WHITE PAPER

A Strategy for U.S. Leadership in Advanced Lithium-ion Battery Development and Production

MARCH 2021

Enovix® Corporation | 3501 W Warren Ave, Fremont, CA 94538 (USA) | www.enovix.com

Table of Contents

Sidebar

Figures

Executive Summary

Recent reports by U.S. energy, economic, and defense experts state that it is strategically important for U.S. industry to have more of a leadership role in the development and production of lithium-ion (Li-ion) batteries, especially next-generation batteries. Dr. George Crabtree, at Argonne National Laboratory, has identified a silicon-dominant battery that can 'drop-in' to the current Li-ion battery manufacturing process as a way the U.S. can regain a competitive and perhaps a leading position in Li-ion battery production.

Enovix has developed an advanced Li-ion battery that uses silicon as the only active lithium cycling material (i.e., 100% active silicon) in the anode to significantly increase energy density and maintain high cycle life. The company has applied an equally innovative approach to develop roll-to-stack Li-ion battery production tools that 'drop-in' to existing battery manufacturing lines. Enovix is now executing a three-phase strategy for U.S. leadership in advanced Li-ion battery development and production.

In phase one, Enovix is constructing its own production facility in Fremont, California to begin commercial deliveries of its 3D Silicon™ Lithium-ion Rechargeable Battery to category leading portable electronic device customers in 2022. The value of collocating and coupling R&D and production in the same facility is extremely high for process-driven advanced battery innovation. The facility also will serve as validation for the Enovix 'drop-in' production process.

Phase two of the Enovix strategy is to scale production of its 3D Silicon Lithium-ion Battery for portable electronic device applications. Enovix may build additional production facilities or partner with established battery producers and help them retrofit their global factories to produce Enovix 3D Silicon Lithium-ion Batteries. Retrofitting an existing U.S. production facility is expected to be a cost-effective way to increase efficiency and provide defence, public safety, and emergency service operations with a secure, reliable supply of U.S. developed and produced advanced silicon-anode Li-ion batteries. Scaling production for next-generation portable electronic devices will also inform Enovix process-driven innovation as the company develops its 100% active silicon-anode Li-ion battery for electric vehicle (EV) and battery energy storage system (BESS) markets.

In phase three, Enovix plans to demonstrate that its 3D Silicon Lithium-ion Battery can combine the energy density, cycle life, and calendar life required for EV battery and BESS market applications, and that its 'drop-in' process can scale for low-cost, high-volume production. This will support the company's strategy to have its Enovix 3D silicon Li-ion technology and production processes adopted by gigafactories through partnerships and licensing by the mid-2020s.

Over the coming decade, the Enovix three-phase strategy is to establish U.S. leadership in advanced Li-ion battery development and production; serve as a strategic foundation for critical, emerging industries such as next-generation portable platforms, electric vehicles, and energy storage systems; and help ensure long-term U.S. economic and national security.

The Need for U.S. Advanced Lithium-ion Battery Leadership

Increased global demand for consumer electronics, electric vehicles, and energy storage systems have made lithium-ion (Li-ion) batteries invaluable in today's global society. China recognized a decade ago the importance of establishing a Li-ion cell manufacturing base.[1] According to the International Energy Agency (IEA), China increased its Li-ion cell production capacity from 9 gigawatt hours (GWh) in 2010 to 145 GWh in 2017.[2] By 2018, China controlled about two-thirds of the global Li-ion cell production capacity, and that is expected to grow to an estimated 73% by 2021, according to BloombergNEF. In comparison, the U.S. controlled only 13% of the global capacity in 2018, with no growth expected.[3]

In written testimony before the U.S. Senate Committee on Energy and Natural Resources on February 5, 2019, Simon Moores, managing director of Benchmark Mineral Intelligence, said, "We are in the midst of a global battery arms race in which the U.S. is presently a bystander." Regarding lithium-ion battery production, he added, "…those who possess the manufacturing and processing know-how will hold the balance of industrial power in the 21st century auto and energy storage industries."[4] On June 24, 2020, he again provided written testimony to the U.S. Senate Committee which reiterated, "Lithium-ion batteries are a core platform technology for the 21st century. A new global lithium-ion economy is being created. Yet, any U.S. ambitions to be a leader in this lithium-ion economy continue to only creep forward and be outstripped by China and Europe."[5]

James Greenberger, executive director of NAATBatt International, makes the case that lithium-ion battery production is strategic to U.S. economic security because it is fundamental to other critical emerging technologies. He says that advanced battery development and production today is analogous to semiconductor development and production in the 1980s, when Japan was a primary competitive threat.[6] Without a vibrant semiconductor industry, U.S. progress in emerging industries such as wireless communications, multimedia, and personal computers would have been hampered, damaging the broader economy.[7] Today advanced battery development and production is strategic to other critical emerging technologies such as next-generation mobile platforms, electric vehicles, and energy storage systems.

> Advanced battery development and production is strategic to other critical emerging technologies such as next-generation mobile platforms, electric vehicles, and energy storage systems.

Recent events, such as trade disputes and a global pandemic, demonstrate that strategic goods produced offshore are at risk of disruption.[8] And the threat is not just economic. A November 2018 article in National Defense, "Offshore Battery Production Poses Problems for Military," states that although the U.S. Defense Department "is a relatively small consumer of lithium battery technologies when compared to the commercial market, the importance of these technologies cannot be understated," and "without a domestic production capability, there are no assurances that a foreign producer will even be willing to ship to the United States in times of conflict."[9] A December 2019 report from The Institute for Defense Analyses, "Lithium Ion Battery Industrial Base in the U.S. and Abroad," states that it is "highly desirable for U.S. industry to have more of a leadership role in the production of Li-ion batteries, especially next-generation batteries."[10]

A Method for U.S. Leadership

In December 2019, Dr. George Crabtree, Director, Joint Center for Energy Storage Research (JCESR), Argonne National Laboratory, penned an article, "What Should the United States Do to Regain Leadership in Lithium-ion Battery Manufacturing?" He asserts that the U.S. can achieve a competitive or even a leading position in Li-ion battery manufacturing with the right technology and production process. He identifies a silicon-anode that significantly increases the energy density of lithium-ion batteries, but qualifies that," the anode material must contain a significant amount of silicon, as much as 50% or more." He also says the advanced battery technology, "should be capable of being 'dropped in' to the current Li-ion battery manufacturing process."[11] Enovix has produced an advanced Li-ion battery with silicon as the only active lithium cycling material in the anode that 'drops-in' to the current Li-ion battery production process.

STRATEGIC LI-ION BATTERY TECHNOLOGIES

Li-ion battery technology is central to delivering significant advances in three critical industries over the next two decades: next-generation mobile platforms, electric vehicles, and energy storage systems.[12]

Next-Generation Portable Platforms – Augmented Reality

The augmented reality (AR) market is projected to grow from under $6 billion (US) in 2018 to over $192 billion in 2025.[13] According to Apple CEO, Tim Cook, AR represents a major new mobile platform. "I regard it as a big idea like the smartphone. I think AR is that big, it's huge."[14] Apple is not the only company that thinks AR is huge. Facebook, Microsoft, and Snap have major development programs. If companies can make the technology reliable and lightweight enough, AR could eventually replace smartphones as the primary mobile platform.[15]

For this to occur, AR glasses must get smaller, lighter, and more powerful. The lenses that display digital imagery in front of people's eyes will need to be high quality while also sufficiently small for a comfortable fit. Broad access to fast 5G mobile networks is considered a critical enabling technology for AR to grow its presence in both consumer and industrial markets. And Li-ion batteries will need to provide more energy capacity in a small-size, lightweight format. Most reports indicate that AR glasses meeting these requirements are expected to be available in 2022 or, more likely, in 2023.[16]

Electric Vehicles

The total value of the EV market is projected to exceed $1 trillion (US) by 2030.[17] The electric passenger vehicle is the largest segment of the total EV market. Passenger EV sales have jumped from 450,000 in 2015 to 2.1 million in 2019, and they are projected to reach 8.5 million in 2025, 26 million in 2030, and 54 million in 2040. This translates to projected passenger EV share, as a percentage of total passenger vehicle sales, growing from 2.7% in 2020 to 10% in 2025, 28% in 2030, and 58% in 2040. However, these projections are based on an absolute necessity that average price parity between EVs and internal combustion engineer (ICE) vehicles will be achieved by the mid-2020s.[18]

The Li-ion battery is the single most costly part of an electric passenger vehicle, making up between 35% and 45% of total cost.[19] By comparison, the Li-ion battery in a mobile device, such as a smartphone, accounts for about 1% to 2% of total cost.[20] The battery is also expected to be the tightest in supply as EV production and supply chains ramp up in the coming years. Not having this strategic part of the production process close by EV manufacturing sites carries significant supply-chain risks.[21]

