property behind the revolutionary battery. Sony was quickly followed by other Japanese firms, beginning with A&T, an Asahi Kasei-Toshiba JV (1992), Sanyo (1993), and Matsushita (1994), all fierce competitors in Sony's main business segment of consumer electronics.

In 1992, Yoshio Nichi, who joined Sony in 1966 and served as general manager of its Li-ion battery team, decided to focus the company's R&D on the anode chemistry of its new battery, innovating by integrating "hard" carbons that significantly improved their performance. However, in 1993, Sony was beaten to the market by Sanyo, which was first to integrate a graphite anode, significantly improving the battery's energy density. As noted below, and notwithstanding Sony's efforts, Sanyo by 1999 replaced Sony as the world leader in Li-ion batteries.

Driving Sony's decision to commercialize the world's first rechargeable Li-ion battery in 1991 was a vertical-integration strategy that viewed battery innovation as a key source of competitive advantage in consumer electronics products. The batteries were first used for its "Handicam", a video recording device for consumers that weighed well under two pounds and fit comfortably into one's hand. The product, first released in 1989, was made "lighter and more compact", as Sony wrote in its 1993 *Annual Report,* by a "newly developed" Li-ion battery.[40]

Shortly after the battery's commercial debut in 1992, Sony was approached by Nissan to collaborate on development of a BEV. In 1996, Nissan unveiled its "Prairie Joy" EV, the world's first Li-ion powered BEV, which was, however, limited to 30 units produced for fleet sales and sold only under lease. The Prairie Joy was succeeded by Nissan's "Altra" in 1998, a second BEV powered by Sony battery packs that was limited to just 200 unit sales.[41]

While the EV industry did not take off in the 1990s, a boom in mobile electronics was underway. In 1995 Sony began external sales by its Li-ion battery operations to meet "surging demand",[42] driven increasingly by cellphone and computer manufacturers eager to design smaller, more powerful devices using Sony's batteries. Sony booked aggregate battery sales under "Others", a subsegment of its core "Electronics" business segment, which, at 909 billion yen in 1995 (about $10.2 billion), exceeded its 899 billion yen audio electronics segment.[43] Another reason for the blowout success of the segment at that time, it should be noted, was the release of the "Playstation" video game system, which used (for the time) high-capacity CD-ROM discs that Sony had pioneered with Netherlands-based Philips in 1986.

Sony's international expansion in battery manufacturing was in part a response to the boom in cellular mobile phones as well as pressure to continue reducing costs. In 2000, Sony spent $23 million to set up a battery plant in Wuxi China, to supply up to 24 million Li-polymer batteries annually to China's mobile phone market.[44] The same year, Sony allocated $12.2 million to add production lines for 8.4 million batteries annually for the North American market produced by its Nuevo Laredo, Mexico plant, which had capacity for 1.2 million units installed in 1999.[45] As it expanded its battery manufacturing footprint, Sony also formally entered the mobile phone business via a 50:50 JV with Sweden's Ericsson in 2001, which it later bought out in 2012 for about $1.5 billion.[46]

By 2004, Sony manufactured prismatic, cylindrical, and pouch-type Li-ion batteries, integrating them into its mobile electronics devices across multiple product lines, which included mobile phones, "VAIO" laptop PCs, "Cybershot" cameras, and video recorders.[47] Sony also recognized that yet more opportunities to sell batteries existed wherever NiMH batteries were found, such as in power tools and electric shavers.

In 2006, however, Sony's battery business became subject to a global recall of 10 million batteries sold to Dell, Apple, and Lenovo for their laptop PCs, which led Sony to book a $343 million provision for battery replacements in 2008.[48] Despite the setback, Sony continued to grow its international manufacturing footprint, in 2008 building a $150 million plant in Singapore, capable of producing 96 million mobile phone batteries.[49]

As competition intensified, with South Korean and Chinese companies emerging to compete with Sony's battery and consumer electronics segments, Sony sought new applications for its Li-ion batteries. In 2009, Sony launched an LFP "Fortelion" battery,[50] and in 2011 announced its LFP-based energy storage modules as a "new pillar" of its battery business, providing large organizations with a valuable new backup and load-leveling power source.[51] After licensing the patents from the LiFePO+C consortium, Sony formed a JV called "Esstalion" with consortium member Hydro-Québec to integrate batteries into renewable power systems as backup and load-leveling solutions.

Sony's first non-Japanese CEO, Howard Stringer (2005-2012), was in office when, in 2007, the company booked record profits of $3.7 billion. The beginning of the "Great Recession" in 2008, however, marked a turning point at Sony, which recorded $12 billion in net losses through 2012. Stringer used the crisis to get Sony out of some of its consumer electronics business lines in which it was no longer competitive, and to rationalize the company's operations, ultimately reducing the worldwide headcount 19 percent from 180,500 employees in 2007 to 146,300 employees in 2012. Under his successor, Kazuo Hirai (2012-2018), Sony returned to profitability in 2015. The company was now well on its way to completing its transformation from a consumer electronics giant into a company dominated by profits from its Playstation gaming products, music business, and motion pictures.

Sony's television business, which had out-innovated and devastated U.S.-based RCA's in the 1970s, found itself struggling to compete with South Korean challengers Samsung and LG in widescreen LCDs. As Stringer was stepping down as CEO of Sony, the company's consumer electronics segment had shrunk from $64 billion to $39 billion in annual sales. LCD TVs contributed to a $2.9 billion operating loss in Sony's consumer electronics segment in 2012, the corporation posting its worst-ever net loss of $5.7 billion that year. Sony faced challenges on other fronts, such as the introduction of the iPhone (and later Samsung Galaxy) smartphones, which outcompeted Sony's own mobile phone products.

With virtually all of Sony's group profits since its 1991 introduction of Li-ion batteries wiped out from the onset and aftermath of the Great Recession, Sony brought in Hirai as Sony's next CEO. Under a strategy he called "One Sony", Hirai continued to oversee employment loss at the company, the headcount falling from 146,300 in 2012 to 117,300 in 2017. In 2013 Hirai changed Sony's segment reporting, with Mobile Communications, Gaming, and Home Entertainment & Sound as Sony's lead segments.

In 2013, as Sony booked a small profit, its financial performance improving, Daniel Loeb, of the U.S.-based hedge fund Third Point began his first "activist" campaign against the company. Taking advantage of Sony's depressed stock price, Loeb accumulated 6.3 percent of its outstanding shares, later upping his stake to 7.0 percent. He publicly argued that Sony should spin-out part of its music and motion picture business, and use the proceeds to re-invest in its electronics businesses.[52] Sony's board of directors ultimately rejected Loeb's proposal, Hirai saying that "should we require capital, or in the event of unanticipated events, our priority would be to raise it without selling a portion of an asset fundamental to our growth strategy, and without unnecessarily burdening Sony's ability to execute our business strategy for both entertainment and electronics."[53]

While the hedge fund failed to budge Sony's strategy, it likely gave its management another reason to re-consider their commitment to batteries, particularly as it became clear that competitors like Panasonic and LG Chem were breaking, in a big way, into EVs. Sony's former partner, Nissan, had already formed the Automotive Energy Supply Corporation (AESC) in 2007 with Nissan taking a controlling 51 percent interest, while NEC and its subsidiary NEC Tokin held the remaining 49 percent. The partners invested $362 million initially, and later an additional $1 billion, to build a plant capable of supplying lithium manganese oxide (LMO) batteries for 200,000 EVs.[54]

In 2014, Hirai sold off the Sony Vaio PC business and spun off its struggling TV and home audio business into a JV controlled by China's TCL. Along with falling sales in its mobile phone and digital camera businesses as well as destruction of its portable audio devices, Sony was rapidly shedding internal demand for its own batteries and was subject to intense competition for external sales by major South Korean and Chinese firms. In 2017, Sony sold its battery business to Murata Manufacturing Co. for 17.5 billion yen (about $156 million), Murata offering jobs to 8,500 Sony employees (about seven percent of Sony's global employment). After a 26-year run, Sony was out of the battery business, for much the same reason it had entered—as its position in consumer electronics shifted, Sony faced technological, market, and competitive uncertainties emerging from multiple directions that challenged its central role in the digital revolution that it had helped bring into the modern world.

Sony transferred Li-ion technology to Japan, but failed, ultimately, to become a leader in rechargeable EV batteries. While Sony served as the first-mover, the Japanese companies most significant to the EV transition were Panasonic and Sanyo, which Panasonic acquired in 2009. We will now document the development of four Asian companies, beginning with the oldest, Panasonic, the only Japanese company to appear among the global top ten EV battery producers in 2025. From there, we will go to South Korea to document the growth of battery producer LG Energy Solution (LGES), the #3 EV battery producer in 2025. We then shift our focus to China to record the emergence of global leadership by BYD, #2, and CATL, #1.

Panasonic

As set out in the introduction to this paper, in 2025 Japan's Panasonic was, with 3.5 percent of the global market, the seventh largest EV battery maker in the world. We include the case of Panasonic here because it is the only non-Chinese or non-Korean company in the top ten list and because Panasonic is a global leader because of its partnership with Tesla, which began in 2006.

Founded in 1918 by Konosuke Matsushita as the Matsushita Electric Housewares Manufacturing Works, the keiretsu was renamed Panasonic in 2008. The oldest of the leading companies, Panasonic has been producing batteries since 1931. The company produced Li-ion batteries in the 1980s and, from 1994, rechargeable Li-ion batteries. In 1996, Matsushita and Toyota set up the Panasonic EV Energy Co. as a JV to develop NiMH batteries for Toyota's hybrid electric vehicles (HEVs).[55] In contrast to PHEVs, HEVs generally use smaller batteries that are charged by the on-board ICE engine, which uses electric motors to boost the overall fuel economy of the vehicle rather than provide a means of electric-only propulsion.

Panasonic EV Energy supplied NiMH batteries for the Toyota Prius HEV, which debuted in Japan in October 1997. The Prius was an important vehicle for Toyota, which, like other automakers, was responding to the California "ZEV mandate". After extensive lobbying by the Detroit "Big Three" in 1998, the California authorities made a significant revision to its ZEV mandate, permitting "Super Ultra-Low Emission Vehicles" (SULEV) to qualify for "partial ZEV" credits (PZEV). The rule-making opened the door for non-BEVs to meet California's new emission standards.

Sales of the Prius in the U.S. began in July 2000. The Prius was the world's first mass-produced HEV, and a great success for Toyota, which celebrated its three millionth unit sale in 2013.[56] At the time it was released in the U.S. market, the Prius qualified as a SULEV, with each unit sold contributing to its share of the California ZEV mandate.

The success of the Panasonic-Toyota HEV drew the attention of Energy Conversion Devices (ECD), founded by Stanford Ovshinsky with his future wife Iris Dibney as Energy Conversion Labs in 1960, whose innovations yielded key NiMH battery patents. In 1994 GM entered a JV with ECD called GM Ovonic, with a 60 percent controlling share. In 2000, GM sold its interest in GM Ovonic to Texaco, which merged with Chevron in October 2001. The new JV, eventually called "Cobasys", filed a patent infringement suit in 2001 against Toyota and Matsushita. Upon losing the patent-infringement case in 2004, Matsushita was forced to pay $10 million for consumer-electronics related violations, while Panasonic EV Energy, Toyota, and Matsushita paid

$20 million for the NiMH batteries used in its HEVs. They were also on the hook for payment of royalties to Cobasys for use of NiMH battery technology going forward.

While Matsushita invested in NiMH technology, it continued to invest in Li-ion batteries, most dramatically by acquiring Sanyo. In 2004, the Chuetsu Earthquake in Japan caused $837 million in damages to Sanyo's semiconductor plant in Niigata.[57] The unexpected costs damaged Sanyo's already weakened financial position. Its struggling semiconductor and consumer electronics segments were among the reasons why, in January 2006, Sanyo accepted a $2.6 billion "bailout" from a Goldman Sachs-led consortium, which acquired 70.5 percent of Sanyo's outstanding shares.[58] About a year later, Sanyo's president Toshimasa Lue "stepped down," putting an end to 60 years of Lue family-control.[59] In December 2009, Panasonic spent $4.6 billion to gain a controlling stake in Sanyo, via a tender offer made to the controlling consortium. In 2011, Panasonic spent an additional $9.4 billion in a share-exchange to complete its purchase of Sanyo as well as the Panasonic electric works, making each of them into wholly owned subsidiaries.[60] With Sanyo, Panasonic took strategic control over a world leader in both NiMH and Li-ion rechargeable batteries.

Sanyo began making NiMH rechargeable batteries in the 1990s. In 2000, the company acquired the NiMH battery business of Toshiba. In 2005, Sanyo released the innovative "Eneloop" NiMH batteries, which greatly reduced self-discharge rates of the batteries. The Eneloop batteries were now superior to alternative NiMH batteries available on the market and competitive with the Li-ion rechargeables then available. To gain approval for the acquisition, in fact, Panasonic had to agree to shed some of its NiMH battery assets to Fujitsu, or it would have otherwise exercised a near monopoly over that battery type.

Sanyo produced primary Li-ion batteries in the 1970s and entered the rechargeable Li-ion battery business in 1993, two years after Sony. However, by 1999, Sanyo had supplanted Sony to become the global leader in rechargeable Li-ion batteries, with a 41 percent global market share in the early 2000s. Sanyo's battery fortunes improved greatly when Nokia, a key customer, replaced Motorola as the world leader in mobile phones.

The Panasonic-combination was able to challenge the rising dominance of newcomers Samsung Electronics and LG Chem in the rechargeable Li-ion battery race.[61] The Sanyo acquisition complimented Panasonic's broader innovation strategy, which was to transform the company into the "green innovation" leader in electronics in the future, which meant competing for leadership in Li-ion battery, solar photovoltaic energy (for which Panasonic had Sanyo's HIT solar PV technology), and energy storage products.[62]

In November 2010, five months after Tesla netted $189 million from its initial public offering (IPO), Panasonic invested $30 million in the California BEV start-up. At the time, Tesla stated that it would collaborate with Panasonic on advanced EV battery development as it also invested in the development and manufacturing of the Model S, its second-generation BEV.[63] Tesla had already purchased Panasonic's batteries by the millions for its first BEV, the Roadster, which benefitted from the development in 2006 of Panasonic's high-performing NCA Li-ion batteries. Panasonic was seeking additional partners in EVs that year, committing $1 billion to expanding its Li-ion manufacturing and R&D in Japan, with plans for high-volume manufacture of its newest 3.4 amp hour rechargeable Li-ion battery by 2012.[64]

Panasonic's partnership with Tesla was more consequential to the company's battery business than its tie-up with Toyota. Tesla both drove Panasonic's expanded investment in Li-ion batteries and served to highlight its need to find additional EV partners to support its innovation strategy going forward. As a startup, while investing in its first EV, the Roadster, Tesla selected Panasonic's Li-ion batteries because they believed they were the best performing batteries in the world at that time. Each Roadster used 6,831 16850 Li-ion cells, but the entire 2008-2012 production run of the Roadster amounted to just 2,500 units. In 2012, however, Tesla released its second-generation product, the Model S BEV, which in 2013 alone sold 22,442 units before peaking in 2017 at 54,715 units.

At the time, Tesla knew it was working toward a third-generation EV that depended upon the ready availability of mass-produced Li-ion batteries, the unit cost of which would fall as more EVs were sold. But, in 2013, Tesla's projected target of 500,000 EVs by 2020 would have consumed the world's output of Li-ion batteries.[65] Recognizing that a shortage of rechargeable Li-ion batteries would slow, if not stop, Tesla's growth, Tesla began pressuring Panasonic to partner in construction of its first "Gigafactory".

In October 2013, Panasonic had signed a three-year agreement to supply 1.8 billion battery cells to Tesla through 2017, which required that it expand its cell manufacturing in Japan.[66] In June 2014, Tesla increased pressure on Panasonic by breaking ground on its own 5.4-million square foot battery facility in Sparks, Nevada. Shortly thereafter, Tesla executives Elon Musk and J. B. Straubel succeeded in persuading Panasonic's new president Kazuhiro Tsuga to co-invest in the Sparks facility. Gigafactory Nevada was central to Tesla's plans to produce a lower-cost EV by driving down the unit cost of Tesla's most expensive component—battery cells—by 30 percent.