Battery Energy Storage Systems

Wind and solar are projected to increase from less than 10% of global power generation in 2018 to over 20% by 2030 and to almost 50% by 2050.[22] Li-ion battery energy storage systems (BESS) are emerging as an essential solution to effectively integrate solar and wind renewables in worldwide power systems. Utility-scale stationary batteries presently dominate global energy storage by storing excess renewable energy generation and smoothing output. Behind-the-meter (BTM) batteries—connected behind the utility meter of commercial, industrial, and residential customers—are on the rise globally.[23]

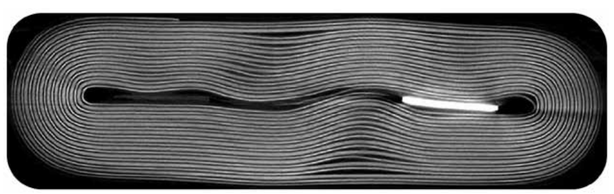
According to the International Renewable Energy Agency (IRENA), total worldwide BESS in 2017 was 11 gigawatt hours (GWh), with utility-scale stationary batteries accounting for about 80%. IRENA projects that BESS will increase to at least 180 GWh by 2030, at which point utility-scale stationary batteries will account for 44% and BTM batteries 56%.[24] According to GMI Research, Li-ion batteries will drive the global battery energy storage system market, which is expected to grow from $1.95 million (US) in 2019 to $34.25 billion in 2026.[25]

A Silicon-Anode in a Lithium-ion Battery

The vast majority of Li-ion batteries use a graphite anode, which is carbon in a crystalline form.[26] A graphite anode absorbs lithium ions when the battery is charging and releases them back into the electrolyte when the battery is discharging. At the anode, lithium (Li) combines with graphite (C) at a one-to-six (1:6) ratio (LiC_6). This gives graphite a theoretical specific capacity of about 372 milliamp-hours per gram (mAh/g).[27] Researchers have long known that a silicon anode could significantly increase the energy density of a conventional Li-ion battery.[28] Silicon (Si) is an attractive anode material because it forms a $Li_{15}Si_4$ alloy. Its increased ratio of Li to Si bonding gives silicon a theoretical specific capacity of about 3,579 mAh/g, over 9 times that of graphite.[29] Volumetrically, lithiated silicon occupies 3 times less volume than lithiated graphite in a charged state (2,194 Ah/l versus 719 Ah/l).[30]

Figure 1

Conventional Li-ion cell architecture



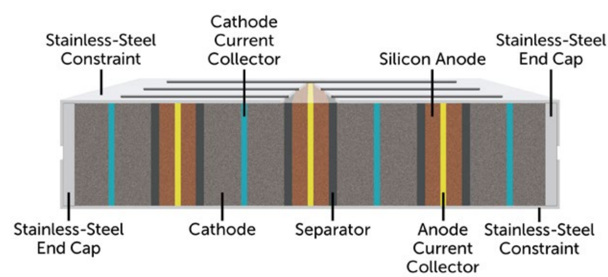
Microscopic cross-section of a conventional wound Li-ion cell shows electrodes and separators wound and flattened (source: Journal of The Electrochemical Society)

Figure 1 shows a photomicrograph cross-section of conventional Li-ion cell architecture, where electrodes and separators are wound to fit into a rectangular metal case or a polymer pouch. Unlike a graphite anode, one that is predominately silicon can cause a conventional Li-ion cell to experience a large volume expansion upon lithiation (charge).[31] During delithiation (discharge), the cell shrinks. As it does, silicon particles discharge non-uniformly, which causes them to electrically disconnect from current collectors, over-discharge, and pulverize. As particles pulverize through repeated discharge cycles, new silicon surfaces open, which causes solid-electrolyte interphase (SEI) to form, and this results in accelerated Li-ion loss. Therefore, a conventional Li-ion cell with a 100% active silicon anode has a very short cycle life, often less than 100 full-depth of discharge cycles to 80% capacity.

With Enovix 3D cell architecture, the electrodes and separators are laser patterned and stacked side-by-side, which enables the application of integrated stainless-steel end plates and constraints. **Figure 2** is a cutaway illustration of proprietary Enovix 3D cell architecture showing the orientation of the electrodes, current collectors, separators and stainless steel end plates enclosed by stainless-steel constraints.

Figure 2

Enovix 3D cell architecture

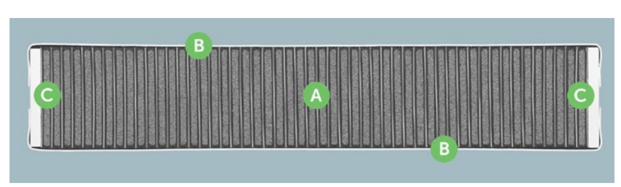


Cutaway illustration (not to scale) of an Enovix 3D cell showing the vertical orientation of electrodes, separators, and stainless-steel end caps enclosed by stainless-steel constraints (source: Enovix Corporation)

Figure 3 is a photomicrograph cross-section of an Enovix 3D cell. Electrodes (A) are stacked side-by-side and enclosed top and bottom with thin (50 micron), lightweight stainless-steel constraints (B) that hold stainless-steel end caps (C) in place. The end caps apply sufficient restraining force on the electrode stack to contain silicon expansion within the cell and limit external swelling during charge cycles. Typical swelling of an Enovix 3D cell after 500 cycles is less than 2%.

Figure 3

Enovix 3D cell architecture



Microscopic cross-section of an Enovix 3D cell shows laser-patterned electrodes and separators vertically oriented within a stainless-steel constraint (source: Enovix Corporation)

Figure 4 compares two 50 mm x 30 mm x 3 mm cells: one of Enovix 3D architecture and another of conventional Li-ion architecture. In conventional Li-ion cell architecture, electrodes are wound or stacked parallel to the (red) face of the battery.

With Enovix 3D cell architecture, electrodes are laser patterned into 3 mm x 30 mm strips and stacked side-by-side to a width of 50 mm. Rather than having long electrodes that run parallel to the face of the battery, Enovix cells have many small electrodes that are orthogonal to the largest face of the battery.

This seemingly small difference has huge benefits. Specifically, the 3D cell architecture is well-suited to accommodate the use of a silicon anode and capitalize on the higher energy density it provides.

In a conventional graphite anode, lithium atoms slip into the vacant spaces between the graphite layers forming LiC_6. As a result, there is very little graphite anode swelling during cycling (<10%). In a silicon anode, however, lithium atoms form an $Li_{15}Si_4$ lithium-silicon alloy that does not have such vacant spaces.

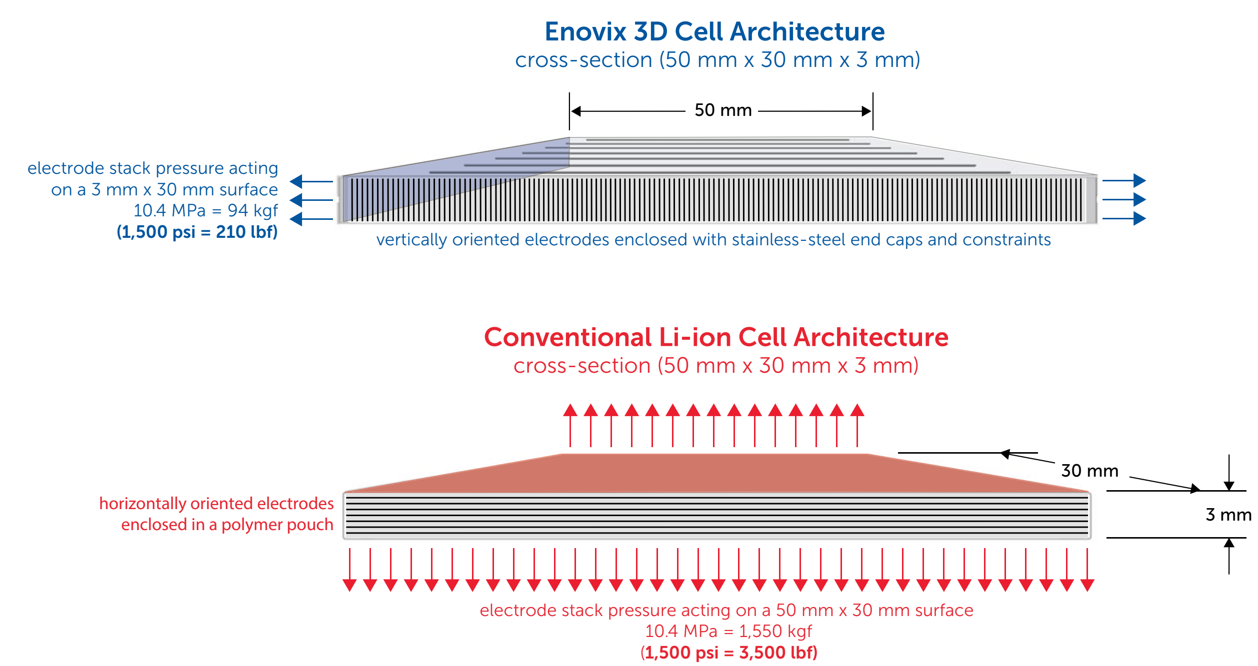
While this alloying process results in an increased ability to store lithium, it can also cause significant expansion of the anode material during charging, creating high pressure within the battery (10.4 MPa or 1,500 psi in an Enovix battery). If a silicon anode were used in a conventional battery architecture, the pressure of anode swelling would act on the large face of the battery (red), requiring a force as large as 1,550 kgf or 3,500 lbf to contain expansion for the battery illustrated in Figure 4.

By contrast, when silicon anodes are used in the Enovix 3D cell architecture, they do not face the largest side of the battery; instead the anodes face a short (3 mm x 30 mm) side of the battery (blue). Because the anode faces are small in area, this same 10.4 MPa or 1,500 psi pressure, requires a force of only 94 kgf or 210 lbf to contain expansion.

The stainless steel constraint system surrounds the cell and limits the battery from swelling and growing in size. Moreover, the constraint system keeps the anode and cathode materials under constant compression, maintaining excellent particle-to-particle connection.

Figure 4

Comparison of electrode stack surface area pressure



Comparison of Enovix 3D cell architecture and of conventional Li-ion cell architecture illustrating the extreme difference in electrode surface area leading to a high differential in resultant force. (source: Enovix Corporation)

A 'Drop-in' Advanced Li-ion Battery Production Process

Enovix has applied an equally innovative, low-cost approach to Li-ion battery production. The result is precision production tools that 'drop-in' to existing standard Li-ion battery manufacturing lines and increase megawatt hour (MWh) capacity by about 30% relative to a conventional Li-ion battery production line at the same volume. **Figure 5** illustrates the three basic stages of standard Li-ion battery production: 1) electrode fabrication, 2) three different 'drop-in' cell assembly processes, and 3) battery packaging and formation.

Figure 5

Three stages of Li-ion battery production

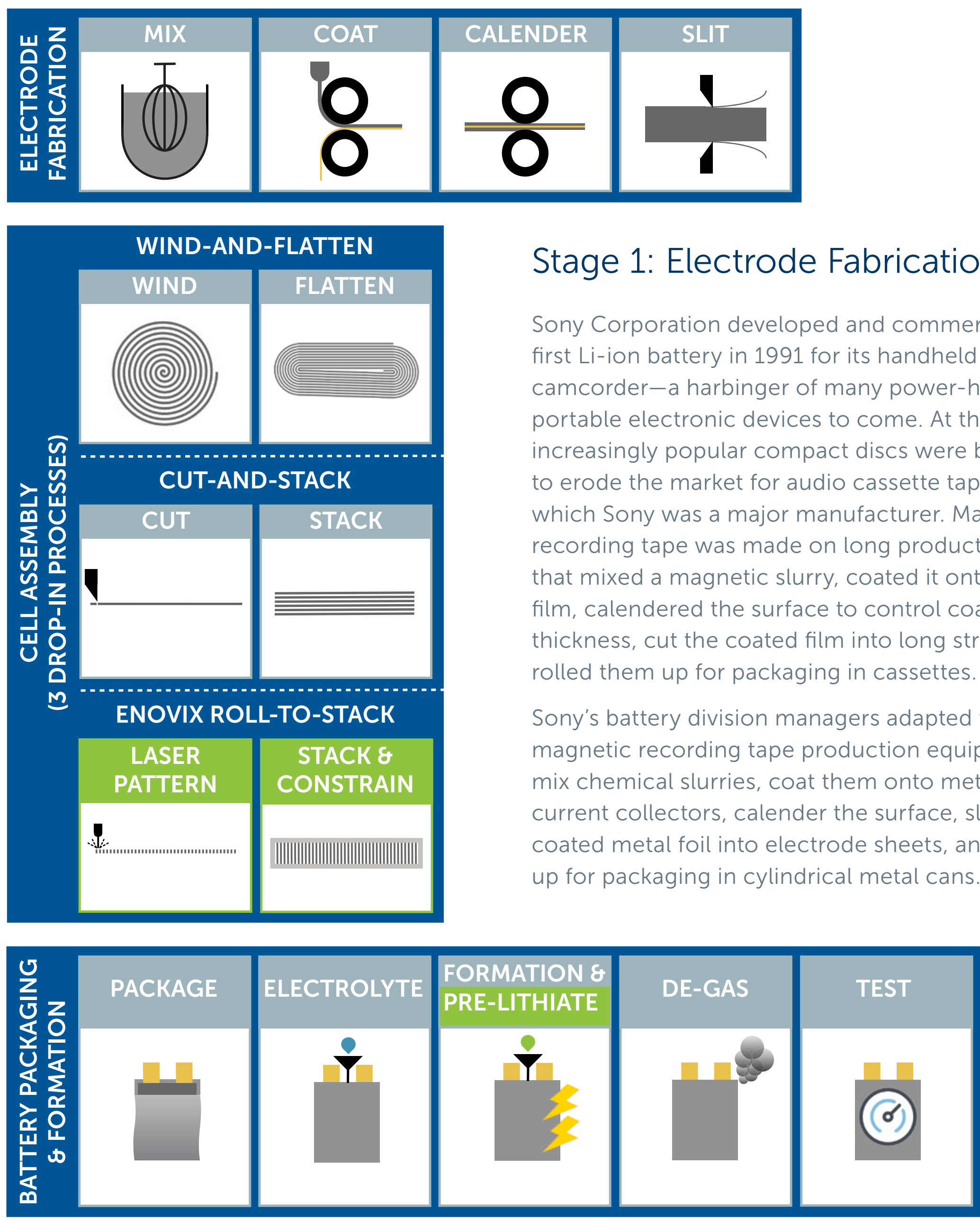


Illustration of the three basic stages of standard lithium-ion battery production—1) electrode fabrication, 2) cell assembly, and 3) battery packaging & formation—with Enovix 'drop-in' processes in green (source: Enovix Corporation)

Stage 1: Electrode Fabrication

Sony Corporation developed and commercialized the first Li-ion battery in 1991 for its handheld camcorder—a harbinger of many power-hungry portable electronic devices to come. At the time, increasingly popular compact discs were beginning to erode the market for audio cassette tapes, of which Sony was a major manufacturer. Magnetic recording tape was made on long production lines that mixed a magnetic slurry, coated it onto a plastic film, calendered the surface to control coating thickness, cut the coated film into long strips, and rolled them up for packaging in cassettes.

Sony's battery division managers adapted the magnetic recording tape production equipment to mix chemical slurries, coat them onto metal foil current collectors, calender the surface, slit the coated metal foil into electrode sheets, and roll them up for packaging in cylindrical metal cans.[32]

Electrode fabrication is a relatively large stage of the overall battery production process. While there have been process improvements over the years, electrodes for all Li-ion batteries are fabricated using this standard method.

Stage 2: Cell Assembly

Cell assembly is a relatively small but critically important stage in the Li-ion battery production process. Li-ion cells were initially assembled by winding electrodes and separators into a naturally cylindrical "jelly roll" configuration packaged in a cylindrical metal can. While some Li-ion batteries still use cylindrical metal cans, low-profile portable electronic devices require thinner, flatter cell formats.[33] Li-ion cell assembly first addressed this need with a wind-and-flatten process introduced in the early 1990s. In 1995, cut-and-stack cell assembly improved spatial efficiency. Enovix has developed a precise roll-to-stack cell assembly process to produce the Enovix 3D cell that significantly increases cell energy density and maintains high cycle life.