Panasonic entered the "vanguard" of the modern EV transition on July 31, 2014, by agreeing to partner with Tesla to supply skilled personnel and battery lines for Gigafactory Nevada. With battery cell output capacity of 35 GWh (and, given additional investment, up to 50 GWh), the facility opened in 2016.[67] It cost $5.4 billion, financed by a $2.0 billion investment by Panasonic, an issue of $2.1 billion in convertible debt by Tesla, and a $1.4 billion incentive package from the State of Nevada.[68]

The Gigafactory was split in half, with Panasonic operating the battery cell manufacturing lines, and Tesla assembling the cells into battery packs for its EVs. Panasonic dramatically increased its own capital expenditures for the Gigafactory. During FY2015, Panasonic reported that a big jump in planned capital spending for 2016 was underway (spending increasing by a factor of 1.5), with about 97.2 billion yen (or $787 million) allocated as part of its share of the costs of the Gigafactory (to which Panasonic eventually contributed $1.6 billion).[69] Panasonic had to dispatch hundreds of its own engineers and managers to set up the battery lines and to train local labor to run them.[70] At peak capacity, Panasonic trained and employed 4,000 people at Gigafactory Nevada.[71] Crucially, Panasonic made these risky investments in plant equipment and people without a guarantee that Tesla would succeed in generating EV sales sufficient to absorb the 400,000 to 500,000 unit output of the factory.

Through the construction of the Gigafactory, Panasonic and Tesla sought to neutralize the possibility that a supply shortage could undermine the production or price targets of Tesla's third-generation mass-market EV. By securing Panasonic's cooperation to double global manufacturing capacity for rechargeable Li-ion cells ahead of realized demand—with global production of Li-ion batteries then totaling approximately 34 GWh—Panasonic made a massive financial commitment to an innovation strategy that left it uniquely exposed to Tesla's ability to execute on its high-volume BEV objectives.[72]

The partnership was conducive to innovation. The Tesla-Panasonic JV developed and began producing larger form factor Li-ion batteries, beginning with the 2170 cells[73] that entered production in 2017 for the company's new Model 3, and later Model Y. The batteries were also used in Tesla's Powerwall product (which, notably, competed with Panasonic's own energy storage business).

Panasonic's relationship with Tesla was damaged, however, as the EV maker struggled through "production hell" in 2017 and 2018 in its attempt to ramp production of the Model 3, nearly going bankrupt in the process. The Model 3 (and its close cousin, the Y) were BEVs on which Panasonic had, in effect, staked its own future as a "green innovator". As Tesla struggled to execute on its production targets, Panasonic's losses mounted. In 2019, after reporting a $180 million loss driven by Tesla's production problems, Panasonic refused to finance a planned 54 percent expansion of the Gigafactory, to 54 GWh, and to invest in battery production lines for Tesla's Gigafactory in Shanghai, China.[74]

In the background of the conflict was Panasonic's yielding, by virtue of the JV structure, strategic control to Tesla's management, led by CEO Elon Musk. His top-down micromanagement style conflicted with Panasonic's approach to problem solving, which was premised on significantly more employee engagement. Improving manufacturing yield was an organizational problem that required Tesla's cooperation. But Panasonic's management had discovered that Musk was potentially volatile and unreliable—even telling a *Wall Street Journal* reporter about their concern with Musk having smoked marijuana in an interview with Joe Rogan the year before.[75] Panasonic CEO Kazuhiro Tsuga told the *Wall Street Journal* that "propping up profitability," was "the number one priority" for Panasonic, adding that "Elon makes these repeated price-cut requests, and one time I told him we would consider a complete withdrawal of my people and facilities from the Gigafactory in response."[76] Having shared in the risk and uncertainty of its own and Tesla's innovation strategy, Panasonic wanted higher prices for the batteries it supplied to Tesla as it became, eventually, profitable.

During "battery day" in 2020, Tesla announced it was working on a new, larger 4680 battery cell, which, along with other planned innovations, would drive its battery costs down 50 percent. Tesla began an in-house 4680 cell production ramp in Q42023 for Tesla's Cybertruck, which, compared to its prior BEVs, was a sales flop.[77] In 2022, Panasonic announced it was building new battery lines at its Wakayama, Japan plant, to provide a commercial source in Japan for its large 4680 EV battery cells. Panasonic's $704 million[78] commitment to the Wakayama plant was made also to establish it as the "mother" of its battery cell and manufacturing process R&D investments that, once successful, could be integrated into its foreign plants.[79] Panasonic announced in September 2024 that it had achieved manufacturing readiness at its Wakayama, Japan facility.[80]

In 2022, Panasonic revealed its decision to build on the success of Gigafactory Nevada by investing $4 billion to open a wholly-owned 32 GWh battery factory in De Soto, Kansas. It commenced operations in July 2025.[81] The investment was matched by $829 million[82] in subsidies that, along with subsidies created by the Inflation Reduction Act (IRA) of 2022, provide billions of dollars more in financial support on condition that Panasonic (like other battery manufacturers not included on foreign entity lists) can find customers to absorb its battery cell output. In its 2024 *Annual Report*, Panasonic claimed that its Kansas plant would boast 30 percent higher productivity than its shared Tesla plant in Nevada as Panasonic applied its cumulative learning and experience to its new plant design.[83] Key to boosting the plant's "competitiveness" according to Panasonic was dealing with high labor turnover, "especially in North America," by setting up "manufacturing that can be done by less experienced operators."[84] Panasonic also took a direct role in financing worker development outside its plant, willing to pay tuition and instructor salaries at community colleges in Kansas close to the new facility.[85]

Though it faces significant competition, Panasonic intends to be a dominant player in the EV battery space, with stated goals of boosting the performance of its batteries significantly to 1,000 Wh/L and investing in 200 GWh of production capacity by 2030.[86] In 2022, Japan's MITI deemed EV batteries a strategic industry, and began making new subsidies available to companies that invested in domestic production. Panasonic responded by entering new supply partnerships. In September 2024, it announced an agreement to supply batteries to Japan's Subaru, allocating $3.3 billion to develop a new 16 GWh plant in Gunma prefecture, which will begin operations in 2028.[87] The same day, Panasonic announced it would expand its Osaka plants by up to 6.5 GWh by 2030 (to reach approximately 10 GWh of annual output), via a $550 million investment made to meet demand from supply partner Mazda. Each investment will be matched by up to $1.2 billion in subsidies from the Japanese government.[88]

In 2016, as Panasonic was in the process of bringing Gigafactory Nevada online, it entered China via a 50:50 JV with Dalian Levear Electric Co. In 2018, Panasonic began to manufacture prismatic Li-ion batteries at the 500-employee Dalian plant for both export and sale on China's EV market.[89] In 2020, Panasonic entered, as the non-controlling partner, a 49:51 JV with Toyota called "Prime Planet Energy & Solutions", to develop and sell prismatic and next-generation battery cells, utilizing the Dalian plant, which had grown to 2,400 employees.[90]

In 2024, Prime Planet Energy & Solutions announced it was building a 30 GWh battery plant in Japan, expanding Toyota's access to innovative batteries.[91] While Panasonic and Toyota continue to cooperate through the Prime Planet JV to produce EV batteries in Japan, the U.S., and China, Toyota in 2025 announced it was buying out Panasonic's share of their previous JV, the Primeearth EV Energy Co., that had been set up originally in 1996 to support its innovative HEVs. The now wholly-owned entity was renamed the "Toyota Battery Co.".[92] In 2022, Toyota broke ground on its first U.S.-based EV battery plant in North Carolina.[93] In November 2025, Toyota announced it had begun production at the $13.9 billion EV battery plant, which at full output will employ 5,000.[94]

Toyota's investment in EV battery manufacturing, both via a JV and through the Toyota Battery Co., is a clear indication of a strategy to begin competing seriously for the EV market, while making a commitment to asserting greater control over its battery technology and supply. In 2025, Toyota was once again the world's largest automaker, selling 10.5 million vehicles worldwide, which included sales of 4.9 million electrified vehicles, the overwhelming majority of which—4.4 million—are, however, HEVs.[95] In the U.S., Toyota sold 2.5 million vehicles, with over 1.2 million sales of electrified vehicles (HEV, PHEV, or BEVs).[96] The massive North Carolina plant, in other words, is just the first of several EV battery plants that could be needed to fully electrify Toyota's vehicle lineup.

Toyota is not the only JV partner that, having benefitted from a relationship with Panasonic, is attempting to break free of dependence on outside EV battery suppliers. Tesla has, since 2019, via its acquisition of Maxwell, sought to utilize a dry electrode battery manufacturing process to reduce the cost of battery cells it intended to produce in-house at Gigafactory Texas for its new Cybertruck EV. The manufacturing process was one of several innovations mentioned during Tesla's 2020 battery day that were expected to significantly lower the cost or increase the performance of Tesla's batteries. In early 2026, Tesla succeeded, at long last, in implementing its dry electrode process successfully. However, the cells it has produced in-house have thus far proven to be inferior to those it was outsourcing—delivering less energy density, slower recharge rates, and, given poor sales of the Cybertruck (for which Tesla hoped to produce 250,000 units annually—it sold 20,237 in 2025[97]), likely doing so at higher costs.[98] Tesla's struggles have left Panasonic's own investments in 4680 cells hanging, as it continues to delay production as it awaits an order from Tesla for the cells it also raced to develop after Battery Day in 2020.[99]

With at least 109 GWh of battery capacity online (73 GWh in the U.S. and 36 GWh or more planned in Japan), Panasonic is more than halfway toward its goal of reaching 200 GWh by 2030. But faced with a downturn in demand for EV batteries, given stagnant sales growth since FY2023 from its largest customer, Tesla, Panasonic needs EV partners that can absorb its increased output. Panasonic has sales agreements with Lucid (2022), Hexagon Purus (2023), Mazda (2024), and Subaru (2024).

Like other battery makers, Panasonic has also hedged the risk that EV market growth could slow, or stall by focusing its efforts on Energy Storage Systems that can backup power systems at industrial, commercial, or residential sites. It could also find success providing Energy Storage Systems for AI data centers.[100] Panasonic's commitment to "green innovation" has shown it to be an entrepreneurial, and adaptive, company. In 2021, for example, Panasonic acquired Arizona-based Blue Yonder for $7.1 billion, giving Panasonic powerful AI software that provides real-time coordination of factory and supply chain operations.

Up to this point, Tesla's mass production of EVs has been critical to the growth of Panasonic's EV battery business, and Panasonic has used its success with Tesla to underwrite its broader strategy of leading in clean technology. What was a blessing, however, could become a curse as the commitment to the EV transition has faltered in the United States, Panasonic's key market. Panasonic's $4 billion Kansas plant is well under half its maximum capacity, as it awaits either a significant new customer or a turnaround in the U.S. market. As with LG Energy Solution, our next company under review, Panasonic must continue to invest in innovation to ensure it is a battery supplier of choice.

LG Energy Solution

The third largest rechargeable Li-ion battery producer, LG Energy Solution (LGES), stands out as the sole firm in our list of leaders with roots in the chemical industry. LGES was established in December 2020 as a spinoff of LG Chem, South Korea's largest chemical company and one of the largest in the world. LG was founded in 1947 by Koo In-hwoi as the Lak Hui (pronounced "Lucky") Chemical Industrial Corporation.[101] Over the next several decades, Lucky Chemical expanded into personal hygiene products, plastics, consumer electronics (under the "Goldstar" brand), petrochemicals, and mobile phones. Lucky Chemical listed on the Korean Exchange in 1969 and was renamed Lucky Goldstar (Geumseong) in 1983. In 1995, Lucky Goldstar was shortened to "LG". The LG Corporation was formed in 2003 as the lead holding company for LG Chemical and LG Electronics. At the end of 2024, the combined group had over 270,000 employees and $134 billion in revenues.[102] In December 2025, LGES employed 32,760 worldwide, and $16.6 billion in sales—making the company about a third of the size of world EV battery leader CATL by employment and a fifth by sales.[103]

LG Chem began R&D efforts in Li-ion batteries in 1992, entered a phase of development in 1996, and then succeeded in mass production of Li-ion batteries in 1999, establishing itself as South Korea's pioneer in producing rechargeable Li-ion batteries.[104] Even as it was scaling up its battery business for portable electronics, LG Chem viewed EVs as a major business opportunity. Given the momentum building up at the time around EVs in the U.S., the success of which hinged on the availability of innovative batteries, LG Chem focused on battery R&D by investing $3 million in Compact Power in March of 2001, a JV based in Colorado focused on li-polymer battery technology.

Compact Power was led by CEO Daniel Rivers, an ex-program manager for GM's ill-fated EV1 BEV.[105] In 2002, months before GM began crushing its EV1s, Rivers was part of an effort to demonstrate the superiority of Li-ion batteries by using them for Compact Power's Electric Racer 2, which set a record for EVs competing in Colorado's Pikes Peak international hill climb race.[106] With Rivers, LG Chem sought to develop and manufacture "next-generation lithium-ion polymer battery technology" for EVs, which LG Chem described at the time as "a fledgling market that's expected to take a major step forward toward becoming a mainstream part of the U.S. auto industry."[107]

As LG Chem began investing in EV batteries, they actively competed with Japanese battery suppliers in portable electronics. LG Chem built its third Li-ion battery production line in 2001, reaching a capacity for 36 million battery cells produced annually.[108] In the years that followed, LG was able to grow its battery business in part by making batteries for its own mobile phones and electronics, while supplying customers like Apple, Nokia, Motorola, and HP.

However, LG's battery business was, at times in its early years, a money loser for the company. In 2001 and in 2005, LG executives wanted to get the company out of batteries entirely. At a meeting in April 2001 with the newly installed CEO, Ki-Ho No, some senior executives recommended termination of the EV battery program, given its cost during difficult times and the superior capabilities of the Japanese.[109] Fortunately, Chairman Koo Bon-moo, the top-ranking member of the family that had founded the LG chaebol, intervened at the meeting in favor of confronting uncertainty, saying: "Do not give up, look further into the future, and focus harder on investment and R&D. I believe it is right for us to continue the battery business. Let's start again with the conviction that we can succeed."[110]

Another significant bump in the road, that could have threatened LG's commitment to its fledgling battery business was a recall in 2005 of defective LG Li-ion batteries. The recall affected 128,000 Apple laptops, which resulted in a $25.2 million loss in LG's otherwise profitable Information and Electronic Materials segment.[111] In its 2005 *Annual Report*, LG also referred to a "strategic misstep"—a focus on high-end products when "the low-price notebook PC market took off globally."[112] Even so, in 2005 LG Chem was the world's third largest Li-ion battery producer.

In 2004, LG Chem attracted $4.6 million from the USABC (the U.S. business-government battery consortium, mentioned earlier), which the company used to develop its Li-ion polymer battery for hybrid vehicles.[113] That year LG Chem also expanded its battery production footprint, establishing a plant in Nanjing China, where it expected demand for batteries to expand rapidly.[114] LG Chem added a production site in Holland, Michigan, in 2012 and Poland in 2017.

In 2005, LG Chem moved Compact Power's headquarters from Colorado to Troy, Michigan, after announcing that it would make an $18 million investment in R&D and manufacturing near the geographic center of automotive R&D in the United States.[115] Now positioned more closely to GM's technical center in Warren, Ford's engineering center in Dearborn, and Chrysler's headquarters in Auburn Hills, LG Chem appointed Dr. Prabhakar Patil as Compact Power's new CEO. Patil was a 27-year veteran of Ford who had led its Escape hybrid EV development program.[116]

In 2007, LG Chem's EV business got its big break by winning a competition against a crowded field of 13 companies for a contract to make batteries for GM's planned "Volt" PHEV.[117] GM determined that LG Chem's "flat cell" Li-polymer design and LMO battery chemistry offered superior packaging, thermal performance, and energy density compared to runner-up U.S.-based startup A123's cylindrical LFP batteries.[118] Upon winning the battery contract, Peter Kim, CEO of LG Chem made clear the implications of the victory, saying, "we now are a global player."[119]

In January 2008, Compact Power received a new round of USABC R&D funding, this time for $12.9 million. As it worked to become a major EV battery supplier, LG Chem decided to complete its buyout of its JV with Compact Power in 2008. LG Chem became the sole supplier for the Volt prior to its 2010 commercial debut, even as GM, in the interim, navigated a State-led bankruptcy re-organization. The battery developed for the production version of the Volt used a blended nickel cobalt manganese (NCM)-nickel manganese oxide (NMO) cathode, and was packaged in pouch form, mirroring the standard design of li-polymer batteries that LG Chem produced for various portable electronics.