Wind-and-Flatten Cell Assembly

Wind-and-flatten cell assembly, introduced in the early 1990s, essentially flattens the cylindrical "jelly roll" into a thin, flat package (see **Figure 1**) for use in portable electronic devices such as laptop computers and mobile phones. The wind-and-flatten electrode assembly can be packaged in a metal case, but it is most often packaged in a polymer pouch for portable electronic device applications. It can also be produced in larger formats with welded aluminium housings for electric power-trains in hybrid and electric vehicles.[34]

Cut-and-Stack Cell Assembly

Cut-and-stack cell assembly was introduced in 1995. Instead of winding and flattening, electrodes and separators are cut (or punched) into sheets, which are stacked horizontally. Cut-and-stack assembly provides better spatial efficiency than "jelly roll" wind-and-flatten assembly. Because the space at the winding core is eliminated and space at the outside edges is reduced, packaging efficiency is improved. Cut-and-stack cells are used in consumer, military, and automotive applications.[35]

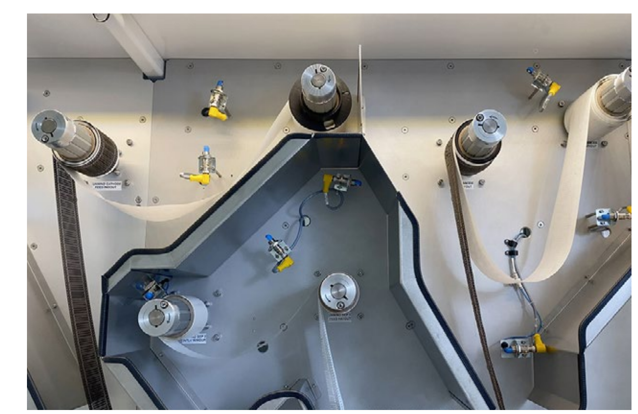
> Enovix has designed tools which incorporate proprietary processes to achieve precise high-speed roll-to-stack cell assembly, and the precision tools 'drop-in' to a standard Li-ion battery production process.

Precision Roll-to-Stack Cell Assembly

Enovix has designed tools, produced by precision equipment companies, which incorporate proprietary processes to achieve precise laser patterning and high-speed roll-to-stack cell assembly. These tools are 'drop-in' replacements for either the wind-and-flatten tools or the cut-and-stack tools in a standard Li-ion production process.

Figure 6

Precision roll-to-stack tool



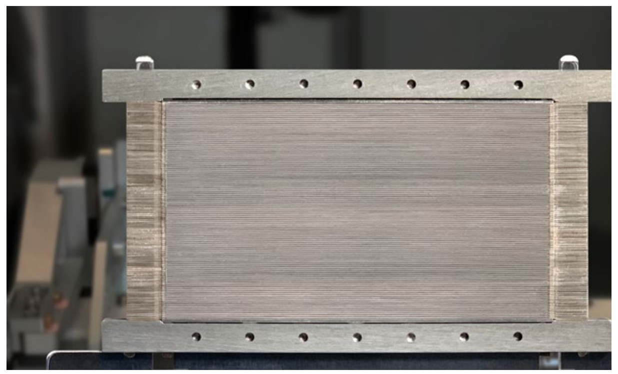
Photograph of electrode and separator rolls on proprietary roll-to-stack tool (source: Enovix Corporation)

Instead of cutting or punching, electrodes and separators are laser patterned and stacked into 3D cell architecture. **Figure 6** shows rolls of electrodes and separators on a proprietary Enovix roll-to-stack tool.

An in-line tool precisely laser patterns the electrodes and separators, which are then fed directly to a high-speed stacking tool. **Figure 7** shows precision laser patterned and stacked electrodes and separators in a 3D cell architecture with the Enovix high-speed stacking tool in the background.

Figure 7

Precision roll-to-stack tool

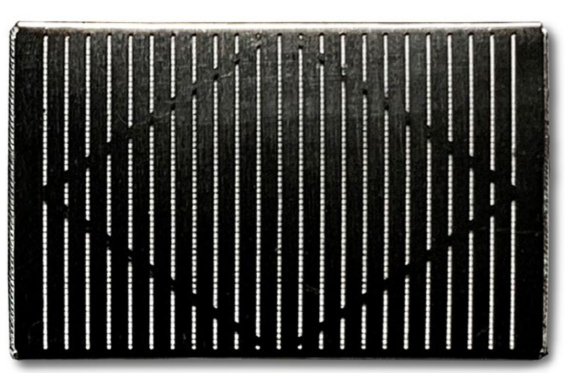


Photograph of stacked electrodes and separators in Enovix 3D cell architecture (foreground) with high-speed roll-to-stack tool (background) (source: Enovix Corporation)

The laser patterning and high-speed stacking of electrodes and separators in the proprietary Enovix 3D cell architecture provides precise alignment and better spatial efficiency than conventional cell assembly. But the critical difference is that the orthogonal orientation of the electrodes enable the application of a high stack pressure with low force.

Figure 8

3D cell with structural constraint



Photograph of Enovix 3D cell with slotted, structural constraint (source: Enovix Corporation)

This enables Enovix to apply a thin (50 micron), stainless-steel constraint to the top and bottom of a 3D cell (**Figure 8**). Because of the orthogonal orientation, Enovix can incorporate an anode with silicon as the only active lithium cycling material into a Li-ion cell and not only significantly increase energy density but also maintain high cycle life.

> Enovix is executing a three-phase strategy to establish U.S. leadership in advanced Li-ion battery development and production.

Stage 3: Battery Packaging and Formation

Battery packaging and formation is another large component of the battery production process. An Enovix 3D Silicon™ Lithium-ion Battery uses the same final assembly process as a conventional Li-ion battery, with one exception. First cycle formation efficiency of a graphite anode is about 90 – 95%. First cycle formation efficiency of a silicon anode is only about 50 – 60%. The pre-lithiation process of the Enovix 3D cell overcomes the first cycle formation efficiency problem.

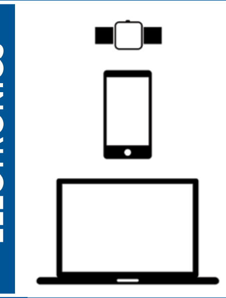
Enovix tools and processes, which 'drop-in' to current Li-ion battery manufacturing lines, enable a silicon anode in the proven chemistry of a Li-ion cell. This is the criteria Dr. George Crabtree, Director of the JCESR, Argonne National Laboratory, described as a way the U.S. "can regain a competitive and perhaps a leading position in lithium-ion battery manufacturing." Along with its production methodology, Enovix has initiated a 3-phase strategy to achieve this goal and rapidly escalate capacity.

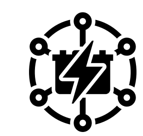
A Strategy to Establish U.S. Leadership in Advanced Li-ion Batteries

Figure 9 illustrates the three-phase strategy Enovix is executing to establish U.S. leadership in advanced Li-ion battery development and production.

Figure 9

Three-phase strategy for U.S. advanced Li-ion battery leadership





		PHASE 1 2022	PHASE 2 2023	PHASE 3 2025
PORTABLE ELECTRONICS	PRODUCTION	■	■	
	PARTNERSHIPS		■	
	LICENSING			
	STRATEGIC PURPOSE	Build New Factory Commercialization Validation Process-Driven Innovation	Build New Factory Retrofit Factories Process-Driven Innovation	Process-Driven Innovation
EV & BESS	PRODUCTION			
	PARTNERSHIPS			■
	LICENSING			■
	STRATEGIC PURPOSE	Development Process-Driven Innovation	Development Process-Driven Innovation	Retrofit Factories Process-Driven Innovation

Illustration of the Enovix three-phase strategy to establish U.S. leadership in advanced Li-ion battery development and production (source: Enovix Corporation)

Phase 1: Production, Commercialization, Validation, and Process-Driven Innovation

To date, only niche applications that can tolerate a very high unit price and low cycle life have employed Li-ion batteries with a silicon-dominant anode, such as solar-electric stratospheric Unmanned Aerial System (UAS). The first phase of the Enovix strategy is to build its own highly automated production facility and begin commercial delivery of its 3D Silicon Lithium-ion Batteries to category leading portable electronic device OEMs. This is expected to simultaneously confirm the performance of its 100% active silicon-anode Li-ion battery and validate its high-volume 'drop-in' production process for mass-market commercial applications.

In 2018, Enovix sampled leading mobile device producers with silicon-anode Li-ion cells that combined increased energy density with high cycle life. In 2019, Enovix achieved important milestones on its path to commercialization. First, the company secured agreements with several category leading customers to develop and produce silicon-anode Li-ion batteries for mobile communication and computing devices. Second, Enovix worked with equipment companies to produce proprietary electrode and separator laser patterning and high-speed stacking tools to meet its specifications, and it incorporated the tools into its semi-automated pilot-production process.

In 2020, Enovix secured funding to build its first silicon-anode Li-ion battery production facility in Fremont, California. The U.S. factory is scheduled to begin production for commercial delivery to customers in 2022. When fully ramped, the facility is designed to produce over 250 MWh of battery capacity per year for mobile communication and computing devices. The company is initially focusing on portable electronic device markets for several reasons.