By 2011, LG Chem had transformed GM's vote of confidence in its batteries into signed deals with ten other leading automakers, including Renault, Ford, and Volvo.[120] As an indication of its growing Li-ion battery business, and as shown in Table 1, LG Chem broke off "Batteries" from its Information and Electronic Materials segment in 2012, revealing it had booked about $2.2 billion in revenue, equal to about 11 percent of the company's annual total. In 2014, GM unveiled its "Bolt", a mass-market BEV. In an "unprecedented" move, according to GM's Mark Reuss, LG Chem then played an expanded as well as key role in developing the Bolt, serving not only as a battery cell supplier but as the lead designer, engineer, and tester of the battery system, while supplying other electronic components for the BEV.[121] LG Chem's capabilities enabled GM to develop and release the Bolt in late 2016, beating Tesla's third-generation BEV, the Model 3, to market, matching its price target of $35,000.[122]

Table 1: LG Chem battery segment growth, 2000-2025 (millions $)*

Year	Total revenues	IT & Electronic Materials rev.	IT & EM Op. income	Batteries	Battery Op. income	Energy Solutions	ES Op. income	Batteries as % of total rev
2000	4,793	515	22					
2001	2,799	132	(17)					
2002	4,345	362	54					
2003	4,758	586	81					
2004	6,224	1,053	38					
2005	7,253	1,239	(24)					
2006	9,724	1,673	51					
2007	11,621	2,296	165					
2008	11,509	2,453	411					
2009	10,744	3,280	391					
2010	17,138	4,242	519					
2011	20,818	4,603	443	2,049	106			10%
2012	20,657	2,904	387	2,200	34			11%
2013	21,142	2,763	346	2,351	30			11%
2014	21,456	2,239	88			2,695	62	13%
2015	17,867	2,783	104			2,783	0	16%
2016	17,820					3,072	(43)	17%
2017	22,761					4,039	26	18%
2018	25,637					5,912	190	23%
2019	23,463					7,163	(390)	31%
2020	25,476					10,473	(140)	41%
2021	37,208					15,551	621	42%
2022	39,467					19,807	941	50%
2023	42,280					25,764	1,655	61%
2024	35,718					18,783	422	53%
2025	32,315					16,646	947	52%

Source: LG Chem and LG Energy Solutions annual reports, various years.
* For the years 2000-2010, LG Chem's battery sales were included in its IT and Electronic Materials segment. Starting in 2012, "Batteries" became a standalone reportable segment. In 2015, LG Chem's battery business was included as part of its new "Energy Solutions" segment, which combined mobile, auto, and electric storage battery products.

In the process of developing the Volt, and later the Bolt, LG licensed rights to the NCM cathode from the U.S. Department of Energy's Argonne National Laboratory, and for the Bolt, 3M's NCM patents as well.[123] With the Chevy Bolt becoming one of the bestselling BEVs in the U.S., LG's battery business, now reported under "Energy Solutions", doubled to $4 billion. In December 2020, as revenues climbed to $10.5 billion, LG Chem spun off the division as "LG Energy Solution" (LGES). In January 2022, LGES completed the largest IPO in South Korean history, raising $10.7 billion, and establishing it as one of South Korea's most valuable listed companies.[124]

In the interim, however, disaster struck. Manufacturing defects in the Bolt's battery packs created fire hazards, leading to a recall that began in November 2020. By the summer of 2021, the recall had been extended to each and every one of the 141,000 Bolt BEVs that had been produced since 2017.[125] LG Chem ultimately lost about $2 billion over the course of the recall, but EV sales were beginning to boom, and the company was able to absorb its losses while generating positive operating income. Notwithstanding the fact that the pouches themselves were not to blame, the recall set the stage for LG Chem to begin to invest as well in cylindrical and prismatic battery form factors as they became essential to emerging "cell to pack" designs that demarcated more advanced BEV platforms from earlier iterations.[126]

With operating profits, and ample cash from its IPO, LGES sought to expand its investment in battery manufacturing and technology. After its spinoff from LG Chem in 2020, LGES entered a 50:50 JV with GM to build their own "gigafactory", capable of producing 30 GWh of GM-branded "Ultium" cells (sufficient for about 500,000 EVs), in Warren, Ohio. LGES committed about $1 billion toward the $2.3 billion cost, the plant opening in 2022.[127] The move represented a major scaling up of LGES's EV battery business, its Holland, Michigan plant previously being capable of about 5 GWh of annual output.[128] In 2021, LGES and GM announced a second Ultium plant in Spring Hill, Tennessee. Requiring another $2.3 billion financial commitment, the plant entered production in 2024. In 2022, LGES announced a third battery plant under its JV with GM in Lansing, Michigan, representing another $2.6 billion commitment to produce EV batteries. With a combined output of over 130 GWh, the LGES-GM JV had the capacity to produce about two million BEVs annually.

LG Chem's willingness to co-invest in so much EV battery capacity was, no doubt, related in part to GM's declaration in 2021 that it would produce nothing but electric vehicles by 2035.[129] GM's goal reflected China's stated policy, announced in October 2020, to transition its automobile market to "new energy vehicles" (hybrids and electrics) by 2035.[130] Having sold 6.8 million vehicles in 2020 (including 2.9 million in China), GM's management thought that, in an all-EV world, it would easily be able to absorb LG Chem's battery output.

At the same time that GM CEO Mary Barra was claiming to be all in on EVs, however, she and her executive team were carrying out record stock buybacks, well in excess of the amounts being allocated to the new EV plants.[131] In late 2023 alone, GM did a $10 billion "accelerated" share repurchase equal to 25 percent of the company's outstanding shares, even as it continued to lose market share in China, GM's most important growth market in the 2010s. In 2017, China sales peaked at 4.0-million units, equal to 45 percent of GM's worldwide sales.[132] By 2023, however, GM's auto sales in China had plummeted to 2.1 million, 34 percent of its worldwide sales.[133]

GM's loss of market share in China reflected its failure to keep up with the rapid EV transition and fierce competition underway there. Under these adverse circumstances, in part of GM's own creation, with the downturn in the U.S. EV market in 2024, it was not surprising that GM opted to sell its share of the Lansing, Michigan plant to LGES for $2 billion.[134] GM's actions repeatedly belie CEO Barra's oft-repeated statements that GM is committed to the EV transition. Since the late 1990s, GM has undermined its commitment to the EV transition by doing billions upon billions of dollars of stock buybacks.[135]

Luckily, LGES has courted customers from all over the world. Upon taking complete control of the Lansing plant, LGES signed an agreement to reallocate the plant's battery output to Toyota, which gave LGES a $1.5 billion order.[136] LGES has also supplied Li-ion batteries to, or entered JVs with, Tesla in China, Rivian, Hyundai, Kia, Ford, Stellantis, Mercedes, and Honda. Aside from its expanding EV battery business, LGES notably began producing "Energy Storage Solution" (ESS) products in 2015, with gigafactory-scale production sites in China, the U.S., and Korea. In 2026, for example, Tesla entered an agreement to purchase $4.6 billion in LFP cells for its Megapack 3 energy storage product from LGES, another boon for its now wholly-owned Lansing plant.[137]

In 2023, LGES published its "road to 540 GWh", announcing an intention to supply batteries for 6.75 million EVs annually by 2025.[138] In 2025, LGES completed an expansion of its Holland, Michigan factory for about $1.4 billion, which will now make LFP batteries for its ESS products and which raised its total global rechargeable Li-ion battery capacity to about 500 GWh.[139] That same year, it inked an agreement to supply 20 GWh of NCMA batteries to Toyota annually, and announced that it would invest $3 billion to expand production in Michigan for Toyota's U.S. BEV offerings.[140] At the end of 2025, LGES had $18.4 billion in total revenues and 32,760 employees.[141] With close to $1 billion in annual operating profits, a unique capability to produce all three of the major battery form factors, and supplier relationships with most of the major auto producers of the world, including Tesla (in China), GM, VW, and the Hyundai Motor Group, LGES' success reflects its commitment to innovation that has not abated when challenged by significant setbacks or uncertainty.

BYD

Founded in 1995, BYD was launched to produce rechargeable batteries for the mobile electronics industry. By 2002, BYD was the world's second largest producer of Li-ion batteries, after Japan's Sanyo. From the start, BYD pursued a vertical integration strategy, which included, in 2003, the purchase of a State-owned automobile company. Its current position as the second largest EV battery producer in the world is integrally related to its recent emergence as the world's leading manufacturer of EVs.

The CEO of BYD from its founding to the present has been Chuanfu Wang. One of eight children from a poor peasant family, Wang was only 29 years old when he launched the company in Shenzhen (home also to China's Huawei, TenCent, and DJI). The young entrepreneur may have been "building his dreams" when he set up shop to produce Li-ion batteries but in fact the company only began suggesting that BYD was an acronym for "Build Your Dreams" once it was producing cars, with the slogan debuting at the Beijing International Automotive Exhibition in November

2006.[142] Insofar as the availability of very high-quality and very low-cost (and hence very low-priced) cars that run on electricity can fulfill people's fantasies, by the third decade of the 21st century, under Wang's continuous leadership, the battery company that he had founded in 1995 had grown into its adopted long-form name.

A gifted student, Wang earned a bachelor's degree in metallurgical physical chemistry in 1987 from Central South Industrial University in Hunan, China, and a master's degree in 1990 from the Beijing General Research Institute of Non-Ferrous Metals. After graduating, he stayed on at the Beijing Institute, working on rechargeable battery research.[143] Just three years after joining the Institute, Wang became vice supervisor of research.[144] In 1993, the Beijing Institute set up the Shenzhen-based Bi Ge Battery Company, and made Wang its general manager, while he retained his position at the Institute.

Wang's co-founders of BYD Industries were Xiangyang Lu and Zuo-quan Xia. Lu was Wang's cousin, investing in BYD after a career in banking that stretched from 1978 to 1992. In 1993, he founded Guangzhou Rongjie Investment Company Limited, which he used to invest $300,000 in BYD in exchange for 31.1 percent of BYD's shares (as disclosed in its prospectus for its IPO on the Hong Kong Stock Exchange in 2002). Lu became vice chairman of BYD, a non-executive position that he has held to the present.[145] Prior to joining BYD as an executive director in 2001, Xia's work experiences were also in finance. In 1995, Xia put up $47,100 to become BYD's third co-founder, holding 10 percent of BYD's shares outstanding in 1997. At the founding in 1995, the remainder of BYD Industries' shares were held by the State-owned Shenzhen Metallurgical and Mining Corporation (SMMC), with 64.4 percent of the shares, and Shenzhen Lidasi Company Limited, which held 4.5 percent of the total shares.

In 1997, SMMC sold its shares in BYD to Guangzhou Rongjie, boosting Lu's total shareholding to 65.5 percent. The remainder of the shares went to Wang, who now held 20 percent of BYD's shares, with Xia holding 10 percent and Shenzhen Lidasi 4.5 percent. In January 1998, BYD increased its registered share capital by 25.5 million RMB (about $3 million), out of contributions made by Lu (16.55 million RMB), Wang (6.40 million RMB), and Xia (2.55 million RMB). In 1998, the founders established a separate entity, Shenzhen BYD Lithium Battery Co. After further internal restructuring of ownership, designed to give Wang a higher proportion of shares as well as to provide shares to managers, the distribution of BYD shareholding after the IPO was Wang 28.9 percent, Lu 12.1 percent, Guangzhou Rongjie 8.6 percent, Xia 6.3 percent, management shareholders 17.0 percent, others 2.1 percent, and public shareholders 25.0 percent.[146]

In 2011, BYD did an IPO on the Shenzhen Stock Exchange, further diluting the shareholdings of the founders. By 2025, dilution left Wang with 17 percent of BYD's shares, Lu 13 percent, and Xia 3 percent.[147] Each of BYD's founders remains on the company's board of directors, which is otherwise populated by three other independent directors, for which they receive an annual fee of $44,500. At no time from the company's founding in 1995 has there been a threat to Wang's strategic control.

From the beginning, Wang has used his strategic control to advance BYD's innovation strategy. In the early years, BYD obtained and reverse-engineered assorted types of foreign rechargeable batteries.[148] Whereas the Japanese firms ran highly automated production systems, BYD initially relied upon labor-intensive methods to produce similar quality batteries at a lower cost. BYD found success focusing, at first, on nickel cadmium and, after licensing the intellectual property from U.S.-based Energy Conversion Devices,[149] NiMH rechargeable batteries produced for and sold to local firms in Shenzhen; for example, for electronic toys. On the strength of its sales of NiCd and NiMH batteries, by 1997, BYD had grown to 1,000 employees, including 20 in R&D, and had begun attracting business from foreign companies. Wang then reinvested BYD's profits and set his R&D employees to work applying the same labor-intensive methods to develop Li-ion batteries.

After tearing down world-leader Sanyo's Li-ion cells, Wang opted to reformulate the battery chemistry to reduce its sensitivity to humidity, eliminating some of the need for investment in the large dry rooms which made Japan's batteries more expensive.[150] BYD's labor-intensive process not only saved costs but also became a basis for product innovation and factory automation. In 1998, BYD set up BYD Lithium to officially enter the Li-ion battery business. With its new Li-ion batteries, BYD moved into rechargeable battery state-of-the-art.

In 2000 and 2002, BYD succeeded in winning contracts to supply batteries to Motorola and Nokia, then the world leaders in mobile phones, propelling BYD to 17,000 employees by 2002.[151] With prismatic-battery contracts from Motorola and Nokia in hand, BYD did an IPO on the Hong Kong Stock Exchange in 2002, raising $180 million.[152] In 2003, Motorola comprised 60 percent of BYD's rechargeable battery business, up from 30 percent in 2002.[153]

Motorola did not just order batteries from BYD. It sent its own engineers into China to upgrade the quality of BYD's operations, until BYD earned Motorola's renowned "Six Sigma" designation for 99.9999 percent defect-free production.[154] Motorola's investment was important to BYD's cost-reduction strategy in the early 2000s, as well as testament to the importance of the Chinese mobile phone market to the American company.

By the early 2000s, BYD had secured a top-three spot in market share in each of its NiCd, NiMH, and Li-ion battery segments, a fact that had not gone unnoticed by its major Japanese rivals, global leaders in Li-ion batteries who were determined to prove that BYD had stolen its success. When BYD procured contracts to supply batteries to Motorola and Nokia, it took business away from Sanyo.[155] In 2002, Sanyo filed a patent infringement case against BYD in U.S. court. That was followed by a second lawsuit, filed by Sony in 2003 in Japanese court, which meant that the number one and number two largest Li-ion battery producers in the world were going after BYD as the third largest.[156] If the lawsuits of the Japanese companies had prevailed, it would have destroyed BYD's ability to sell batteries outside of China. However, BYD triumphed in court against Sanyo in March 2005 and Sony in December 2005.

In 2003, as BYD was fending off Japan's Li-ion battery leaders in court, it began moving into mobile phone manufacturing. In 2005, BYD succeeded in attracting assembly work from Motorola and Nokia, damaging direct-competitor Foxconn, which depended on the two mobile phone companies for over 90 percent of its revenues. In 2006, Foxconn filed a lawsuit in Shenzhen against BYD, alleging it had built its mobile phone manufacturing business by actively recruiting its engineers and managers, and engaging them in industrial espionage, stealing trade secrets and IP. Foxconn filed a second suit in Hong Kong civil court in 2007.[157] The lawsuits led to conviction and prison sentences for four individuals—one Foxconn employee and three BYD employees recruited from Foxconn. However, Foxconn abruptly dropped its suit in 2008, when it was revealed that they had fabricated as well as destroyed evidence after bribing agency officials and employees involved in the lawsuit.

BYD's successful defense against Japan's leading Li-ion battery manufacturers and its averting of criminal prosecution in its conflict with Foxconn were significant. The victories offered proof that BYD's success was the result of its investment in collective and cumulative learning to develop internal production methods that yielded batteries or mobile phone devices of similar quality to its competitors at lower prices—in other words, innovation.

With the lawsuits behind it by 2008, BYD's battery and mobile electronic assembly business continued to grow. By 2011, BYD supplied batteries to not only mobile phone makers Nokia and Motorola, but also China's leading communications equipment companies, Huawei and ZTE. As the years passed, the list of customers grew to include Dell, Microsoft, Bosch, TTi, Ecovacs, iRobot, Apple, Samsung, HTC, Lenovo, HP, Toshiba, Asus, Xiaomi, and Vivo.[158]

In January 2003, BYD acquired a 77 percent stake in State-owned Xi'an Qinchuan Automobile, permitting it to enter the rapidly growing and hyper-competitive auto business in China. BYD's stock price was battered by the decision, but automobile manufacturing was Wang's next step in his evolving innovation strategy, which was to leverage BYD's expertise in batteries to produce innovative EVs. To learn how to make autos, BYD applied the same approach it had taken with batteries—reverse engineering products that were best-in-class. Wang and his engineering teams tore down a Toyota Corolla, and at one point his personal Mercedes Benz S-Class, to learn about their assembly and quality.[159] Having mastered battery and mobile electronic manufacturing, Wang would later say that "a mobile phone is more difficult to make than a car," which Wang described as "just a pile of iron and steel".[160]

Building ICE vehicles was nevertheless a precursor to BYD's development of EVs. In 2005, BYD released its first vehicle, the F3 (a product loosely based on what BYD learned tearing down a Toyota Corolla).[161] In 2008, it released the world's first Li-ion powered plug-in hybrid (PHEV), a variant of the F3 called the F3DM, an achievement notably two years ahead of GM's first PHEV, the Volt, and four years ahead of Toyota's PHEV version of its bestselling Prius. In 2010, as BYD's ICE sales peaked at about 520,000 (see Table 2, below), it released its first BEV, the e6, as a taxi in Shenzhen and also abroad.[162]

It should be noted that three months after BYD made the decision in January 2003 to enter the automobile industry for the purpose of producing EVs using the batteries that it would develop, GM had definitively terminated its EV1 program—repossessing the leased EV1 and crushing them—with no plans for a successor EV. GM's decision to exit the incipient industry, in turn, inspired Martin Eberhard and Marc Tarpenning to found Tesla in July 2003, and in 2004 Elon Musk joined the company, becoming its chairman after putting $6.5 million into its first funding round.

Table 2: BYD unit auto sales and percent New Energy Vehicles (NEVs), 2006-2025

Year	BYD Total auto sales	BYD NEV Sales	BYD NEVs as % of total BYD sales	BEVs as % of BYD NEVs	BYD NEVs as % of total auto market in China	BYD NEVs as % total NEV market in China
2006	55,038					
2007	85,942					
2008	170,000					
2009	450,000					
2010	520,000					
2011	437,000					
2012	420,000					
2013	470,000	3,096	0.7		0.0	17.5
2014	373,000	27,867	7.5		0.1	37.3
2015	380,000	58,000	15.3		0.2	17.5
2016	422,000	96,000	22.7		0.3	18.9
2017	355,000	110,000	31.0		0.4	14.2
2018	520,687	247,811	47.6	41.7	0.9	19.7
2019	461,399	229,506	49.7	64.1	0.9	19.0
2020	426,972	189,689	44.4	69.0	0.7	13.9
2021	740,131	603,783	81.6	53.1	2.3	17.1
2022	1,868,543	1,863,494	99.7	48.9	6.9	27.1
2023	3,024,417	3,024,417	100.0	52.1	10.0	31.9
2024	4,272,145	4,272,145	100.0	41.3	13.6	33.2
2025	4,602,436	4,602,436	100.0	49.0	13.4	27.9

Sources: BYD *Annual Reports*, various years; BYD voluntary production and sales volume disclosures, various years. BYD NEV sales for 2013 and 2014, and vehicle sales in China for 2006 are estimates based on disclosures in *Annual Reports*.

Though BYD was a first mover in PHEVs and BEVs, the F3DM sold relatively poorly. Its batteries were expensive, and charging infrastructure in China at the time was not widespread. The strategy of producing taxis, and later buses, permitted BYD to generate revenues from its R&D investment in EVs while continuing to develop its battery and powertrain technologies. PHEVs still play an important role as a bridge technology for China's EV consumers as rapid charging infrastructure spreads. Since 2022, hybrids have comprised approximately 50 percent of BYD's unit sales.

Around 2008, Li Lu, an investment manager who had begun buying shares of BYD in 2002, touted the company to Charlie Munger, who pitched buying shares in BYD to his long-time investment partner, Warren Buffett.[163] Wang was, according to Munger, a modern-day Thomas Edison-Jack Welch hybrid, noting that "Edison was good at solving technological difficulty. Welch was good at getting what he needed to succeed. Wang Chuan-Fu also has these qualities."[164] Buffett dispatched David Sokol to investigate the company. Sokol was at the time CEO of MidAmerican Energy Holdings, Berkshire Hathaway's utility energy business. With Sokol's approval of the purchase, in 2008 BYD agreed to sell Berkshire 9.89 percent of its treasury H-shares for $232 million. When interviewed, Sokol was clear that Berkshire was placing its bet on BYD's battery business, not its growing auto business, stating, "the only part that played into [the investment decision] was the battery technology," adding, "whether or not they can manufacture their own cars isn't that relevant to us, because we see their real expertise is in the development of the batteries, the motors, the control systems."[165]

Berkshire initially asked for 25 percent of BYD's shares. Buffett took it as a "good sign" that Wang rejected the proposal as it indicated he "didn't want to sell his company".[166] Though BYD gave Berkshire's Sokol a board seat as a condition of the transaction, Wang retained 28 percent of BYD's voting control overall, and, with his co-founders Lu and Xia included, 54 percent. Apart from the funding it received, BYD benefitted from the publicity that attracting Berkshire Hathaway as an investor created.[167]

During FY2009, BYD's $3.1 billion in revenues from its auto segment surpassed those of its handset components and assembly business segment for the first time (53 percent versus 36 percent). On June 11, 2011, BYD completed a second IPO on the Shenzhen Stock Exchange, raising an additional $219 million to invest in batteries, a dedicated R&D facility in Shenzhen for its auto business, and its expanding auto business more generally.[168] That same year, the company opened its U.S. headquarters in Los Angeles, California. Struggling to gain a foothold for EV sales in the U.S. market, in 2013, BYD pivoted to producing electric buses, opening a plant in Lancaster, California. In 2015, BYD began producing electric buses in the U.K.

BYD sold 55,038 vehicles in 2006, which grew to 520,000 in 2010, when BYD had 5.0 percent of China's auto market. BYD lagged far behind Volkswagen and GM, whose JVs with domestic automakers produced millions of vehicles annually and dominated the Chinese market. Creating a new opportunity for BYD was the growth of China's "new energy vehicle" (NEV) market, which began its meteoric rise in 2013, with sales of NEVs in China soaring from about 23,100 in 2013 to 1.3 million in 2018. With sales of 470,000 vehicles of all types in 2013, BYD's share of the total Chinese car market slipped to about two percent. BYD's market share declined further through 2017, as it began producing EVs at scale. In 2022 BYD announced it would cease producing ICE vehicles entirely, completing its transition to 100 percent EVs more than a decade ahead of China's official 2035 mandate. In 2023, BYD completed its EV transition profitably, its finances supported in part by its electronics segment, State subsidies, asset sales, and sales of raw scrap.

In 2024, BYD's sales of 4.2 million EVs were equal to 33.2 percent of China's NEV market and 13.6 percent of its total auto market. BYD's blew past VW, which reported sales of 2.9 million units in 2024, as China's best-selling auto brand for 2024, while also surpassing GM, whose sales in China declined significantly.[169]

In 2024, BYD became the largest EV company in the world, with 4.27 million combined EV unit sales, its 1.76 million BEVs falling just short of Tesla's 1.79 million.[170] In 2025, however, BYD became the world leader in BEV sales as well, with 2.3 million BEVs versus Tesla's 1.6 million.[171] With 4.6 million EVs sold in 2025, BYD was the world's largest EV maker and the world's 6th largest auto manufacturer globally, bumping Ford into the number seven spot.[172]

Tesla has sought to protect its lofty stock market valuation by claiming a competitive advantage in batteries, self-driving, AI, and robotics. In BYD, it faces a direct competitor on all fronts. In March 2020, BYD released its “Blade” LFP battery, which features an innovative “cell to pack” design. The Blade battery has closed much of the performance gap with rival battery chemistries, while permitting Wang to demonstrate, for a global audience, the ability to drive nails through the battery cells without them bursting into flames.[173]

Six years later, on March 5, 2026, the company announced Blade battery 2.0, boasting a new Li-ion manganese phosphate chemistry, improving energy density by five percent, and significantly improving its rate of recharge. According to BYD, the Blade battery 2.0 can charge from ten percent to 70 percent in five minutes, or to 97 percent in nine minutes. In extreme cold, it can be recharged from 20 percent to 97 percent in just 12 minutes.[174] To ensure that BYD buyers benefit from their extreme recharging capabilities, BYD also announced that it was beginning to build out thousands of FLASH rapid charging stations, which can deliver 1.5 megawatts into its EVs. While BYD has improved upon its battery technology, it has expanded its EV product offerings to compete at all price points, from the low-end of the market all the way up to ultra-luxury and ultra high-performance segments of the market.

In 2023, BYD announced the release of its “God’s Eye” self-driving technology, which combines visual and lidar detection hardware with in-house software and electronics developed for the system. In 2026, BYD took an additional step of announcing that it would insure its customers of God’s Eye 5.0, its most advanced technology, for one year against accidents related to the use of its system, for which BYD charges about $1,770.[175] Like other automakers, BYD has been developing humanoid robots since 2022, and has, since about 2021, begun building “lights out” factories—plants with near 100 percent automation rates that can produce an EV in minutes, significantly reducing costs.[176]

In 2021, BYD began its push to sell NEVs around the world, beginning with Norway. In 2022, it entered Brazil and made plans to manufacture there in 2023. Even as it has ramped up production abroad, BYD’s exports have exploded. In 2023, exports of EVs were 242,765. BYD exported 1,046,086 EVs in 2025, and 972,794 EVs in the first half of 2026, BYD’s innovations are already starting to change the global auto industry in markets outside of China.[177]

To support its global expansion, BYD announced in 2022 that it was allocating $687 million to begin building a fleet of EV transport ships to reduce its shipping costs and remove a key bottleneck preventing it from meeting demand for its products worldwide.[178] In 2024, it sailed its first two roll-on, roll-off (ro-ro) ships, the Explorer No.1 and the Changzhou, each of which can carry 7,000 EVs.[179] The BYD Shenzhen transports up to 9.200 EVs.[180]

The decision to build a fleet of transport ships occurred as BYD’s EV sales more than doubled to 1.9 million units, generating $48.3 billion in revenue, equal to 77 percent of its total revenue and making its auto segment dominant. BYD’s electronic components and assembly business added another $14.7 billion. For its efforts over the course of 2024, BYD booked $107 billion in total revenue, $5.6 billion in net income, and employed 968,900 people, more than General Motors had at its peak in 1979.[181] During 2025, BYD had 4.6 million in overall EV sales, booking $112 billion in revenue and $585 million in net income. Meanwhile, its automation strategy drove employment down to 869,600.

With its rapid growth, deep vertical integration, and commitment to retaining and reinvesting earnings in innovation, BYD is no doubt one of the Chinese firms that Tesla CEO Elon Musk had in mind when, in 2024, he said that “frankly, I think, if there are not trade barriers established, they will pretty much demolish most other companies in the world.”[182] This statement represents an about-face from derisive comments Musk made about BYD 13 years earlier.[183] Wang could respond to Musk’s current prognosis by saying “it’s the Blade battery, stupid.”

Contemporary Amperex Technology Limited (CATL)

By far, the world leader in EV batteries is CATL. Headquartered in Ningde, China, CATL is the EV battery business spun off from Amperex Technology Limited (ATL) in 2011. ATL was co-founded in 1999 by Shaokang Liang, Tang-Hua Chen (1944-2010) and Yuqun Zeng (aka Robin Zeng).

Chen was born in China, raised in Taiwan, and educated in the U.S., earning an MS in chemistry at the University of Arizona and a PhD in physical chemistry at the University of California, Berkeley. He joined IBM in 1973, working on disk drives, before leaving in 1982 to work for several startup companies, including his own consulting company. In 1995, he returned to China by joining SAE Magnetic, a subsidiary of Japan-based TDK, located in Hong Kong, with operations in Dongguan, China.[184] SAE Magnetic was a maker of components for hard disk drives.

Born near Ningde in 1968, Zeng received a bachelor’s degree in engineering from Shanghai Jiao Tong University in 1989. Following his graduation, he left secure employment at a State-owned company after just three months to join SAE Magnetic, rising to the position of director of engineering. While working there, he earned a master’s in electronics and information engineering from the South China University of Technology in 2001 and a PhD in condensed matter physics from the Chinese Academy of Sciences in 2006.

Shaokang Liang was an employee of SAE Magnetic before it was acquired by TDK in 1986. With a master’s degree in engineering from the University of Hong Kong, Liang rose through the ranks to become SAE Magnetic’s CEO. TDK, founded in Tokyo, Japan, in 1935 is a storied enterprise that diversified from its roots in magnetic materials into electronic and recording media. With Liang’s help, it developed a globally dominant hard disk drive head business.

In the late 1990s, as the market for mobile devices was booming, Liang convinced Chen and Zeng—each having spent a decade or more at SAE Magnetic—to leave to establish a battery startup.[185] In July 1999, the trio co-founded Amperex Technology Limited (ATL) as a rechargeable Li-ion battery company, with Liang assuming the role of chairman, Chen appointed as the company’s first president and CEO, and Zeng, then only 31 years old, becoming executive vice president.[186] Liang retained his position as SAE Magnetic’s CEO.

ATL’s innovation strategy was to produce Li-ion batteries for mobile electronics. The group utilized $1 million, about 40 percent of their $2.5 million startup funds, to obtain a license for a rechargeable Li-ion polymer battery from U.S.-based Telcordia (formerly Bellcore), the research consortium of the regional Bell operating companies in the U.S.[187] Li-ion polymer batteries had several key advantages. Firstly, they promised greater energy density. Also, with their flexible "pouch" form factors, and semi-solid electrolytes, they could be significantly thinner than the "AA"-sized 16850 or prismatic cells then in use. With customizable dimensions, Li-polymer batteries gave electronic device makers significant new design flexibility. The Li-polymer battery became the basis for ATL's successful push into rechargeable Li-ion production after Zeng, over the course of just two weeks, solved the problem of the battery swelling by tweaking the electrolyte. As a result, ATL became the first company to successfully commercialize Li-polymer batteries based on the Bellcore patent, having outsmarted 20 other Bellcore licensees, including Sony and Panasonic, which had up to that point been unsuccessful in overcoming the same swelling problem.[188]

With the technical problem of the Li-polymer battery solved, ATL turned to production. Within three months, the company had implemented a low-cost, labor-intensive manufacturing process and was generating profits from the sale of its new battery.[189] With new market opportunities, ATL needed cash to scale its operations. In 1999, ATL completed its Series A funding round, raising $1.6 million from the Asia Pacific Fund of Hambrecht & Quist (H&Q), a prominent Silicon Valley venture capital company.[190] In return for the funding, H&Q gained two of ATL's five board seats and a 48 percent equity stake.[191]

In December 2001, China entered the World Trade Organization, which increased the confidence of foreign financial companies that, should they want to exit their investment in an unlisted Chinese firm, a buyer for their shares could be found. In June 2003, with growing battery orders, ATL completed a series B funding round, attracting $22.5 million from U.S.-based Carlyle private equity group and $7.5 million from the U.K.-based 3i group.[192] Upon completing its acquisition of ATL's shares, Carlyle's Gabriel Li described ATL as a low-cost manufacturer supplying global multinationals "at the cutting-edge of battery production," with "thinner and safer" batteries that offered "10-20% more higher [sic] energy density".[193]

In 2004, ATL's reputation for producing high-quality, low-cost Li-polymer batteries attracted Apple as a major customer, which placed an order for 18 million batteries.[194] At the time, Apple was struggling to procure enough batteries to keep up with demand for its iPod, a portable music player for which sales had exploded from 939,000 units in 2003 to 4.4 million units in 2004, and then 22.5 million units in 2005.[195] The iPod was a hit product that provides an example of interdependence of innovation in rechargeable batteries and consumer electronics at the time. The iPod used a proprietary variation of the superior "MP3" music compression algorithm developed in 1997, which it called AAC, a miniaturized hard disk drive, and ATL's new lithium-polymer battery. The battery allowed for a significantly smaller, thinner, and lighter device than had been possible with portable cassette or CD players that had been available since the 1970s and 1980s, while offering all-day battery life.

As ATL's battery business generated profits, the founders decided they wanted TDK to buy them out. In May 2005, TDK purchased all the shares of the venture capitalists, private equity investors, and founders for about $100 million.[196] With this change in control, the company became a subsidiary of TDK, with Chen and Zeng retained as senior executives to run the ATL division.

At the time that the sale to TDK was completed, Chen and Zeng had overseen ATL's growth to 3,000 employees. Zeng had simultaneously upgraded his own technical expertise by finishing (as mentioned above) his master's degree in 2001 and PhD in 2006. ATL's rapid growth benefitted from TDK's superior financial resources and expertise in materials science, and TDK benefited from the willingness of Zeng to stay on as senior vice president and general manager of TDK's battery business,[197] with Chen serving as vice chairman and Shilin Huang, who had long served as Zeng's "right hand man", as director of R&D and vice president.[198] TDK reported that the acquisition of ATL was made "for the purpose of obtaining an operating base on which to develop the Company's materials technology", viewing Li-ion batteries as a significant business opportunity.[199] And it was; batteries became TDK's largest segment by revenue in 2018.[200] In fact, in 2022, incoming President Noboru Saito noted that TDK's efforts to rebalance its earnings generation from its operating segments was making progress after years of becoming "highly dependent" on the battery business.[201]

Apple was a key ATL customer, procuring its batteries as it developed other hit products—the iPhone, introduced in 2007, and the iPad, introduced in 2010.[202] Apple also procured batteries from Samsung SDI, but in 2011, when Samsung Electronics developed a mobile phone that was a major competitor to Apple's iPhone, Apple began shifting its battery manufacturing away from Samsung SDI, further strengthening ATL's relationship as a key supplier of batteries to the American company.[203] Apple sold over 125 million iPhones in 2012, driving revenues of TDK's ATL division to increase by almost 60 percent from the previous year.[204] In 2016, ATL added Samsung—then the world's largest smartphone maker, with over 309 million unit sales (compared to Apple's 212 million unit sales)—to its customer base.[205]

As ATL built up its mobile electronics battery business, becoming the leader in market share, it was approached by EV makers interested in integrating Li-ion batteries into their electric powertrains. In 2006, under the direction of Zeng and Huang, ATL began doing R&D into EV batteries, seeking licenses for new battery chemistries from the United States. In 2008, the company established an official EV R&D battery research division. In the same year, ATL supplied LFP batteries for electric buses used during the Beijing Olympics.[206] With the development of its "Ten Cities, Thousand Vehicles" policy in 2009, China's EV policy makers, led by Wan Gang, a former researcher and engineer for Audi who had returned to China in 2000, were positioning batteries and EVs as strategic technologies, investing billions of dollars into the establishment of a domestic industry. By investing in EV battery R&D, ATL's leaders were aligning with Chinese government policy to transition China's booming automobile industry from ICE vehicles to EVs.