First, the portable electronics market is large—projected to reach $13 billion by 2025—and we expect device OEMs will pay more for batteries than electric vehicle manufacturers. For example, a lithium-ion battery represents about 1% to 2% of the total component cost of a smartphone.[38] Over the past decade, survey after survey has revealed that the number one consumer wish for their smartphones and other mobile devices is better battery life.[37] In addition, better battery performance has enabled producers to add greater functionality in smaller form factors to improve consumer satisfaction.[38] Because the battery is such a small fraction of the total cost, OEMs of portable electronic devices have indicated they are willing to pay a premium for a battery that significantly increases storage capacity.

Targeting portable electronic device markets now allows Enovix to build a production facility in the U.S. at a relatively low cost (e.g., gigafactories being built to produce EV batteries are estimated to cost from about $2 billion[39] to $5 billion,[40] depending on capacity), in a relatively short time frame, and deliver millions of batteries to a large commercial market. As a result, Enovix expects to generate revenue in Q2 2022.

Second, the Enovix production facility is expected to validate that its 'drop-in' changes are a quick, cost-effective way to retrofit existing standard Li-ion battery production lines and increase production capacity. This will provide the company with flexibility to pursue multiple paths to expand production capacity through building additional facilities or by retrofitting existing Li-ion production facilities.

Third, advanced battery development is occurring at the frontier of science where process innovations are evolving rapidly. Since even minor process changes can have an immense impact on battery performance, the value of collocating and coupling R&D and manufacturing is extremely high, and the risks of separating them are enormous.[41] As more production facilities are added in phases 2 and 3, the phase 1 production facility will be used to develop and scale the next generation of advanced batteries.

Phase 2: Scale Production and Retrofit Existing Li-ion Battery Factories

In 2010, the global Li-ion battery production base was 19 GWh.[42] Most factories had annual production capacity of much less than 1 GWh, with about 95% of the batteries produced for portable electronic devices.[43] Benchmark Mineral Intelligence described it as a "cottage industry geared to supplying a mobile consumer market for smartphones, laptops, and power-tools."[44]

Over the past decade, the Li-ion production landscape has undergone a major upheaval. Electric passenger vehicles coming to market now have batteries with over 5,000 times more storage capacity than a cell phone.[45] BloombergNEF projects that total global Li-ion battery capacity demand will grow to over 2,000 GWh (2 TWh) by 2030, with about 80% for EV applications.[46] This explosive growth in demand is driving the construction of 115 new gigafactories (annual capacity of 10 GWh or more) with a projected total annual capacity of 2,068 GWh[47] and capital costs between $2 billion and $5 billion per factory.

EV dynamics have mostly obscured the continued growth in demand for Li-ion battery capacity to power portable computers, smartphones, tablets, and other mobile electronic devices. But demand is expected to reach about 160 GWh by 2030.[48] The growth in demand will be driven more and more by wearable devices, where batteries need to provide significantly more storage capacity in a smaller package. The step-change increase in storage capacity of an Enovix 3D Silicon Lithium-ion Battery is ideal for such applications, and the Enovix production strategy is a quick, cost-effective way to increase capacity and meet demand.

Compared to new construction, Enovix projects that retrofitting an existing, standard Li-ion battery production line for Enovix battery production can be completed significantly faster and at lower cost, i.e., with quicker time to market and better financial margins. Electrode fabrication is unchanged, with 'drop-in' changes to electrode assembly and a minor change to battery packaging and formation for pre-lithiation. And, due to the increased energy density of each silicon-anode Li-ion battery produced, the change is anticipated to increase capacity by about 30%.

Phase 2 of the Enovix strategy is to scale production of its 3D Silicon Lithium-ion Battery for portable electronic device applications. The Enovix strategy is to build additional production facilities and/or retrofit existing Li-ion production facilities. Enovix may partner with battery producers and help them retrofit their global factories to produce Enovix 3D Silicon Lithium-ion Batteries. This is expected to increase production efficiency and capacity of existing factories and produce differentiated advanced silicon-anode Li-ion batteries for present and next-generation portable electronics devices.

> Compared with new construction, retrofitting a standard Li-ion battery production line for Enovix silicon-anode battery production can be completed in a fraction of the time at a fraction of the cost required to build a new factory of similar capacity.
> .

There are presently only a handful of Li-ion battery factories in the United States.[49] None produce Li-ion batteries for mass-market portable electronic device applications. Some specialize in batteries for military and defense applications, and others were built, in part, with stimulus funding after the 2007 – 2009 financial crisis for anticipated EV applications. The U.S. military has a strong preference for batteries produced in the United States. Retrofitting one or more existing production facilities to silicon-anode Li-ion batteries will be a cost-effective way to increase production efficiency and provide the military with a U.S. developed and produced advanced silicon-anode Li-ion battery. Scaling production for next-generation portable electronic devices will also inform Enovix process-driven innovation as the company develops its silicon-anode Li-ion battery for EV and BESS markets.

Phase 3: Advanced Silicon-Anode Li-ion Batteries for EVs and BESS

Global sales of passenger EVs are projected to increase from 2.1 million in 2019 to 8.5 million in 2025 and to 26 million in 2030. But these high-growth projections are predicated on average price parity between EVs and internal combustion vehicles by mid-2020s. Batteries constitute 35% to 45% of total passenger EV cost. Therefore, reducing EV battery cost is synonymous with reducing EV price. According to BloombergNEF, "for mass market [adoption of] passenger EVs, low battery prices will remain the most critical goal."[50] Li-ion battery prices were above $1,100 (U.S.) per kilowatt-hour (kWh) in 2010. Prices have fallen 87% in real terms to $156/kWh in 2019. And prices are predicted to drop to $100/kWh by 2024 and to $61/kWh by 2030.[51] But some of the factors that have driven the rapid price decrease may not persist, and, according to The Wall Street Journal, "If the cost of batteries doesn't continue to fall, long-range affordable EVs will remain a pipe dream."[52]

As with EVs, a major driver of battery energy storage systems (BESS) adoption is the decreasing cost of Li-ion batteries.[53] Li-ion BESS are emerging as one of the key solutions to effectively integrate solar and wind renewables in utility-scale power systems worldwide.[54] Pairing Li-ion BESS with solar and wind renewable resources will stabilize the grid by levelling loads, while also providing a full range of energy management services and improving a utility system's overall capacity factor.[55] Behind-the-meter (BTM) batteries, connected behind the utility meter of commercial, industrial, and residential customers, are growing even faster than grid scale applications.[56] BloombergNEF projects that by 2030 the demand for stationary storage (utility-scale grid plus BTM) will be about 180 GWh,[57] with utility-scale stationary batteries accounting for 44% and BTM batteries for 56%.[58] As with EVs, the projections are based on the price of Li-ion batteries falling to $100/kWh and below.

Raw materials are a critical supply and cost factor for Li-ion batteries. Graphite, which is the predominant or sole material in the anode of currently available Li-ion batteries, is an example. According to Mineral Commodity Summaries 2019, an annual report published by the U.S. Geological Survey, there are currently no graphite mines in the U.S. About 40,000 metric tons of the carboniferous material was imported to the U.S. during 2018. Benchmark Mineral Intelligence estimates that the amount of graphite needed for the anode material in Li-ion batteries will rocket to 1.75 million metric tons by 2028.[59]

While the price of graphite (per metric ton) declined sharply from about $2,500 (U.S.) in 2011 to about $750 in 2016, it rose to about $1,100 in 2017 before falling back to about $750 in July 2020.[60] A July 2019 article in The Wall Street Journal examines how a sharp decline in the price of key raw materials in 2018 contributed to a 24% decline in EV battery costs that year. But it also issues a warning. "It is usually assumed that the pattern of deflation will continue, following the example of the consumer electronics and solar industries. But batteries are a different kind of product. One problem is that, whereas solar cells are made of abundant silicon, batteries contain volatile commodities. Betting on ongoing declines seems a risky strategy for car makers."[61]

Silicon makes up 27.7% of the Earth's crust by mass and is the second most abundant element (behind only oxygen).[62] According to research conducted on battery innovation by scientists at the Mobility, Logistics and Automotive Technology Research Centre, using silicon-based batteries can achieve a cost reduction per kWh of 30%, and the $100/kWh cost will be reached between 2020 and 2025. The research concludes that, "This low price will have a significant impact on the overall price of an electric vehicles [sic] since the battery represents the largest cost," and "This price reduction will aide in the mass adoption of electric vehicles."[63]

Li-ion battery manufacturers are expecting gigafactories to reach economies of scale and decrease the unit cost of production in the near term.[64] But this alone will not be sufficient to continue the required pace of decreasing battery cost needed to drive EV and BESS market penetration at projected rates. According to BloombergNEF, "As we get closer to the second half of the 2020s energy density at the cell and pack level will play a growing role, as it allows for more efficient use of materials and manufacturing capacity."[65]

An anode with silicon as the only active lithium cycling material has the potential to deliver a threefold benefit: 1) significantly increase energy density, 2) decrease material cost, and 3) leverage an abundant supply of raw material. But not all silicon anode production techniques are cost effective. The Enovix 3D cell architecture has been designed for the use of low-cost commodity silicon anode materials. Other approaches involve nanowires, nanoparticles or other structurally engineered materials, which involve additional silicon processing cost. And if the cost of silicon anode material processing exceeds the present, baseline cost of graphite anode production, it reduces the energy density benefit and diminishes the overall advantage of a silicon-anode Li-ion battery.

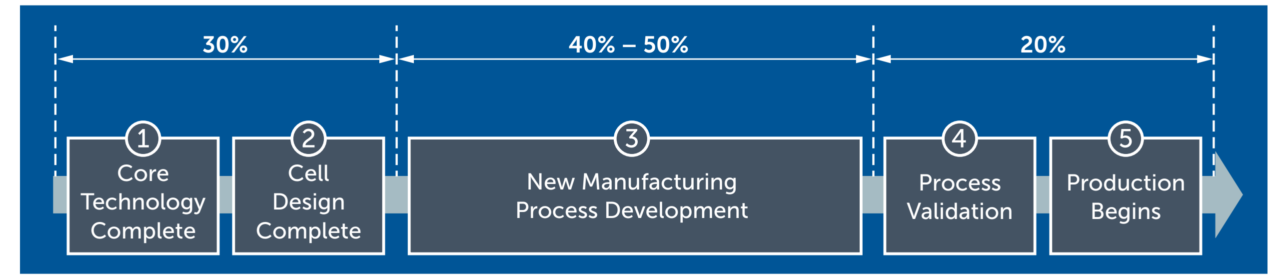
Tesla has blended small amounts of silicon with graphite in its EV batteries since 2015. At the time, Elon Musk said, "This is just sort of a baby step in the direction of using silicon in the anode."[66] At Tesla's Battery Day, on September 22, 2020, Musk outlined a list of (primarily process) improvements the company plans to significantly improve battery performance over the next three to four years. One of the components of Tesla's battery improvement program was the goal to leverage silicon-anode technology and to manufacture it internally. Musk said, "Silicon oxide-based solutions should be the advanced anode of choice for mainstream battery producers today, and they should be expected to dominate the market over the next five to seven years."[67] This means that other EV producers will need to adopt similar technology or face a serious competitive disadvantage by 2025.

In January 2020, the U.S. Department of Energy (DOE) launched the Energy Storage Grand Challenge—a comprehensive strategy to create and sustain U.S. global leadership in energy storage technology, utilization, and exports.[68] About the same time, Enovix completed a proof-of-concept research program with a leading international automobile manufacturer. The program demonstrated that the Enovix silicon anode could be paired with automotive class NMC cathodes in its proprietary 3D architecture to achieve significant gains in gravimetric and volumetric energy density while maintaining excellent cycle life and reducing cost.[69] In July 2020, the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) announced that Enovix had been selected for FY2020 federal funding of $3.2 million to advance research and development on Li-ion batteries using silicon-based anodes. Enovix expects to achieve energy density over 350 Wh/kg, greater than 1,000 cycle life and 10-year calendar life, with a 100% active silicon anode for EV Li-ion battery applications using a combination of Enovix 3D cell architecture and optimized electrolyte chemistry.[70]

Figure 10 is an "Automotive Development Timeline for Batteries" adapted from one published by Benchmark Mineral Intelligence. It illustrates that cell design consumes 30% of total time to market. However, 50% of the total time to market is the development of a production process. Process validation and initial production consumes the final 20%. Many advanced silicon-dominant anode and solid-state battery producers have gone all-in on the EV market, and none have demonstrated a low-cost high-volume production process—in fact, most are just approaching this development phase. Enovix has taken a different direction to the EV battery market. It is proceeding on a parallel process-driven R&D and production path.

Figure 10

Automotive development timeline for batteries



About half the time required to produce a new automotive battery is for development of a new manufacturing process.

As Enovix commercializes existing battery products in multiple mobile device markets, it will continue to develop its 3D cells for the EV market. Enovix believes that validating and commercializing its silicon anode Li-ion battery technology and production process for the portable electronic market will significantly reduce its technology and production risks and enable entry into the larger EV battery market. Rather than creating a novel production process for the EV battery market, Enovix expects to scale its proven production process for the EV battery market. The value of collocating and coupling R&D and production in the same facility for process-driven innovation will pay dividends for transferring production from one mass market to another.

By the mid-2020s, Enovix expects to demonstrate that its 3D Silicon Lithium-ion Battery can combine the energy density, cycle life, and calendar life required for EV battery and BESS market applications, and that its 'drop-in' process can scale for low-cost high-volume production. This will pave the way for Enovix 3D Silicon Li-ion technology and production processes to be adopted by gigafactories through partnerships and licensing.

The Enovix Business Model: Profitable Growth and IP Ownership

It's not unusual for a startup to conceive of an innovative new product. But it's much more difficult for one to transform a concept into a product, produce it, commercialize it, and build a successful, sustainable business around it. Over the past decade, there has been a parade of high-profile battery startups announced with great fanfare, often proclaiming a new technology "breakthrough." Most of the initial claims have not materialized. Some of the companies have radically restructured, and some have ceased operations completely.[71] The majority of the failed ventures were focused solely on the EV battery market, as are many of today's advanced battery startups. The EV battery market is characterized by massive capital investment and ruthless price competition. And, by their own admission, today's startups are years away from commercialization.

Enovix has taken a different path. Its initial target is the portable electronics market, which is expected to reach a total available market (TAM) of $13 billion by 2025. Because it is such a small component of a mobile device's total cost (about 1% to 2%), but provides significant consumer satisfaction through increased functionality and improved user experience, Enovix expects premium portable electronic device OEMs will pay a higher average price, than an EV producer, for a battery with significantly higher energy density. Enovix began generating revenue in 2019 and 2020 from OEM contracts to develop batteries for portable electronic devices and to reserve production capacity.[72]

Enovix is currently securing supply agreements with customers for commercial deliveries in early 2022, and the company projects it will generate revenue in Q2 2022. Meanwhile, Enovix expects to leverage its process-driven innovation to develop its proprietary 100% active silicon-anode cell technology, prepare its 'drop-in' production tools, and secure partnerships to meet the energy density and cost demands of the EV and BESS markets by the mid-2020s.

Enovix is combining technological and production innovation with a business model built on profitable growth and ownership of intellectual property to create enterprise value and build a sustainable business with competitive barriers for years to come.

Unlike many advanced battery startups, which license core technology from government or academic research laboratories, Enovix has developed and owns its intellectual property. Enovix received its first four patents in 2012, and, to date, the company has been issued 89 patents, and it has submitted over 50 pending applications. Its patents cover design and production innovations, including 3D cell architecture, a 100% active silicon anode, and 'drop-in' production techniques. Enovix is combining technological and production innovation with a business model built on profitable growth and ownership of intellectual property to create enterprise value and build a sustainable business with competitive barriers for years to come.

Conclusion

In the 1980s, semiconductor development and production was strategic to progress in critical emerging industries such as wireless communications, multimedia, and personal computers. Without a vibrant semiconductor industry, U.S. progress in these industries would have been hampered, damaging the broader economy. Today, advanced Li-ion battery development and production are strategic to U.S. progress in critical emerging industries such as next-generation portable electronic platforms, electric vehicles, and battery energy storage systems. But the U.S. presently lags China and Europe in Li-ion battery production.

Dr. George Crabtree, Director, JCESR, Argonne National Laboratory, has identified a silicon-dominant battery that can 'drop-in' to the current Li-ion battery manufacturing process as one way the U.S. can regain a competitive and perhaps a leading position in Li-ion battery production. Enovix has developed a Li-ion battery with silicon as the only active lithium cycling material in the anode to significantly increase energy density and maintain high cycle life. The company has applied an equally innovative approach to develop roll-to-stack Li-ion battery production tools that 'drop-in' to existing battery manufacturing lines and increase MWh capacity by about 30% relative to a conventional Li-ion battery production line at the same volume. Enovix is now executing a three-phase strategy for U.S. leadership in advanced Li-ion battery development and production.

In phase one, Enovix is constructing its own production facility in Fremont, California to begin commercial deliveries of its 3D Silicon Lithium-ion Battery to category leading portable electronic device customers in 2022. The value of collocating and coupling R&D and production in the same facility is extremely high for process-driven advanced battery innovation. The facility also will serve as validation for the Enovix 'drop-in' production process with its present and future battery manufacturing partners.