On December 12, 2010, Chen died, halting plans for ATL to file for an IPO in the U.S., as the smartphone market, and ATL's battery business, continued to boom.[207] Five months later, in April 2011, China's National Development and Reform Commission (NDRC) signaled through its "Foreign Investment Catalogue" that it was contemplating a prohibition on foreign-owned battery makers from operating in China's market. In late 2011, the NDRC determined that foreign EV battery makers would be restricted to 50 percent ownership, which stymied ATL's ambitions to produce batteries for a Chinese EV market because it was majority-owned by Japan-based TDK.

As a direct response to this problem, in December 2011, Zeng and Huang spun out ATL's nascent EV battery business as Contemporary Amperex Technology Limited (CATL), with 85 percent of its shares held by the Chinese entity and 15 percent by TDK. With this structure, CATL would be able to operate in the world's largest automobile market. With the support of generous subsidies from the Chinese government, CATL also had the potential to become the world's largest EV battery maker. Zeng and Huang provided significant financial resources to the new venture, establishing themselves as dominant shareholders. A key executive recruited from outside CATL was Bob Gaylen, a battery industry veteran and ex-GM employee of 21 years, including during its ill-fated EV1 program in the 1990s. Gaylen was named chief technology officer, a position that he would hold for eight years.[208]

The LCO cathodes and Li-polymer battery technology that ATL had mastered, however, were not suitable for EVs. CATL had to search for a new chemistry. NMC batteries were, at the time, a risky bet, given patent infringement cases lodged by its key patent holders, 3M and the U.S. Department of Energy's Argonne National Laboratory.[209] NCA chemistry would require, and most likely not receive, cooperation from Japanese patent holders Sumitomo and Panasonic. CATL opted, initially, to rely upon lithium iron phosphate (LFP) batteries to provide the technological foundation for their push to make innovative EV batteries.

CATL's decision to use LFP chemistry benefitted from the prior successful move of the Chinese Battery Industry Association (CBIA) to block enforcement of foundational LFP patents, held abroad, controlled by the LiFePO+C consortium in Canada. In 2011, the CBIA, comprised of BYD, ATL, BAK, Lishen, Gotion, and Pulead, all of which had invested in LFP batteries in the mid-2000s, convinced Chinese officials to invalidate the patents. The LiFePO+C consortium tried, and then failed, to collect royalties on its intellectual property. China's domestic firms were banned from exporting LFP batteries for ten years, after which time key LFP patents either expired or were set to expire.[210]

On paper, LFP came with disadvantages, namely, lower energy density relative to NMC or NCA batteries. But LFP batteries also had advantages. The chemistry was innately safer, offered a long duty cycle, could be charged to 100 percent routinely with less damage to its future capacity, and, making use of relatively abundant raw materials, was relatively low cost.

In 2012, CATL was approached by BMW, the German luxury-vehicle producer. BMW had commenced a JV with China's Brilliance Auto to produce an EV, but (like other automakers) was seeking a Chinese supplier of EV batteries. Recognizing that CATL was run by the same persons who had proven capable of meeting Apple's exacting quality standards for ATL, BMW shared an 800-page technical document with the startup, and dispatched its engineers to partner with, and help oversee, CATL's investment in EV battery manufacturing. Over the next two years, CATL learned to meet BMW's technical and quality standards, which Zeng, in 2016, noted was an important contribution to CATL's rapid growth as an EV battery producer.[211]

In March 2015, China's Ministry of Industry and Information Technology (MIIT) issued the "Standard Conditions for the Automobile Power Storage Battery Industry". A "voluntary" list of recommended component suppliers for EV producers, foreign and domestic, it became known as the "white list". In effect, access to the billions of yuan being spent by the Chinese government to foster a market for EVs required selection of a domestic battery supplier. The white list ended on June 21, 2019, but it succeeded in establishing a "wall" that prevented dominant foreign Li-ion battery firms at the time—LG Chem, Samsung SDI, or Panasonic, for example—from establishing strong operations in China, in some cases even when investments in new facilities were already underway.[212] The end of the white list opened the Chinese EV market to foreign competition, most significantly by allowing Tesla to set up a wholly-owned gigafactory in Shanghai. But by that point, selection of CATL or BYD as a battery supplier by Tesla was partly preferential. It was no longer "required".

Given the restrictions put into place by China's policy makers, CATL needed to break its ties to TDK. Once more, TDK accommodated CATL—this time by selling its 15 percent stake in the company in 2015 for an undisclosed amount,[213] so that CATL could qualify as a wholly owned domestic battery supplier and therefore benefit from government subsidies. As the leading "pure play" producer of EV batteries, CATL was a prime benefactor of China's preferential treatment, in 2017 emerging–with the white list in place–as the world's largest EV battery maker, a title it has since held for a decade.

On June 11, 2018, CATL completed its IPO on the Shenzhen Stock Exchange, raising $850 million (which also revealed Zeng to be the largest stockholder with 26 percent of the company's shares, while Huang held 12 percent).[214] CATL completed a second IPO on the Hong Kong Stock Exchange in 2025, raising a massive $4.6 billion and cementing Zeng as one of the world's richest persons.[215] In 2021, TDK and CATL announced the formation of a JV, with each sharing technology for the purpose of addressing "medium" sized rechargeable battery opportunities in, for example, electric motorcycles and residential energy storage systems.[216]

In 2024, CATL reported that it had 37.9 percent of the global market for EV batteries, with $50.5 billion in revenues, $7 billion in net income, and over 100,000 employees, including over 20,000 in R&D.[217] In the five years from 2020 through 2024, it expanded its battery manufacturing capacity from 69.1 GWh to 676 GWh—enough batteries for about nine million BEVs. CATL's innovations in batteries have driven the cost of EV batteries well below the cost believed to provide "parity" with ICE vehicles, while improving their range and safety.

CATL has also transitioned from consuming battery patents to authoring them, filing over 35,000 during 2020-2024 as it spent $11.8 billion on R&D.[218] Its latest generation EV batteries exploit multiple battery chemistries, while increasing their safety and enabling, in some cases, 12C rapid charging rates—granting them the ability to rapid charge an EV in minutes, or about the same amount of time one would spend at a gas pump.[219] CATL has also expanded into energy storage systems, materials and recycling, and mineral extraction and refining. CATL is driving the battery frontier by commercializing new chemistries such as Sodium-ion, better suited for colder climates or grid power storage, and dual-chemistry battery packs that can be optimized for different applications.[220]

As with BYD, CATL's operations have become more automated over time, and now include so-called "lights out" factories, which are nearly 100-percent automated and can be run 24/7.[221] In 2018, CATL began expanding its operations outside of China, announcing a factory in Erfurt, Germany, to supply European automakers. In 2022, CATL expanded into Indonesia and Hungary, while also announcing a strategic supply agreement with Ford.[222] Subsequently, Ford faced pushback from U.S. lawmakers, even as it restructured its agreement with CATL as a technology license, meant to permit Ford to invest in a $3-billion LFP battery plant in the U.S., while qualifying for billions of dollars in available U.S. subsidies.[223] In 2025, CATL broke ground on a battery factory in Zaragoza, Spain, the result of a JV into which it entered with Stellantis.[224] A vertically integrated powerhouse, CATL's innovations are likely to continue to underpin the global EV transition, and preserve and possibly even extend the company's place as the world's leading EV battery company.

Global leadership in the EV transition?

In 2019, when John Goodenough, Stanley Whittingham, and Akira Yoshino received the Nobel Prize in Chemistry for their contributions to the development of rechargeable Li-ion batteries, it looked as if the United States was at the forefront of the EV transition. Even though, back in 2000, GM had made the deliberate decision to cease production of its pioneering EV1, the mantle in the U.S. was picked up by Tesla, which in 2019 succeeded in mass producing, largely for the U.S. market, 367,656 of its BEV Models S, X, 3, and Y. From the perspective of 2026, however, it is clear that leadership in the EV transition has shifted to China, and especially to BYD in cars that use its own batteries and CATL in batteries.

Batteries are the core technology of the EV transition. Coming into the 1990s, the United States led the world in battery science and engineering,[225] and possessed the world's largest automobile market. Despite those two key facts, the United States does not at the time of this writing have a major EV battery producer. The global leaders in EV batteries are all based in Asia. In this paper, we have documented the rise of four of them, one in Japan, one in South Korea, and two in China. The next step in our project, which is the focus of a forthcoming paper, is the systematic application of the "Theory of Innovative Enterprise" (TIE) to explain how these companies became leaders.[226]

TIE focuses on three social conditions of innovative enterprise—strategic control, organizational integration, and financial commitment—that must be analyzed to understand the success or failure of a business corporation in producing the higher-quality, lower-cost products that can give it a sustained competitive advantage. Strategic control requires that corporate resource-allocation decisions be exercised by senior managers who, in the face of technological, market, and competitive uncertainty, have the ability and the incentive to invest in innovation. Organizational integration entails large numbers of people working in a complex hierarchical and functional division of labor to engage collectively in the organizational learning that can generate higher-quality products and processes. Financial commitment mobilizes money to sustain cumulative learning processes that are both uncertain and collective until they can generate financial returns by selling high-quality, low-cost products.

Our research for this paper makes it clear that strategic control has varied across these four companies, grounded in part in different socioeconomic institutions in the three countries in which they are based. Japan's Panasonic exemplifies the operation of a well-established managerial corporation, where the people who are in positions of making major resource-allocation decisions are lifetime employees who have risen through the managerial hierarchy. The same is true at LGES in South Korea, except that, as we have indicated in this paper, ultimate decision-making power lies with members of the family that founded and continue to control the chaebol. In the cases of both BYD and CATL, from their founding to the present, strategic control has resided with the original entrepreneurs, Chuanfu Wang at BYD and Yuqun (Robin) Zeng at CATL, who continue to occupy the top positions at their now massive business corporations. Through higher education and work experience, each of them had already by their late 20s acquired impressive capabilities in batteries. Over the decades, their leadership of these companies has deepened their abilities to run them as innovative enterprises. They are among the wealthiest people in China, but, by all accounts, as CEOs of their companies, Wang and Zeng remain committed to investing in battery innovation.

In a world where there is a demand for talent on global labor markets, the key challenge that confronts organizational integration is attracting, retaining, and motivating personnel who can engage in the company's collective and cumulative learning processes. Employees must be integrated into these learning processes even as they may have the option of choosing to leave to go to work for another employer, which could very well be at a location halfway around the world. The company can structure the content of work, remuneration systems, and career paths to try to manage the organizational integration of these employees.

In Japan's rise to industrial leadership in the 1980s and 1990s, lifetime employment provided the institutional foundation for organizational integration, enabling scientific, engineering, and managerial personnel to achieve career goals working for one company.[227] In the "lost decade" of the 1990s, however, many Japanese companies had to "choose and focus" on new lines of business that required new skill sets.[228] As a result, mid-career hiring became common, even though (as continues to be the case) the system of lifetime employment has remained intact.[229] During the 1990s, Matsushita (Panasonic from 2008) resisted changes to the traditional employment system until 2000 when, under Kunio Nakamura as CEO, there were significant reforms to the prevailing seniority-pay structures and the absence of interfirm mid-career employment mobility.[230] The shift to mid-career hiring intensified at Panasonic in the 2010s as the company shed its consumer-electronics businesses and focused on Li-ion batteries for EVs and energy-storage systems.[231]

Career-long employment at LGES differs from the Japanese system by the ways in which individualized modes of rewarding employees are built into career paths.[232] Korean employees receive annual cash bonuses that often reflect their specific positions in and value to the company. In recent years, management's lack of transparency in calculating the bonuses has become a contentious issue.[233] During the first half of 2026, there was substantial disruption to this system because, based on formulae used to determine the bonuses, those received by tens of thousands of employees who work at SK Hynix and Samsung Electronics have shot through the roof because of the extraordinary profits that these companies have gained from the sale of high bandwidth memory chips for AI servers. Their good fortune has reverberated throughout South Korean industry as those who have been much less well positioned to be paid massive bonuses (including employees at Samsung Electronics who do not work in the chip division) have protested, in some cases publicly and vociferously, the perceived inequity.[234]

Stock-based compensation for a broad base of professional, technical, and administrative employees, which has been widespread in Silicon Valley since the 1970s,[235] is virtually absent in Japan and South Korea. Not so in China. At both BYD and CATL, for mid- to high-level engineers and managers, stock-based compensation has become an important source of remuneration.[236] The systems that these companies have put in place seek to have the stock market pay the price of extra employee compensation, while permitting the companies to conserve their cash for reinvestment in innovation. However, stock-based compensation schemes can also result in stock market-driven variations in earnings among employees at a point in time and over time, which may undermine the equitable distribution of income that promotes organizational integration.[237] In some cases, as is happening with annual bonuses for AI engineers at SK Hynix and Samsung Electronics, the new found wealth may be sufficient to permit key employees to realize what in South Korea is called the "FIRE" fantasy–Financial Independence, Retire Early–with their departures disrupting the company's organizational-learning processes. In the case of China, the organizational challenge for companies like BYD and CATL is to manage the distribution of stock-based pay among employees, at a point in time and over time, rather than permit stock market volatility to determine the outcomes.

An innovative enterprise needs finance to sustain its organizational-learning processes until the sale of an innovative product results in financial returns. Government investment and subsidies often provide a foundation for financial commitment, but ultimately, a successful business enterprise must generate its own sources of sustained finance. For a startup that has yet to develop and sell its first products, critical sources of financial commitment may come from personal savings, credit, or "venture capital". When and if the innovative enterprise becomes a going concern, the critical source of financial commitment is retained earnings, leveraged, if need be, by debt or equity issues. In choosing to issue debt, the firm risks incurring high borrowing costs, restrictions on how it may use its funds, or a total loss of strategic control over restructuring or liquidation options in bankruptcy. In choosing to raise funds by issuing equity, the firm dilutes shareholding, which, depending on the relationship between shareholding and the distribution of voting power for a given firm, may pose a threat to the exercise of strategic control. Different modes of financial commitment have impacts on actual and potential strategic control.

Panasonic was already a massive company in the mid-1990s, with hundreds of thousands of employees and well-developed capabilities in batteries, when its top executives were investing in Li-ion rechargeables. With its battery division contained within its larger conglomerate structure, Panasonic's workforce was able to engage in collective and cumulative learning processes, until, in 1994, the company was ready to enter the Li-ion battery market pioneered by Sony. Panasonic drew upon its retained earnings to fund its expanding battery business but issued debt to acquire Sanyo's battery assets in 2009. Panasonic used corporate cash in the first phase of its investment in Gigafactory Nevada, but then used debt to finance the second phase, when Tesla ramped up production of the Model 3.[238] Panasonic pays regular dividends to its shareholders, distributing $16.8 billion in dividends (about 42 percent of net income) over the period 1988-2025.[239]

As Panasonic booked $68 billion in annual revenues in 1999, LG Chem was a comparatively "small" company, with just $3.8 billion in revenues. By 2023, however, with its EV battery business booming, LG Chem had grown to $42 billion in revenues, with $1.6 billion in net income. Organized under a chaebol structure, LG Chem, like Panasonic, has been able to divert retained earnings from profitable business divisions into uncertain ventures, creating a critical source of internal financial commitment to its innovation strategy of investing in Li-ion batteries. Shareholders were not left out as LG Chem built up its battery business. During 1999-2020 LG

Chem's board distributed $4.3 billion in dividends to shareholders, equal to 23 percent of its net income. LGES, which was spun off of LG Chem in 2020, did not distributions to shareholders from 2021 to 2025, retaining about $530 million, available for reinvestment in the company. The IPO of LGES on the Korea Exchange in 2022 was the biggest in Korean history, raising about $8.6 billion for LGES and $2.1 billion for LG Chem.[240]

For BYD and CATL, the initial sources of financial commitment included the willingness of family members or coworkers to pool their savings together, in some cases through investment vehicles set up for the purpose. BYD, as we have seen, secured venture funding from a State-owned enterprise, but within two years came up with funds to buy it out. ATL tapped "Western" funds, but in 2005 turned to Japan-based TDK to acquire the westerners' shares along with the founders' shares, thus completely taking over strategic control of ATL.