Phase two of the Enovix strategy is to scale production of its 3D Silicon Lithium-ion Battery for portable electronic device applications. Enovix expects to build additional production facilities and/or retrofit existing Li-ion production facilities. Enovix may partner with battery producers and help them retrofit their global factories to produce Enovix 3D Silicon Lithium-ion Batteries. Retrofitting an existing U.S. production facility is expected to be a cost-effective way to increase production efficiency and provide the military with a U.S. developed and produced advanced silicon-anode Li-ion battery. Scaling production for next-generation portable electronic devices is also expected to inform Enovix process-driven innovation as the company develops its silicon-anode Li-ion battery for EV and BESS markets.

In phase three, Enovix plans to demonstrate that its 3D Silicon Lithium-ion Battery can combine the energy density, cycle life, and calendar life required for EV battery and BESS market applications, and that its 'drop-in' process can scale for low-cost high-volume production. This will pave the way for Enovix 3D Silicon Li-ion technology and production processes to be adopted by gigafactories through partnerships and licensing by the mid-2020s.

Over the coming decade, the Enovix three-phase strategy will establish U.S. leadership in advanced lithium-ion battery development and production; serve as a strategic foundation for critical, emerging industries such as next-generation portable platforms, electric vehicles, and energy storage systems; and help ensure long-term U.S. economic and national security.

END

References

[1] H. J. Mai, “To compete in the global battery arms race, the US must spur its domestic market, analysts say,” *UtilityDive*, June 24, 2019, https://www.utilitydive.com/news/creating-a-domestic-market-is-paramount-for-us-battery-industry-to-close-th/557339/, accessed June 9, 2020.

[2] “Commissioned EV and energy storage lithium-ion battery cell production capacity by region, and associated annual investment, 2010-2022,” *IEA*, updated April 10, 2020, https://www.iea.org/data-and-statistics/charts/commissioned-ev-and-energy-storage-lithium-ion-battery-cell-production-capacity-by-region-and-associated-annual-investment-2010-2022, accessed June 9, 2020.

[3] Mai.

[4] Ibid.

[5] Simon Moores, “Written Testimony to the U.S. Senate Committee on Energy and Natural Resources,” *Benchmark Mineral Intelligence*, June 24, 2020, https://www.energy.senate.gov/public/index.cfm/files/serve?File_id=6A3B3A00-8A72-4DC3-8342-F6A7B9B33FEF, accessed July 27, 2020.

[6] James Greenberger, “What Makes Certain Goods Strategic?” *NAATBatt International*, May 15, 2020, https://naatbatt.org/what-makes-certain-goods-strategic/, accessed June 9, 2020.

[7] Leslie Helm, “In the Chips: America’s semiconductor industry again leads the world. But new Asian competitors are gaining strength. And you can never count Japan out.” *Los Angeles Times*, March 5, 1995, https://www.latimes.com/archives/la-xpm-1995-03-05-fi-39145-story.html, accessed June 9, 2020.

[8] Jacob M. Schlesinger, “How the Coronavirus Will Reshape World Trade,” *The Wall Street Journal*, June 19, 2020, https://www.wsj.com/articles/how-the-coronavirus-will-reshape-world-trade-11592592995?mod=searchresults&page=2&pos=12, accessed June 23, 2020.

[9] Marc D. Gietter, “Viewpoint: Offshore Battery Production Poses Problems for Military,” *National Defense*, November 8, 2018, https://www.nationaldefensemagazine.org/articles/2018/11/8/offshore-battery-production-poses-problems-for-military, accessed June 9, 2020.

[10] Abby R. Goldman, Frank S. Rotondo, and Jessica G. Swallow, “Lithium Ion Battery Industrial Base in the U.S. and Abroad,” *Institute for Defense Analyses*, December 2019, https://www.ida.org/-/media/feature/publications/l/li/lithium-ion-battery-industrial-base-in-the-us-and-abroad/d-11032.ashx, accessed June 9, 2020.

[11] George Crabtree, “What Should the United States Do to Regain Leadership in Lithium-ion Battery Manufacturing?” *NAATBatt International*, December 6, 2019, https://naatbatt.org/what-should-the-united-states-do-to-regain-leadership-in-lithium-ion-battery-manufacturing-by-dr-george-crabtree/, accessed June 9, 2020.

[12] Kurt Baes, Florence Carlot, Yuma Ito, Michael Kolk, and Adnan Merhaba, “Future of batteries: Winner takes all?” *Arthur D Little*, May 2018, https://www.adlittle.com/sites/default/files/viewpoints/adl_future_of_batteries-min.pdf, accessed August 4, 2020.

[13] Augmented reality (AR) market size worldwide in 2017, 2018 and 2025, ©2020 Statista, https://www.statista.com/statistics/897587/world-augmented-reality-market-value/, accessed August 4, 2020.

[14] David Phelan, “Apple CEO Tim Cook: As Brexit hangs over UK, ‘Times are not really awful, there’s some great things happening,’” *The Independent*, February 10, 2017, https://www.independent.co.uk/life-style/gadgets-and-tech/features/apple-tim-cook-boss-brexit-uk-theresa-may-number-10-interview-ustwo-a7574086.html, accessed August 4, 2020.

[15] Nick Wingfield and Alex Heath, “As Apple Plans Come Into Focus, Big Challenges Remain for AR,” *The Information*, November 12, 2019, https://www.theinformation.com/articles/as-apple-plans-come-into-focus-big-challenges-remain-for-ar, accessed August 4, 2020.

[16] Ibid.

[17] Richard Collins, Peter Harrop, Luke Gear, Na Jiao, David Wyatt, and James Edmondson, “Electric Vehicles 2020-2030: 2nd Edition,” *IDTechEx*, https://www.idtechex.com/en/research-report/electric-vehicles-2020-2030-2nd-edition/716, accessed August 4, 2020.

[18] Electric Vehicle Outlook 2020, *BloombergNEF*, https://about.bnef.com/electric-vehicle-outlook/, accessed August 4, 2020.

[19] James Eddy, Alexander Pfeiffer, and Jasper van de Staaij, “Recharging economies: The EV-battery manufacturing outlook for Europe,” *McKinsey & Company*, June 3, 2019, https://www.mckinsey.com/industries/oil-and-gas/our-insights/recharging-economies-the-ev-battery-manufacturing-outlook-for-europe, accessed August 5, 2020.

[20] Jegan Venkatasamy, “Lithium-ion Batteries – Price Trend and Cost Structure,” *Beroe Market Intelligence*, November 26, 2019, https://www.beroeinc.com/article/lithium-ion-batteries-price-trend-cost-structure/, accessed August 17, 2020.

[21] Eddy.

[22] New Energy Outlook 2019, *BloombergNEF,* https://about.bnef.com/new-energy-outlook/, accessed August 5, 2020.

[23] “Battery Storage Paves Way for a Renewable-powered Future,” *International Renewable Energy Agency (IRENA)*, March 26, 2020, https://www.irena.org/newsroom/articles/2020/Mar/Battery-storage-paves-way-for-a-renewable-powered-future, accessed August 5, 2020.

[24] Ibid.

[25] Battery Energy Storage System Market, *GMI Research*, February 2020, https://www.gmiresearch.com/report/battery-energy-storage-system-market-opportunities-forecast-2019-2026/, accessed August 5, 2020.

[26] Steve LeVine, “We are racing toward an electric-car future. Can battery scientists keep up?” Quartz, June 16, 2016, https://qz.com/699909 siliconbatteries-electric-car-future/, accessed June 18, 2018.

[27] Xinghao Zhang, Denghui Wang, Xiongying Qiu, Yingjie Ma, Debin Kong, Klaus Müllen, Xianglong Li and Linjie Zhi, “Stable high-capacity and high-rate silicon-based lithium battery anodes upon two-dimensional covalent encapsulation,” *Nature Communications*, July 31, 2020, https://www.nature.com/articles/s41467-020-17686-4, accessed December 4, 2020.

[28] Levine.

[29] Manisha Phadatare., Rohan Patil, Nicklas Blomquist, et al. Silicon-Nanographite Aerogel-Based Anodes for High Performance Lithium Ion Batteries, *Scientific Reports 9*, 14621 (2019), https://doi.org/10.1038/s41598-019-51087-y, accessed February 28, 2021.

[30] Xiuyun Zhao and Vesa-Pekka Lehto, Challenges and prospects of nanosized silicon anodes in lithium-ion batteries, *Nanotechnology, volume 32, Number 4*, 042002 (2021), https://doi.org/10.1088/1361-6528/abb850, accessed March 12, 2021.

[31] Phadatare.