BYD staged its IPO on the Hong Kong Stock Exchange in 2002, choosing early in its history to issue H-shares to gain access to international finance. It did a second IPO on the Shenzhen Stock Exchange in 2011, issuing A-shares to tap into the savings of Chinese households. In between, as we have seen, in a private transaction in 2008, Warren Buffett purchased 10 percent of BYD's H-shares—with BYD gaining international recognition that added considerable value to the $232 million in cash that flowed from Berkshire Hathaway to BYD.

CATL did its Shenzhen IPO first, in 2018, which, along with a private placement in 2022 raised significant cash for battery R&D and for expansion of manufacturing capacity in China. Its Hong Kong IPO in 2025 brought in $4.6 billion from global financiers, which provided funds for a plant in Hungary, as CATL continued to expand its manufacturing footprint into foreign auto markets, a process that the company had begun in 2022.

For both Chinese companies, A shares (Shenzhen) and H shares (Hong Kong) have one vote each. Institutional shareholders dominate the *holding* of BYD and CATL H-shares, while speculative retail shareholders do most of the *trading* that provides liquidity to the A-shares. There are restrictions on foreigners' right to purchase A-shares. Each company can, therefore, reduce the influence that a large foreign shareholder (such as an American-style shareholder activist) might try to exert on the company by increasing the number of A-shares in the Hong Kong-Shenzhen mix.

BYD and CATL have chosen to share some of their profits with their shareholders. Between 2014 and 2025 (years for which it consistently paid a dividend), BYD paid $4 billion in dividends, equal to 19 percent of its net income. At CATL, dividend payments began as its profits grew well into the billions. Over the 2018-2022 period, CATL paid $441 million in dividends, equal to five percent of its net income. With its profits exploding between 2023 and 2025, CATL raised its dividend, allocating $10.3 billion, an annual average of 44 percent of its net income. Though, as of late, CATL has been more generous to its shareholders than any of the other Asian firms we have analyzed, its distributions still allow for ample reinvestment of its earnings into its growing battery business.

Thus far, the retention and reinvestment of profits into innovative products around related business lines have provided the managements of both BYD and CATL with strategic independence from outside shareholders who might have other ideas as to how Wang or Zeng should allocate BYD or CATL's corporate cash. While CATL increased its exposure to outsiders by raising substantial funds from the stock market in its 2025 Hong Kong IPO, BYD has accessed large sums of money by issuing "perpetual bonds", a financial instrument that looks like a loan but which, for purposes of accounting and control, is treated as equity, subordinate to shareholding.

A perpetual bond does not have a fixed maturity date, and interest payments can be deferred indefinitely. BYD has used perpetual bonds to raise the large amounts of money needed to fund its uncertain innovation strategies over two distinct phases of its growth without placing Wang and his insiders in jeopardy of losing strategic control. First, between 2015 and 2020, the company used $1.2 billion in perpetual-bond funds for investment in R&D, as it sought to build its EV market share. Then, in 2024 and 2025, as its EV sales skyrocketed, the company issued $6.5 billion in perpetual bonds to fund its strategy of vertical integration, from component supply all the way to building its own line of transport ships. In this second phase, the perpetual-bond issues have carried much lower interest rates than those issued during the first phase because BYD has demonstrated its capability (and credit worthiness) as a profitable innovative enterprise. By the end of 2025, BYD had already repaid $3.9 billion of the bonds issued in 2024 and 2025. Its internal cash flow from successful innovation has enabled BYD to use the perpetual bonds as a huge, low-cost line of credit—with no threat to Wang's strategic control.

In a forthcoming paper, we will undertake an in-depth analysis—just touched upon in this current paper—of the evolution of the social conditions of innovative enterprise of the leading Asian EV battery makers to explain their rise to dominance and provide a basis for monitoring their performance in real-time. In another forthcoming paper, we will present the results of our study of the evolution of the rechargeable battery industry in the United States. We will explain why, in the third decade of the 21st century, with the EV transition in full swing worldwide, the United States is not the home to any major EV battery makers. The reason, to put it succinctly, is corporate financialization—a business disease that since the 1980s has crippled the innovative capabilities of major U.S.-based companies in the automobile, chemical, and consumer electronics industries. As suppliers or buyers of rechargeable batteries, firms in those industries could have contributed to the innovative success of one or more U.S.-based EV battery makers capable of challenging the Asian leaders in global competition. The most direct manifestation of corporate financialization is the open market share repurchase—aka stock buyback—which, as we have shown elsewhere, is at the root of a diseased U.S. economy, characterized by unprecedented income inequality and a loss of global competitiveness in a range of critical technologies.[241]

Notes:

---

[1] Richard Stevenson, "G.M. Displays the Impact, An Advanced Electric Car," *New York Times*, January 4, 1990.
[2] Caltech Heritage Project, "Johnny Carson joking about the GM Impact EV," *YouTube*, March 15, 2022.
[3] Ann Notthoff, "California's Clean Car Program Under Attack," NRDC, February 13, 2003: Gustavo Oscar Collantes, "The California zero emission mandate: A study of the policy process, 1990-2004," PhD dissertation, University of California, Davis, 2006.
[4] Jim Mateja, "'Car man' Stempel named GM chief: Move may put product over profit," *Chicago Tribune*, April 4, 1990; United Auto Workers, "UAW's Yokich welcomes new GM Chairman Stempel," PR Newswire, August 1, 1990; Merrill Goozner, "General Motors on road to recovery: UAW contract a sign decline may be ending," *Chicago Tribune*, September 23, 1990; Michael Cimini, "Collective bargaining in 1990: Search for solutions continues," *Monthly Labor Review*, January 1991, pp. 20-21; Maureen Simari and Aimee Ergas, "Finding aid for 'UAW Vice-President's Office: Don Ephlin Records,'" Archives of Labor and Urban Affairs, Wayne State University, January 11, 2011.
[5] Saul Rubinstein and Thomas Kochan, *Learning from Saturn: A Look at the Boldest Experiment in Corporate Governance and Employee Relations,* Cornell University/ILR Press, 2001; Andrew C. Inkpen, "Learning Through Alliances: General Motors and NUMMI," *California Management Review*, 47, 4, 2005: 114-136.
[6] Alex Taylor III, "The road ahead at General Motors," *Fortune*, May 4, 1992; John Greenwald, "What went wrong? Everything at once," *Time*, November 9, 1992; Warren Brown and Frank Swoboda, "Managing the march of change; At GM, new team shakes up culture from top down," *Washington Post*, January 31, 1993.
[7] Michael Shnayerson, *The Car that Could: The Inside Story of GM's Revolutionary Electric Vehicle*, Random House, 1996.
[8] Shnayerson, *Car that Could*, p. 256.
[9] Chris Paine, *Who Killed the Electric Car?* Sony Pictures Classics, 2006.
[10] We tell this story in greater detail in our follow-up paper on the U.S. companies.
[11] Matt Hopkins and William Lazonick, "Tesla as a Global Competitor: Strategic Control in the EV Transition," *Institute for New Economic Thinking*, Working Paper No. 225, September 7, 2024.
[12] JDPower, "Which brand sold the most EVs in 2025?" *AutoVista24*, February 11, 2026.
[13] Lei Kang, "Global EV battery market share in 2025: Full rankings and key takeaways," *CN EVPost*, February 3, 2026.
[14] Charles Morris, "Forget about X, AI and robots—Tesla is quietly building a complete EV battery supply chain," *Charged*, March 6, 2026; Fred Lambert, "Tesla launches startup challenge to scale Giga Berlin battery cells," *Electrek*, July 7, 2026.
[15] Marie Carpenter and William Lazonick, "Losing Out in Critical Technologies: Cisco Systems and Financialization," *Institute for New Economic Thinking*, February 28, 2023.
[16] William Lazonick and Matt Hopkins, "How Intel Financialized and Lost Leadership in Semiconductor Fabrication," *Institute for New Economic Thinking*, July 7, 2021.
[17] William Lazonick and Mustafa Erdem Sakinç, "Make Passengers Safer? Boeing Just Made Shareholders Richer," *American Prospect*, May 31, 2019.
[18] Stephanie Brinley, "2025 automotive sales data highlights mixed global trends," *S&P Global*, January 8, 2026; "EV Sales Grew 20% Globally in 2025," *Institute for Energy Research*, January 20, 2026.
[19] The Nobel Prize, "They created a rechargeable world," *Nobel Prize Press Release*, October 9, 2019.
[20] Charles Murray, *Long Hard Road: The Lithium-Ion Battery and the Electric Car*, Purdue University Press, 2022, ch. 5.
[21] Sony, "Sony History: Chapter 13, 'Recognized as an International Standard'," *Sony*. Accessed via Wayback Machine, August 7, 2026.
[22] Prior to the corporate name change in 2008, Panasonic was Matsushita's best known brand name.
[23] In December 2020, LG Chem spun off its battery division as LG Energy Solution, a separate corporate entity, listed on the Korea Exchange. LG Chem owns about 80 percent of LG Energy Solution.
[24] In 2011, Contemporary Amperex Technology Co., Ltd. (CATL) took the EV battery business of Amperex Technology Limited (ATL) to become a distinct corporate entity.
[25] Shannon Brescher Shea, "Charging Up the Development of Lithium-Ion Batteries," Department of Energy: *Office of Science*, October 15, 2019.

[26] Kelly Gallagher and Laura Anadon, "Database on U.S. Department of Energy (DOE) budgets for Energy Research, Development, & Demonstration (1978-2025)," *University of Cambridge*, July 8, 2024. In deriving our total, we summed figures for "Transportation" and "Other ARRA deployment".
[27] National Research Council, *Effectiveness of the United States Advanced Battery Consortium as a Government-Industry Partnership*, National Academies of Sciences, Engineering, and Medicine, 1998, ch. 2.
[28] Sam Baldwin, Ellen Williams and Charles Russomanno, "Technology Transition Case Study: United States Advanced Battery Consortium," *Department of Energy*, September 18, 2015.
[29] Jay Turner, *The Big Green Machine*, Wellesley College, accessed April 24, 2026.
[30] Cox Automotive, "Electric vehicle sales report: Q4 2025," *Coxautoinc*, January 13, 2026; International Organization of Motor Vehicle Manufacturers (OICA), "*Sales Statistics*," OICA, accessed August 8, 2026; International Energy Agency, "Trends in electric cars," *IEA*, accessed August 12, 2026;
[31] Michael Wayland, "Ford to move forward with $3.5 billion EV battery plant with Chinese company," *CNBC*, February 13, 2023; Editorial Board, "US Gigafactories: Powering the Electric Vehicle Revolution," *EVBoosters*, September 5, 2023.
[32] Dan McCarthy, "Chart: Trump is killing the country's clean-energy manufacturing momentum," *Canary Media*, April 25, 2025.
[33] Patrick George, "A big, beautiful disaster for America," *InsideEVs*, July 4, 2025; Raghav Agnihotri et al., "One Big Beautiful Bill Act Cuts the Power: Phase-Outs, Foreign-Entity Restrictions, and Domestic Content in Clean-Energy Credits," *FBR Gibbons*, July 4, 2025.
[34] Keiji Nakamura, "Regarding the Acquisition of the Primary Battery Business from Murata Manufacturing Co., Ltd.," *Maxell*, June 16, 2025.
[35] Seth Fletcher, *Bottled Lightning: Superbatteries, Electric Cars, and the New Lithium Economy*, Hill and Wang, 2011, pp. 45-46.
[36] Thomas J. Lueck, "Union Carbide is target of takeover bid by GAF," *New York Times*, December 10, 1985.
[37] Fletcher, *Bottled Lightning*, p. 48.
[38] Murray, *Long Hard Road*, pp. 118, 122.
[39] Ibid.
[40] Sony, *1993 Annual Report*, p. 10.
[41] Nissan, "Nissan's Pursuit for Zero Emission Mobility: The Unplugged Story," *Nissan Press Release*, August 1, 2009.
[42] Sony, *1995 Annual Report*, p. 21.
[43] The "others" segment included semiconductors, electronic components, CRTs, batteries, telephone and telecommunications equipment, computers, computer peripherals, its new "Playstation" video game system, batteries, and FA systems.
[44] Sony, "China's first plant manufacturing Lithium-ion Polymer Rechargeable Batteries," *Sony Press Release*, September 7, 2000.
[45] Sony, "Sony to make lithium battery packs in Mexico," *Dow Jones*, December 4, 1998; Sony, "Sony to double lithium battery production," *JiJi Press*, June 8, 2000.
[46] Tarmo Virki, "Sony buys Ericsson out of mobile phone venture," *Reuters*, October 27, 2011.
[47] Sony, *2004 Annual Report*, p. 44.
[48] Sony, *2006 Annual Report*, p. 54; Sony, *2008 Annual Report*, p. 2.
[49] Sony, "Sony announces lithium ion polymer battery production in Singapore," *Sony Press Release*, August 14, 2007.
[50] Sony, "Sony launches high-power, long-life lithium ion secondary battery using olivine-type lithium iron phosphate as the cathode material," *Sony Press Release*, August 11, 2009.
[51] Sony, *2011 Annual Report*, p. 14.
[52] Hiroko Tabuchi, "Sony rejects call to divide its businesses," *New York Times*, June 20, 2013.
[53] Wakabayash Daisuke and Ben Fritz, "Sony CEO Hirai rejects Loeb's spinoff plan," *Wall Street Journal*, August 6, 2013.
[54] Nissan, "Nissan and NEC joint venture – AESC – starts operations," *Nissan Press Release*, May 19, 2008.
[55] Panasonic, *2001 Annual Report*, p. 22.
[56] Toyota, "Worldwide Prius Sales Top 3-Million Mark," *Toyota Press Release*, July 3, 2013.
[57] Staff reporter, "Earthquake damage lands Sanyo in the red," *EETimes*, December 21, 2004.
[58] Goldman Sachs, "Goldman Sachs Takes an Equity Stake in Sanyo Electric and Sanyo Electric Credit," *Goldman Sachs*, accessed July 15, 2026.

[59] Yukari Iwatani Kane, "Sanyo ends era of family rule; President steps down as owners push to shed weak businesses faster," *Wall Street Journal*, March 28, 2007.
[60] Daisuke Wakabayashi and Juro Osawa, "Panasonic to buy up two units," *Wall Street Journal*, July 29, 2010; Dealbook, "Panasonic to spend $9.4 billion in 2 deals," *New York Times*, July 29, 2010.
[61] By 2011, previously dominant Japanese battery producers were losing market share to South Korean producers. Sanyo and Panasonic stood at about 23% market share, versus Samsung's 25.3% and LG Chem's 17.3%. See Jae-man Koh and Su-hyun Song, "S. Korea Tops Global Lithium-Ion Battery Market," *Pulse*, September 2, 2011.
[62] Panasonic, *2011 Annual Report*, p. 1.
[63] Tesla, "Panasonic Invests $30 Million in Tesla: Companies Strengthen Collaborative Relationship," *Tesla Press Release*, November 3, 2010. Toyota also invested $50 million in a private placement, concurrent with the IPO.
[64] Jeff Shepard, "Tesla and Panasonic collaborate to develop next-generation battery cell technology," *EE Power*, January 6, 2010; Panasonic, *2010 Annual Report*, p. 30.
[65] John Voelcker, "Tesla's lithium-ion battery gigafactory: What you need to know," *Green Car Report*, February 26, 2014.
[66] Panasonic, "Panasonic and Tesla Reach Agreement to Expand Supply of Automotive-grade Battery Cells," *Panasonic Press Release*, October 30, 2013; Panasonic, *2014 Annual Report*, p. 16.
[67] Panasonic, "Panasonic and Tesla Sign Agreement for the Gigafactory," *Panasonic Press Release*, July 31, 2014.
[68] Dave Smith, "How Elon Musk cleverly manipulated 7 states to compete for Tesla's huge factory," *Business Insider*, November 14, 2013.
[69] Fred Lampert, "Tesla and Panasonic are making money at Gigafactory 1, in talks to expand battery production," *Eletrek*, May 18, 2020; Panasonic, *2015 Annual Report*, p. 31. 1 Japanese yen = $0.008 USD. Around that time, Musk indicated he expected Panasonic to absorb about "30-40%" of the cost of the plant. See also Takashi Mochizuki, "Panasonic plans big investment in Tesla battery plant," *Wall Street Journal*, October 7, 2014.
[70] Tim Lenard, "At Gigafactory, Workers From Japan Teach Americans To Make Batteries," *KUNR*, August 21, 2018; Stephen Edelstein, "Tesla Gigafactory to host 'hundreds' of Panasonic workers starting this fall," *Green Car Reports*, June 9, 2015.
[71] "Our story," *Panasonic Energy*, accessed July 30, 2026.
[72] Hopkins and Lazonick, "Tesla as a Global Competitor."
[73] 2170 meaning 21mm in diameter, 70mm in length.
[74] Andrew Krok, "Tesla Gigafactory expansion reportedly on hold as Panasonic ponders the future," *CNET*, April 11, 2019.
[75] Tim Higgins and Takashi Mochizuki, "Tesla rattles its battery maker --- Musk's conduct makes some at Panasonic question alliance; both sides point fingers," *Wall Street Journal*, October 9, 2019.
[76] Ibid.
[77] Fred Lampert, "Tesla starts mass production of new '2170' battery cell at the Gigafactory, will be used in Model 3 in Q2 ," *Elektrek*, January 4, 2017.
[78] Mark Kane, "Panasonic announces 4680 battery cell production in Japan," *Inside EVs*, February 28, 2022.
[79] Panasonic, "Panasonic Energy Ready to Commence Mass Production of 4680 Automotive Lithium-ion Batteries," *Panasonic Press Release*, September 9, 2024.
[80] Ibid.
[81] Anon., "Kansas Lands $4B, 4,000-Job Panasonic Energy Electric Vehicle Battery Plant," *Kansas Department of Commerce*, July 13, 2022; Panasonic Energy, "Powering Progress: Panasonic's New EV Battery Facility in De Soto, Kansas," *Panasonic Energy Press Release*, July 14, 2025.
[82] Kevin Hardy and Katie Bernard, "Here's how much Kansas offered Panasonic to bring massive battery plant to De Soto," *Kansas City Star*, January 4, 2023.
[83] Panasonic, *2024 Annual Report*, p. 10.
[84] Panasonic, *2023 Annual Report*, p. 8.
[85] Kavitha Cardoza, "Colleges partnered with an EV battery factory to train students and ignite the economy. Trump's clean energy war complicates their plans," *Hechinger Report*, April 28, 2025.
[86] Ibid, p. 1
[87] Panasonic, "Subaru and Panasonic Energy to Begin Preparation for Supply of Automotive Lithium-ion Batteries and Joint Establishment of New Battery Factory in Japan," *Panasonic Press Release*, September 6, 2024.
[88] Staff reporter, "Japan increases support for domestic EV battery output," *Reuters*, June 16, 2023; Panasonic, "Panasonic Energy and Mazda to Begin Preparation for Supply of Automotive Lithium-ion Batteries," *Panasonic Press Release*, September 6, 2024; Staff reporter, "Japan to give up to $2.4 bln in new support for domestic EV battery production," *Reuters*, September 6, 2024.

[89] Panasonic, "Panasonic Factory in Dalian, China Begins Mass Production and Shipments of Automotive Lithium-ion Batteries," *Panasonic Press Release*, March 13, 2018.
[90] Toyota, "Toyota and Panasonic Decide to Establish Joint Venture Specializing in Automotive Prismatic Batteries," *Toyota Press Release*, February 3, 2020.
[91] Michael Brady, "Toyota to buy EV battery company, ending venture with Panasonic," *Automotive Dive*, March 6, 2024; Prime Planet Energy & Solutions, "Prime Planet Energy & Solutions to Produce Next-Generation Performance Batteries at Himeji Facility," *Prime Planet Energy & Solutions Press Release*, September 6, 2024.
[92] Toyota, "PEVE to Change Name to Toyota Battery Co., Ltd. and Produce Batteries for a Wide Range of Electric Vehicles," *Toyota Press Release*, March 27, 2024
[93] Toyota, "Toyota Battery Manufacturing North Carolina," *Toyota Press Release*, May 2026.
[94] Toyota, "Toyota powers on new North Carolina automotive battery plant," *Toyota Press Release*, February 5, 2025; Michael Wayland, "Toyota opens new U.S. battery plant, confirms $10 billion in new investments," *CNBC*, November 12, 2025;
[95] Toyota, "Sales, Production, and Export Results for 2025 (January-December)," *Toyota Press Release*, January 29, 2026.
[96] Toyota, "Toyota Motor North America Reports 2025 U.S. Sales Results" *Toyota Press Release*, January 5, 2026.
[97] C. da Costs, "Tesla's Cybertruck sales are in freefall—so bad it invites Ford Edsel comparisons," *Yahoo!Autos*, July 22, 2026.
[98] Fred Lampert, "Tesla's 4680 battery cells are underperforming and frustrating buyers," *Electrek*, May 7, 2026.
[99] Stewart Burnett, "Panasonic's 4680 mass production pushed back yet again," *Automotive World*, May 12, 2026.
[100] Colleen Cabili, "Panasonic is converting its Kansas EV battery plant to make AI data center batteries," *QZ*, June 8, 2026; April Bonner, "Panasonic to convert Kansas EV battery factory for data centre applications," *Energy Storage News*, June 12, 2026.
[101] LG Chem, "History of LG Chem," *LG Chem*.
[102] LG Energy Solution, "Company Introduction," *LG Energy Solution*; Ahn Sung-mi, "Koo Kwang-mo highlights LG's commitment to AI, biotech, cleantech for sustainable future," *Korea Herald*, December 19, 2024.
[103] Ibid.
[104] LG Energy Solution, "The Start of Korea's Battery History," *LG Energy Solution*.
[105] LG Chem, *2001 Annual Report*, p. 10.
[106] Anon., "Ex-GM EV1 pioneers(x2) fully committed to development of ultra long-range battery EV's," *EV UK*, March 2003; Jeff Shepard, "Compact Power's ER2 breaks Pikes Peak EV record," *EE Power*, July 8, 2002.
[107] LG Chem, *2001 Annual Report*, p. 44.
[108] Ibid, p. 6
[109] Jung Seung-hyun, "Electric vehicle batteries power Korea ahead," *Korea JoonAng Daily*, April 18, 2011; LG Chem, "Challenge and Innovation: Advancing into further future with secondary battery," *LG Chem*, accessed August 2, 2026.
[110] Ibid.
[111] Staff reporter, "Apple Computer inc.: Computer maker will recall 128,000 LG Chem batteries," *Wall Street Journal*, May 23, 2005.
[112] LG Chem, *2005 Annual Report*, p. 44.
[113] LG Chem, *2004 Annual Report*, p. 13.
[114] China was at that time already 29% of world demand, and LG Chem intended China to become a "second home market". See LG Chem, *2003 Annual Report*, pp. 39-45.
[115] Alejandro Bodipo-Memba, "Alternative energy firms join Nextenergy project: two plan to build in Oakland county," *Detroit Free Press*, May 18, 2005; Katherine Yung, "Hotbeds for auto research growing: U.S., import firms expand labs," *McClatchy-Tribune Business News*, December 9, 2007. At the time, Compact Power had just 40 employees, and LG Chem held 61% of Compact Power's shares. See LG Chem, *2004 Annual Report*.
[116] Compact Power, "Compact Power, Inc. Appoints Dr. Prabhakar Patil as Chief Executive Officer," *Business Wire*, November 18, 2005.
[117] Jewel Gopwani, "GM's battery suppliers face tall order with Volt," *Detroit Free Press*, June 6, 2007.
[118] Staff reporter, "US automakers roll out hybrid plans GM will open battery factory," *Boston Globe*, January 13, 2009.
[119] Tom Krisher, "GM picks S. Korea's LG Chem to make Volt batteries," *Associated Press*, January 12, 2009.
[120] LG Chem, *2011 Annual Report*, p. 9. The list includes GM, Renault, Hyundai/Kia, Ford and Volvo, and in 2009 the company was also supplying in China to Chang'an Motors, the third largest automaker at the time.

[121] John Voelcker, "2017 Chevy Bolt EV Development: GM, LG Chem reveal deep relationship," *Green Car Reports*, October 21, 2015.

[122] Melissa Burden, "GM partners with LG companies to develop Chevy Bolt EV," *Detroit News*, October 20, 2015.

[123] Angela Hardin, "Argonne strikes licensing deals with LG Chem, GM for advanced battery technology," *Argonne National Laboratory*, January 10, 2010; Charles Morris, "3M licenses NMC patents to LG Chem," *Charged*, August 13, 2015.

[124] Staff reporter, "LG Energy Solution debuts after $13 trillion frenzy in Korea's biggest IPO," *Korea Times*, January 27, 2022; Scott Murdoch and Heekyong Yang, "LG Energy Solution raises $10.8 bln in S.Korea's biggest IPO," *Reuters*, January 14, 2022.

[125] John Voelcker, "Chevy Bolt battery recall: How could this have happened?" *Car and Driver*, September 13, 2021.

[126] LG Energy Solution, "LG Energy Solution and GM to jointly develop prismatic battery cell technology," *LG Energy Solution Press Release*, December 4, 2024.

[127] LG Corp, "LG Chem Establishes EV Joint Venture with General Motors of USA," LG Corp Press Release, December 6, 2019; David Shepardson, "GM, LG Energy joint venture Ohio battery plant begins production," *Reuters*, August 31, 2022.

[128] LG Energy, "LG Energy Solution Expands Holland Manufacturing Plant with $1.7 Billion Investment," *LG Energy Press Release*, March 22, 2022.

[129] Michael Wayland, "General Motors plans to exclusively offer electric vehicles by 2035," *CNBC*, January 28, 2021.

[130] Jameson Dow, "China plans 2035 gas car ban that doesn't actually ban gas cars," *Electrek*, October 27, 2020.

[131] William Lazonick and Matt Hopkins, "GM's Stock Buyback is Bad for America and the Company," *Harvard Business Review*, March 11, 2015; Matt Hopkins and William Lazonick, "What the UAW and Everyone Else Need to Know About CEO Pay," *Institute for New Economic Thinking* October 2, 2023; Matt Hopkins and William Lazonick, "How GM's $10-Billion Buyback May Ice its EV Transition," *Institute for New Economic Thinking*, December 18, 2023.

[132] Keith Bradsher, "G.M. led in China for years. Here's how it ended up 16th in sales," *New York Times*, December 19, 2024.

[133] Haley Cawthon, "GM CEO Mary Barra: China market is a 'race to the bottom'," *Wards Auto*, August 14, 2024.

[134] Jaelyn Cambell, "LG Energy Solution acquires Michigan EV battery venture from GM for up to $2B," *CBT News*, April 1, 2025.

[135] Matt Hopkins and William Lazonick, "The U.S. Battery Maker That Could, and the U.S. Auto Company That Wouldn't," Institute for New Economic Thinking, August 26.

[136] Kalena Thomhave, "LG Energy Solution picks up Michigan's subsidies for Ultium plant," *Automotive Dive*, April 14, 2024; Stephen Edelstein, "Toyota steps in, spends $1.5 billion for Michigan battery factory with LG," *Green Car Reports*, February 19, 2025.

[137] Fred Lampert, "US confirms Tesla (TSLA) is buyer in LG's $4.3B LFP battery deal for Megapack 3," *Electrek*, March 17, 2026.

[138] LG Energy Solution, "(Infographics #2) 2025 Global Production Target of LG Energy Solution," *LG Energy Solution*, May 19, 2023.

[139] Julian Spector, "LG opens massive Michigan factory to make LFP batteries for the grid," *Canary Media*, June 25, 2025.

[140] Toyota, "LG Energy Solution and Toyota Sign Long-term Battery Supply Agreement to Power Electric Vehicles in the U.S.," *Toyota Press Release*, October 4, 2023.

[141] LG Energy Solution, "Company overview: Fast facts," *LG Energy Solutions*.

[142] Michael Baumann, "Ungebremster Autoboom im Reich der Mitte; VW entwirft einen Personenwagen nur für den chinesischen Markt," *Neue Zürcher Zeitung*. November 27, 2006.

[143] Russell Flannery, "China's Richest 2017: Wang Chuanfu steers EV leader BYD deeper into new markets," *Forbes*, November 15, 2017.

[144] BYD, *2006 Annual Report*, p.14.

[145] BYD Company Ltd., Prospectus for Listing on the Hong Kong Stock Exchange, 2002, accessed August 14, 2026; Flannery, "China's Richest 2017"; Laurie Burkitt, "The World's Largest Electric Vehicle Maker Hits a Speed Bump," *MIT Technology Review*, May 8, 2018.

[146] BYD, Prospectus, p. 74.

[147] BYD, *2025 Annual Report*, p. 120.

[148] Leo Breevort, "The big read: History of BYD," *Car News China*, August 1, 2021. In its early years, BYD sold nickel cadmium and NiMH batteries. See BYD, *2002 Annual Report*, p. 6.
[149] Energy Conversion Devices, "ECD Grants Patent License to Chinese Company," *PR Newswire*, July 11, 2000:1.
[150] Xue Yujie, Daniel Ren and Pearl Liu, "Risky road to success," *South China Morning Post*, April 15, 2023.
[151] Laurie Burkitt, "The World's Largest Electric Vehicle Maker"; Arun Kharpal and Evelyn Cheng, "Musk once laughed off BYD as a threat. Now the Chinese giant has taken Tesla's EV crown—here's how," *CNBC*, January 4, 2024;
[152] Staff reporter, "BYD's mainland China IPO approved by stock regulator," *Automotive News*, May 9, 2011.
[153] Staff reporter, "HK hot stocks: QPL jumps on tech recovery hopes," *Reuters*, November 5, 2003.
[154] William Wiggenhorn, "Motorola U: When Training Becomes an Education," *Harvard Business Review*, July/August 1990; Ted Fishman, "The Chinese century," *New York Times*, July 4, 2004; Anon., "History of Six Sigma: Exploring the Roots," *Six Sigma Online*, accessed May 8, 2026.
[155] Anthony Tran, "BYD pays price for Sanyo lawsuit," *The Standard*, September 26, 2002.
[156] Staff reporter, "Sony files lawsuit against BYD for patent infringement," *SinoCast China Business Daily News*, July 11, 2003.
[157] Yahong Li, Jiangyong Lu, Zhigang Tao and Shang-Jin Wei, "Foxconn v BYD (A): Commercial espionage or learning by hiring?" *Asia Case Research Centre*, Columbia Business School, 2009 Yahong Li, Jiangyong Lu, Zhigang Tao and Shang-Jin Wei, "Foxconn versus BYD (B): Strategic Approach to Intellectual Property Management in Emerging Markets" *Asia Case Research Centre*, Columbia Business School, 2014.
[158] BYD, *Annual Reports*, various years.
[159] Wang also had his company engineers tear down his personal Mercedes S-Class. Breevort, "The big read: History of BYD".
[160] Staff reporter, "Fully charged, raring to go," *Week in China*, July 24, 2009.
[161] Burkitt, "The World's Largest Electric Vehicle M," *MIT Technology Review*, May 8, 2018.
[162] Avril Yu, "The electric vehicle industry: a background of BYD, China's #1 automaker," *Michigan Journal of Economics*, December 11, 2023.
[163] Bill Freehling, "Keep an eye on Lu, who may help fill Buffett's post one day," *Free Lance-Star*, July 4, 2010; Eleanor Oloctt, "No other investor has a life story quite as unbelievable as Li Lu," *Financial Times*, September 7, 2023.
[164] Staff reporter, "Fully Charged."
[165] Chang-Ran Kim and Kevin Krolicki, "BYD car business secondary to battery tech: investor," *Reuters*, January 12, 2009.
[166] Marc Gunther, "Buffett takes charge," *Fortune*, April 27, 2009; Theron Mohamed, "Warren Buffett's Berkshire Hathaway has scored a 3,000% gain on its BYD investment. Here's the story of its bet on the Chinese electric-vehicle company," *Business Insider*, January 23, 2021.
[167] Gunther, "Buffett takes charge".
[168] BYD, *2009 Annual Report*, p. 12; Nina Pablo, "Warren Buffet-backed BYD reduces IPO price due to market volatility," *The Asset*, June 22, 2011.
[169] "Volkswagen, "Volkswagen Group deliveries," Volkswagen, *2024 Annual Report*.
[170] BYD sold 1,764,992 million BEVs in 2024, Tesla sold 1,789,226.
[171] Liu Miao "BYD surpasses Tesla in global pure-electric vehicle sales with already nearly 400,000 unit lead in 2025," *Car News China*, October 3, 2025; Tesla and BYD, *Annual Reports*, various years.
[172] Milos Komnenovic, "Why BYD passing Ford is a bigger deal than it looks," *Yahoo! Finance*, April 10, 2026.
[173] Inc., "The nail test: Why this $54 billon innovation is terrifying Western auto executives," *Fast Company*, April 4, 2026; IEST, "BYD Blade 2.0: The battery changing the EV landscape in 2026," *IEST Industry News*, July 31, 2026.
[174] BYD, "BYD Unveils 2nd Generation Blade Battery and FLASH Charging Technology," *BYD Press Release*, March 6, 2026.
[175] BYD, "BYD Becomes World's First Automaker to Pledge Full Damage Coverage for Both Intelligent Parking and Urban NOA," *BYD Press Release*, May 28, 2026. Tesla, in contrast, charged about $10,000 for access to its "full self driving" technology, which it recently revised to a $99/month subscription.
[176] Bimal Khatiwada, "BYD's robot-run factory in China builds an EV in under a minute," *Kathmandu Post*, May 17, 2026.
[177] BYD, *2025 Annual Report*, p.8; BYD, "Voluntary announcement: Production and sales volume," various months, *Hong Kong Stock Exchange*.
[178] Jesus Diaz, "What BYD's massive new shop reveals about its business," *Fast Company*, April 28, 2025.