[32] Steve Levine, “The story of the invention that could revolutionize batteries—and maybe American manufacturing as well,” Quartz, June 22, 2015, https://qz.com/433131/the-story-of-the-invention-that-could-revolutionize-batteriesand-maybe-american-manufacturing-as-well/, accessed May 24, 2018.

[33] Types of Battery Cells, *Battery University*, https://batteryuniversity.com/learn/article/types_of_battery_cells, accessed July 27, 2020.

[34] Ibid..

[35] Ibid.

[36] Venkatasamy.

[37] Christopher Mims, “Our One Wish? Longer Battery Life,” *The Wall Street Journal*, February 22, 2015, http://www.wsj.com/articles/our-one-wish-longer-battery-life-1424650700?cb=logged0.2274062824435532, accessed August 17, 2020.

[38] Joanna Stern, “Apple Watch Series 4 Review: Why I Finally Fell for This Wearable,” *The Wall Street Journal*, October 2, 2018, https://www.wsj.com/articles/apple-watch-series-4-review-why-i-finally-fell-for-this-wearable-1538485200, accessed September 14, 2020.

[39] Andrew J. Hawkins, “GM is building an EV battery factory with LG Chem in Lordstown, Ohio’” *The Verge*, December 5, 2019, https://www.theverge.com/2019/12/5/20996866/gm-lg-ev-electric-vehicle-battery-joint-venture-chem-lordstown, accessed August 17, 2020.

[40] Fred Lambert, “Tesla expects Gigafactory 3 in China to cost $5 billion, report says,” *Electrek*, August 1, 2018, https://electrek.co/2018/08/01/tesla-gigafactory-3-china-cost-5-billion-report/, accessed August 17, 2020.

[41] Gary P. Pisano and Willy C. Shih, “Does America Really Need Manufacturing?” *Harvard Business Review*, March 2012, p 6.

[42] “Who is Winning the Global Lithium-ion Battery Arms Race,” *Benchmark Mineral Intelligence*, January 26, 2019, https://www.benchmarkminerals.com/who-is-winning-the-global-lithium-ion-battery-arms-race/, accessed August 18, 2020.

[43] “The Rechargeable Battery Market and Main Trends: 2014 – 2025,” *Avicenne Energy*, 32nd International Battery Seminar & Exhibit, March 9, 2015.

References (continued)

[44] Benchmark Mineral Intelligence.

[45] Mal Skowron, “Better Battery Technology—The Tipping Point for EV Adoption?” Green Energy Consumers Alliance, May 13, 2019, https://blog.greenenergyconsumers.org/blog/better-battery-technology-the-tipping-point-for-ev-adoption, accessed August 18, 2020.

[46] “Electric Vehicle Outlook 2020 – Batteries and charging infrastructure,” BloombergNEF, https://bnef.turtl.co/story/evo-2020/page/6/1?teaser=yes, accessed August 18, 2020.

[47] Benchmark Mineral Intelligence.

[48] BloombergNEF.

[49] Donald Chung, Emma Elgqvist, and Shriram Santhanagopalan, “Automotive Lithium-ion Cell Manufacturing: Regional Cost Structures and Supply Chain Considerations,” *Clean Energy Manufacturing Analysis Center*, April 2016, p 2

[50] “Battery Pack Prices Fall as Market Ramps Up with Market Average at $156/kWh in 2019,” BloombergNEF, December 3, 2019, https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/, accessed August 21, 2020..

[51] Ibid.

[52] Stephen Wilmot, “The Big Obstacle on the Road to Electric Vehicles,” *The Wall Street Journal*, July 18, 2019, https://www.wsj.com/articles/the-big-obstacle-on-the-road-to-electric-vehicles-11563459592?shareToken=st2fd2d65bd7514b60b9a09f3a817bc700, accessed August 21, 2020.

[53] Parag Diwan, "Battery Energy Storage System," *Medium*, May 1, 2019, https://pdiwan.medium.com/battery-energy-storage-system-eb0e9a57d546, accessed November 20, 2020.

[54] IRENA.

[55] Tom Jones, “Enabling Renewable Resources Through Battery Energy Storage Systems,” *Energy Central*, January 29, 2020, https://energycentral.com/c/cp/enabling-renewable-resources-through-battery-energy-storage-systems, accessed August 24, 2020.

[56] IRENA.

[57] “Electric Vehicle Outlook 2020 – Batteries and charging infrastructure,” *BloombergNEF*, https://bnef.turtl.co/story/evo-2020/page/6/1?teaser=yes, accessed August 18, 2020.

[58] IRENA.

[59] Shane Lasley, “EV batteries to drive 9x graphite growth,” *Mining News*, June 22, 2020, https://www.miningnewsnorth.com/page/ev-batteries-to-drive-9x-graphite-growth/5754.html, accessed August 21, 2020..

[60] Matt Bohlsen, “Graphite Miners News for The Month of July 2020,” *Seeking Alpha*, July 28, 2020, https://seekingalpha.com/article/4361220-graphite-miners-news-for-month-of-july-2020, accessed August 21, 2020.

[61] Wilmot.

[62] Royal Society of Chemistry, Periodic Table, Silicon, https://www.rsc.org/periodic-table/element/14/silicon, accessed August 24, 2020.

[63] Gert Berckmans, Maarten Messagie, Jelle Smekens, Noshin Omar, Lieselot Vanhaverbeke, and Joeri Van Mierlo, “Cost Projection of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030,” *MPDI Journal: Energy Storage and Application*, September 1, 2017, https://www.mdpi.com/1996-1073/10/9/1314/htm, accessed August 21, 2020.

[64] “Battery Pack Prices Fall as Market Ramps Up with Market Average at $156/kWh in 2019,” *BloombergNEF*, December 3, 2019, https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/, accessed August 21, 2020.

[65] BloombergNEF.

[66] Christian Ruoff, “Tesla tweaks its battery chemistry: a closer look at silicon anode development,” *Charged*, September 15, 2015, https://chargedevs.com/features/tesla-tweaks-its-battery-chemistry-a-closer-look-at-silicon-anode-development/, accessed October 14, 2020.

[67] Andy Colthrope, “Experts react to Tesla Battery Day: The key technology takeaways,” *Energy Storage*, September 30, 2020, https://www.energy-storage.news/blogs/experts-react-to-tesla-battery-day-the-key-technology-takeaways, accessed October 14, 2020.

[68] “DOE launches Grand Challenge to accelerate U.S. energy storage supply chain, deployment,” *Power Engineering*, January 9, 2020, https://www.power-eng.com/2020/01/09/doe-launches-grand-challenge-to-accelerae-u-s-energy-storage-supply-chain-deployment/#gref, accessed October 14, 2020.

[69] “Enovix Corporation Booking Capacity Reservations for Production and Commercialization of its 3D Silicon™ Lithium-ion Battery“ Cision PR Newswire, October 30, 2019, https://www.prnewswire.com/news-releases/enovix-corporation-booking-capacity-reservations-for-production-and-commercialization-of-its-3d-silicon-lithium-ion-battery-300947708.html, accessed August 24, 2020.

[70] “Enovix Selected by U.S. Department of Energy for Fiscal Year 2020 Advanced Vehicle Technologies Research Funding,” Cision PR Newswire, https://www.prnewswire.com/news-releases/enovix-selected-by-us-department-of-energy-for-fiscal-year-2020-advanced-vehicle-technologies-research-funding-301118333.html, accessed August 26, 2020.

[71] Richard Martin, “Why We Still Don’t Have Better Batteries,” MIT Technology Review, August 29, 2016, https://www.technologyreview.com/s/602245/why-we-still-dont-have-better-batteries/, accessed June 22, 2018.

[72] “Enovix Secures $45 Million from Investors and Customers to Produce and Commercialize its 3D Silicon™ Lithium-ion Battery“ Cision PR Newswire, March 31, 2020, https://www.prnewswire.com/news-releases/enovix-secures-45-million-from-investors-and-customers-to-produce-and-commercialize-its-3d-silicon-lithium-ion-battery-301032372.html, accessed March 16, 2021.

[73] Venkatasamy.

[74] Enovix Corporation Booking Capacity Reservations.

About Enovix

Enovix is a leader in advanced silicon-anode lithium-ion battery development and production. Our proprietary 3D cell architecture increases energy density and maintains high cycle life. And we're building the first advanced silicon-anode lithium-ion battery production facility in the U.S. Our initial goal is to provide designers of category-leading mobile devices with a high-energy battery so they can continue creating innovative portable products. We're also developing our 3D cell technology and production process for the electric vehicle and energy storage markets to enable widespread utilization of renewable energy. For more information, go to **www.enovix.com**

Enovix Corporation | 3501 W Warren Ave, Fremont, CA 94538 (USA) | www.enovix.com