[179] BYD, *2024 Annual Report*, p.16, p.37; Zetta Hannany and Dhika Priambodo, "BYD builds 7 large ships to deliver its own cars worldwide," *IDN Financials*, August 18, 2025.

[180] Peter Johsnn, "BYD just launched the world's largest car carrier to charge up its global EV ambitions," *Electrek*, January 17, 2025.

[181] BYD, *2024 Annual Report*, pp. 49, 130. BYD remains active in consumer electrics, supplying batteries and performing assembly services that represent about 21% of revenues.

[182] Arjun Kharpal, "Elon Musk says Chinese EV makers will 'pretty much demolish' most competitors without trade barriers," *CNBC*, January 25, 2024.

[183] Betty Liu, "Back in 2011 Tesla CEO Musk mocked Chinese competitor BYD," *Bloomberg Business*, December 27, 2023.

[184] Henry Sanderson, "China's electric vehicle battery king," *Time*, September 29, 2022.

[185] Ibid; Henry Sanderson, *Volt Rush: The Winners and Losers in the Race to Go Green*, OneWorld, 2022, ch. 4.

[186] Sanderson, *Volt Rush*, ch. 4.

[187] Ashok Bindra and Yoshiko Hara, "Bellcore to demo lithium-ion rechargeable; Matsushita ready to enter," *Electronic Engineering Times*, March 14, 1994; Valence Technology, "Valence Technology Enters into Agreement to Acquire All Bellcore Lithium-ion Polymer Battery Intellectual Property Rights from Telcordia for Three Million Shares," *PR Newswire*, November 9, 2000; (Chinese articles translated by Google's Chrome browser): Staff reporter, "The Chinese man behind Elon Musk: He made his fortune through gambling and became Fujian's new richest man by spending 1 million yuan on scrap metal," *Sina Finance*, December 29, 2020; Staff reporter, "CATL honorary chairman passes away: Strong gambling rendency, he mentored Zeng Yuqun, and claimed to be both lazy and desired to win," *Sina Finance*, February 15, 2022; (in English): Staff reporter, "Intellectual property protections foster innovation, healthy global competition: CATL chairman," *Bastille Post Global*, December 3, 2025,, We note that there appears to be confusion as to whether ATL licensed its key Li-poly patents from Bell Labs or Bellcore. From our research, the answer is that the key patents were sourced from Bellcore, which at that time had been re-named Telcordia. In 2000, Telcordia's IP, trademarks, and existing licensees were acquired by U.S.-based Valence, itself a former Bellcore licensee.

[188] Choe Seung-chul, "World's first lithium-polymer battery production system developed by Finecell," *Korea Herald*, December 2, 1999; Chen Jin, "Growth and Competitiveness of Chinese Electric Vehicle and Electric Vehicle Battery Companies: Observation and Analysis from an Ecosystem Perspective," *International Relations and Diplomacy*, 13, 3, 2025, p. 125.

[189] Sanderson, *Volt Rush*, ch. 4.

[190] Tom Holland, "Private equity party nears an end as gatecrashers arrive," *South China Morning Post*, June 16, 2005. We believe that the Post, in this case, erred in claiming that H&Q's 1999 investment was for $12 million - it is clear that H&Q was referring to their investment in Hong Kong dollars, which works out to about $1.6 million.

[191] Staff reporter, "Faith of steel," *Asia Private Equity* Review, July 1, 2003.

[192] Carlyle Group, "Carlyle Issues Summary of 2003 Investment Activity; $2.5 Billion Invested; $2.1 Billion Returned to Investors; $2 Billion Raised," *Carlyle Group Press Release*, February 4, 2004; Staff reporter, "Faith of steel". It is likely that ATL's success during its series b funding round was a result of their having signed an agreement to supply batteries to Apple, however, we could not identify a definitive source.

[193] Staff reporter, "Faith of steel".

[194] (Chinese translated by Google Chrome web browser): Li Shuguang, "CATL cannot forever make choices," *Xinhua News Agency*, March 2, 2020.

[195] Apple, *10-K Annual Reports*, various years.

[196] Holland, "Private equity party"; Tom Holland, "Asian character becomes a capital advantage—H&Q changes image of private equity funds by giving regional look to US-style venture capitalism," *South China Morning Post*, August 8, 2005; Keith Bradsher and Michael Forsythe, "Why a Chinese company dominates electric car batteries: Race to the future," *New York Times*, December 22, 2021; TDK, *2005 Annual Report*, p. 74.

[197] TDK, *2015 Annual Report*, p. 61. Zeng appears as a vice president up until 2015. In the *2012 Annual Report*, he appears as the general manager of the energy devices business group.

[198] Jeff Shepard, "TDK announces acquisition of Amperex Technology," *EE Power*, June 1, 2005; Kanis Leung, "Shares in China's CATL, world's biggest EV battery maker, surge in Hong Kong after $4.6 billion IPO," *Associated Press*, May 20, 2025.

[199] TDK, *2005 Annual Report*, p. 74.

[200] TDK, *Annual Reports*, various years.

[201] TDK, *2022 Annual Report*, p. 5.

[202] Sanderson, "China's electric vehicle king"; Patrick Mannion, "Software at heart of iPhone's simplicity," *Information Week*, July 2, 2007.

[203] Anon., "China firms benefit from Apple, Samsung competition," *SinoCast Computers & Electronics Beat*, November 27, 2012; Kim Young-gyo, "Apple turns to Chinese makers for its battery supply," *Yonhap English News*, November 29, 2012; Gina Roos, "Samsung's other battery supply chain problem," *EE Times*, September 23, 2016.

[204] ATL was not Apple's sole supplier, which was limited to about 40 percent of Apple's total battery purchases. See Roos, "Samsung's other battery problem".

[205] Tim Hardwick, "Apple overtakes Samsung as world's top smartphone vendor in Q4 2016," *Macrumors*, Feb 1, 2017. Problems with the design of the Samsung Note 7 smartphone led to battery fires, whether the batteries were made by Samsung or ATL: Timothy Martin and John McKinnon, "Samsung traces battery problem," *Wall Street Journal*, January 21, 2017.

[206] Akshat Rathi, "The inside story of how CATL became the world's largest electric-vehicle battery company," *Quartz*, July 20, 2022; Matt Blois, "Lithium iron phosphate comes to America," *Chemical & Engineering News*, January 29, 2023.

[207] Anon., "Life after death series #3," *Memorial to Tang-Hua (TH) Chen, Ph. D*, December 15, 2022.

[208] Biographical sketch, "Bob Gaylen," *NAAT BATT 2025*, accessed August 7, 2026.

[209] Steve LeVine, "Two industrial titans are duking it out over a technology that could make electric cars mainstream," *Quartz*, July 20, 2022; Umicore, "Umicore Acquires NMC Battery Material Patents from 3M," *Umicore Press Release*, January 10, 2017.

[210] International Energy Agency, "Global Supply Chains of EV Batteries," *International Energy Agency*, July 2022, p. 13; Matt Blois, "Lithium iron phosphate comes to America," *Chemical & Engineering News*, January 29, 2023; Kang Heejong, "Patent seal lifted on LFP, can Korea catch up with China?" *Asia Business Daily*, December 2, 2023.

[211] Akshat Rahti, "The inside story of how CATL became the world's largest electric-vehicle battery company," *Quartz*, July 20, 2022.

[212] Echo Huang, "China's breaking up the EV battery monopoly it carefully created," *Quartz*, July 20, 2022; Xiaoying You, "'They're just so much further ahead': How China won the world's EV battery race," *BBC*, November 13, 2025.

[213] We could find no record of TDK's stock sale in TDK or CATL filings. However, the stake would have been worth about $1.84 billion had TDK been able to retain it until CATL's IPO, and many multiples of that if it held the shares to the present.

[214] Russell Flannery, "Big CATL debut lifts fortunes of China battery billionaires," *Forbes*, June 11, 2018; Russell Flannery, "CATL went public on Shenzhen stock exchange," *Chinabuses*, June 13, 2018.

[215] Kanis Leung, "Shares in China's CATL, world's biggest EV battery maker, surge in Hong Kong after $4.6 billion IPO," *Associated Press*, May 20, 2025.

[216] TDK, "Announcement on Business Alliance and Establishment of Joint Venture with Contemporary Amperex Technology Co., Limited," *TDK Press Release*, April 28, 2021.

[217] CATL, *2024 Annual Report*, p. 57; CATL, *2025 Annual Report*, pp. 124-128.

[218] CATL, "CATL Named Among Clarivate's Top 100 Global Innovators," *CATL Press Release*, March 13, 2025.

[219] CATL, "CATL Unveils Six Major Innovations: Multi-Chemistry Systems to Redefine New Energy Mobility Experience," *CATL Press Release*, April 21, 2026; Suvrat Kothari, "CATL's new LFP battery beats BYD's 5-minute EV charging speeds," *Inside EVs*, April 21, 2025.

[220] CATL, "Naxtra Battery Breakthrough & Dual-Power Architecture: CATL Pioneers the Multi-Power Era ," *CATL Press Release*, April 21, 2025; Alex Scott, "Sodium-ion batteries: Should we believe the hype?" *Chemical & Engineering News*, November 17, 2025.

[221] Staff reporter, "Inside China's dark factories: Where robots produce 'one smartphone per second'" *Open Bureau & Agencies*, April 8, 2026.

[222] CATL, "CATL and Ford Announce Global Strategic Cooperation to Promote EVs Worldwide," *CATL Press Release*, July 21, 2022.

[223] David Shepardson, "US lawmaker scrutinizes Ford battery partnership with Chinese company CATL," *Reuters*, January 28, 2026.

[224] CATL, "CATL, Stellantis Break Ground on Battery Plant in Spain," *CATL Press Release*, November 26, 2025.

225 Fletcher, *Bottled Lighting*; Steve Levine, *Powerhouse: America, China, and the Great Battery War*, Penguin Books, 2015; Murray, *Long Hard Road*.

[226] See William Lazonick, "The Theory of Innovative Enterprise: Foundations of Economic Analysis," in Thomas Clarke, Justin O'Brien, and Charles R. T. O'Kelley, eds., *The Oxford Handbook of the Corporation*, Oxford University Press, 2019: 490-514; William Lazonick, "Is the Most Unproductive Firm the Foundation of the Most Efficient Economy? Penrosian Learning and the Neoclassical Fallacy," *International Review of Applied Economics*, 38, 1-2, 2024: 58-89; William Lazonick, "Schumpeterian Influences on the Theory of Innovative Enterprise," in Uwe Cantner, Bernd Ebersberger, and Patrick Llerena, eds., *Schumpeterian Legacy in Modern Times: The Contribution of the International J. A. Schumpeter Society and Its Members,* Springer International, 2026: 157-189; William Lazonick, **"**Productivity and the Theory of the Firm," in Roy Green and Phillip Toner, eds., *Understanding Productivity*, Routledge, forthcoming 2027: 141-156.

[227] Ryo Kambayashi and Takeo Kato, "Long-term Employment in Japan: Past and Present," *Japanese Economic Review*, 77, 2026: 559-575.

[228] Ulrike Schaede, *Choose and Focus: Japanese Business Strategies for the 21st Century,* Cornell University Press, 2011.

[229] Christina L. Ahmadjian and Patricia Robinson, "Safety in Numbers: Downsizing and the Deinstitutionalization of Permanent Employment in Japan," *Administrative Science Quarterly*, 46, 4, 2001: 622-654; Marcus Rebick, *The Japanese Employment System: Adapting to a New Economic Environment,* Oxford University Press, 2005, ch. 4; *Sanford Jacoby, The Embedded Corporation: Corporate Governance and Employment Relations in Japan and the United States,* Princeton University Press, 2005: chs. 2-3.

[230] Michael Yoshino and Yukihiko Endo, "Transformation of Matsushita Electric Industrial Co. Ltd. (A, B, & C), Harvard Business School Cases 9-905-412, 9-905-413, 9-905-414, June 13, 2005.

[231] Ulrike Schaede, *The Business Reinvention of Japan: How to Make Sense of the New Japan and Why It Matters*, Stanford Business Books, 2020, chs. 3, 8-9; Tatsuo Kinoshita, "Turning Human Potential into Business Strength" Panasonic Group, July 17, 2026; Miyo Tanaka, "Japan's half-cancelled employment bargain, *East Asia Forum,* July 23, 2026.

[232] Soo Kyeong Hwang, "Wage Structure and Skill Development in Korea and Japan," Korea Labor Institute. May 28, 2006; Sea-Jin Chang, *Sony vs Samsung: The Inside Story of the Electronics Giants' Battle for Global Supremacy*, Wiley. 2008; Jiyeoun Song*, Inequality in the Workplace: Labor Market Reform in Japan and Korea*, Cornelll University Press, 2014; Sophia Seung-yoon Lee and Jaewook Nahm, "From Segmentalist to Liberal Skill Formation System: A Comparative Analysis of Labour Market Activation Policies in Japan and South Korea," *Journal of International and Comparative Social Policy*, 40, 1, 2024: 42-56.

[233] Sarah Chea, "'Reflect our blood and sweat': LG Energy Solution employees stage angry protest," *Korea JoongAng Daily*, February 5, 2024; Kim Hyun-ho and Cha Jae-seo," LG Ensol performance bonus conflict spreads...Union holds 'Truck Protest' from Yeouido to Gangnam," *Newsway*, March 6,2024.

[234] Luke James, "Every SK Hynix employee could receive $477,000 bonuses this year, almost $900,000 next year — 35,000 workers reportedly set to benefit from share of $169 billion projected operating profit," *Tom's Hardware,* April 20, 2026; Jae-Lim Lee, "Samsung's $20 billion bonus deal fuels wage demand beyond AI sector," *Korea JoongAng Daily*, May 21, 2026; Matthew Broersma, "Samsung reaches last-minute deal to avert strike," *silicon.co.uk.,* May 21, 2006; Staff reporter, "Samsung Electronics to step up share buybacks to fund chip bonus," *Asian News International,* May 21, 2026;.

[235] William Lazonick, *Sustainable Prosperity in the New Economy? Business Organization and High-Tech Employment in the United States*, W. E. Upjohn Institute for Employment Research, 2009, chs. 2, 6.

[236] See for example, BYD Company Limited, *2022 Employee Stock Ownership Plan*, BYD internal document. May 2022 (translated from Chinese by Adobe Express). See also Yan Dai, Zhanfeng Wang, and Chenchen Zhao," Analysis of BYD Zero Cost Shareholding Incentive Plan," *Highlights in Business, Economics and Management*, 24, 2024.

[237] Lazonick, *Sustainable Prosperity,* ch. 2.

[238] Fred Lambert, "Tesla Gigafactory: Panasonic is raising $3.9 billion, strategic investment 'mostly' for battery factory in response to Model 3 demand," *Electrek*, July 29, 2016.

[239] Unless otherwise indicated, all financial information reported in this section on financial commitment at Panasonic, LGES, BYD, and CATL is based on data in the companies' annual reports.

[240] Eun-Soo Jin, "LG Energy Solution stock sells well despite market volatility," *Korea JoongAng* Daily, January 19, 2022.

[241] William Lazonick and Matt Hopkins, "Does America want a CHIPS for Buybacks Act," Institute for New Economic Thinking, October 4, 2021; Öner Tulum and William Lazonick, *Innovation versus Financialisation in the US Pharmaceutical Industry*, Cambridge University Press, 2025; Hopkins and Lazonick, "How GM's $10-Billion Buyback"; William Lazonick, *Investing in Innovation: Confronting Predatory Value Extraction in the*

U.S. Corporation, Cambridge University Press, 2023; William Lazonick, "Corporate Finance in the Theory of Innovative Enterprise," in Sofia Johan, Geoffrey Wood, and Anna Grosman, eds., *The Oxford Handbook of Corporate Finance*, Oxford University Press, forthcoming 2026.