



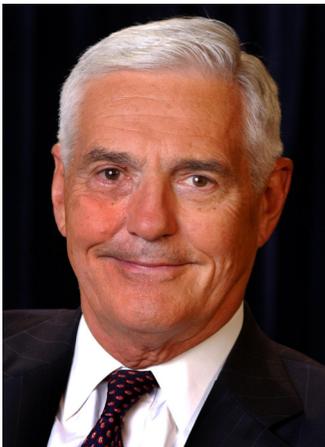
The Energy Storage Future: New ideas, New Innovations, New Collaborations

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Driving Toward a Clean Energy Economy



BOB LUTZ
GROUP 14 TECHNOLOGIES
BOARD MEMBER

Building a broad-based clean energy economy in the United States would bring major benefits. Despite our recent gains in domestic oil and gas production, America's industries and everyday citizens are still vulnerable to price hikes and supply shocks from overseas producers. Volatile supply and pricing have plagued our economy for too long. Reducing our dependency on petroleum by expanding the use of renewable electricity would stimulate economic growth and increase our energy security.

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In support of this goal, our government, industry leaders and research labs have spent a lot of time and money exploring technology needed to build electric vehicles. But today, EVs are still no more than a niche product. That's because the current price and performance of EV batteries is not competitive with internal combustion engines. EVs are too expensive, still have limited range, and are inconvenient to re-charge. We need to build cars that consumers want to buy. Obviously they must be affordable for everyone. Tesla, for example, makes some beautiful EVs, but they are too expensive for most people. Even the sales of more affordable EVs and hybrids often slump when gasoline prices are low.

To get EVs to a tipping point, we will need to improve both cost and performance to compete with gas powered engines. And those same improvements could stimulate related innovations that make our computers, phones, appliances and gadgets work better, last longer, charge faster and cost less. All of this requires advances in technology and materials, which is the focus of Group14Technologies. It has assembled a team of brilliant minds focused on commercializing cost-effective, advanced silicon-carbon composite anode materials for lithium-ion batteries -- breakthrough science that will help push batteries to the next level. They know the importance of cost and scalability. They know that showing impressive lab data is a long way from a successful product, and even farther from creating a change in the industry.

By driving innovation that dramatically improves lithium-ion battery performance, Group 14 Technologies is pushing us closer to the day when electric cars are the standard. And that in turn will unlock potential U.S. economic growth, powered by stable, reliable domestic sources of energy.

Manufacturing Gap Stifles U.S. Innovation



DOUG MORRIS
CEO, POLARIS BATTERY LABS

The historical decline in U.S. manufacturing capacity has spurred vigorous discussion on the loss of domestic factory jobs, notably to China and greater Asia. But that decline also creates less obvious problems. Namely, it stifles innovation here at home, leaving promising new consumer product technologies just out of reach.

In the energy storage industry, a lot of cutting edge research is driven by smaller companies working to make batteries more powerful, longer lasting, less expensive and faster charging. Many new technologies have been delayed for years simply because they can't find an easy path into a factory. It can take a decade or even longer to develop the new materials to enable these improvements. And that's just too long.

Imagine if your laptop computer or cordless drill had 50 percent longer battery life, or if you could fully charge your phone in 15 minutes at an airport kiosk. Even bigger benefits could come in the electric vehicle market. Today, you might sit in a coffee shop for an hour waiting for your car to charge. Technology in the works now could let you pull in to a service center and swap out a depleted battery for a new one, or to fully recharge your existing battery, in less than five minutes, much like a visit to the gas station today. And better storage technology on the power grid is one of the few remaining barriers to a massive expansion of cost-competitive renewable energy across the U.S.

To accelerate commercialization of these new technologies, startup companies need smaller batches of raw materials that are currently expensive and difficult to obtain from suppliers based in Asia. Larger original equipment manufacturers (OEMs) like Apple and Samsung can generally get what they need at scale. But for many others,

developing a new cell can be so difficult and so expensive that they end up settling for the next closest thing they can find. That usually means their product won't perform as well as it could. If we were able to produce cells in the United States that could enable product manufacturers to get special sizes and special chemistries more freely, a tremendous boost in access to new and innovative new technologies would occur.

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Asian suppliers have longstanding cost advantages over U.S. industry, but today that price gap is only 5 to 10 percent. Most of that advantage comes from lower labor

costs and government support. But the full cost of Asian sourcing includes additional factors that aren't easy to quantify. For example, support costs can be much higher for a U.S. manufacturer relying on a supplier in Asia. Quality control – assessing inventories and shipping them back to a supplier – can come with significant costs in both time and money.

Supply assurance can also be more risky. Many Asian cell suppliers look at supporting U.S. contract business as kind of a side note. If they're in a slow period and they have some extra capacity, they'd be happy to have the work. But if they get busy, their interest can wane, even to the point of ending the partnership. Major manufacturers buying in large quantities can find supply more readily. It's the smaller niche players than can get locked out.

Lastly, the lack of intellectual property protection in some parts of Asia is a serious concern, especially for companies that have developed some kind of new technology. Not knowing that your manufacturing partner will protect your secrets is risky and scary. And in general, that's the case in China. If you could add up all the hidden costs and risks of sourcing from Asia, the price advantage compared to U.S. suppliers might evaporate completely. So, what would it take to bring battery manufacturing back to the United States?

It might be possible to reduce labor costs through automation. Fully automated battery production lines are feasible, along with technological improvements that could lower production costs. Well-placed government supports could also reduce or eliminate the price gap between U.S. and Asian suppliers.

Competitive pricing would certainly get the attention of large OEMs. But more important would be the ability to buy better performing advanced cells, using new materials and new enhancements that aren't available today from suppliers in Asia. Supporting current innovation occurring in the U.S. with dedicated, nearby manufacturing muscle could accelerate production of more flexible, versatile specialized cells that OEMs have waited years for. Until that time, OEMs will continue to buy the best product they can get at the lowest price, and consumers will continue to wait for tantalizing product enhancements that will forever seem just around the corner.

Will the U.S. Compete in Clean Tech?



STEVE J. VISCO,
CEO AND CTO AT POLYPLUS
BATTERY COMPANY

A friend of mine with a Ph.D. in chemistry once worked for a major consumer battery manufacturer, where he led a team researching rechargeable lithium metal batteries. Shortly after launching his project, he presented his plan to senior company managers, one of whom said, "Nice job, but to be fully honest with you, I hope you fail." The company was making lots of money selling throwaway batteries. Why would they want to mess with complicated, unproven new technology?

Technological advances like lithium batteries are essential for the growth of renewable energy, electric cars and a wide range of compelling new products and services. But indifference -- or even resistance -- to innovation, from both companies and the federal government, have left the U.S. far behind other countries in the pursuit of next generation technology. We have ceded crucial new industries to competitors, mostly in Asia, where heavy investment in research and ample government support have helped create good jobs and new markets for cutting edge products.

In stark contrast, the U.S. government provides only tenuous support for renewables, with limited tax credits and inconsistent research funding. Current federal budget proposals include big cuts in funding for important research at the Department of Energy. President Trump is focused on reviving the failing coal industry and withdrawing from previous commitments to reduce air pollution.

If we stay on that shortsighted path, the results could be disastrous for our energy sector and our economy. New technologies that could boost growth, increase our energy independence, and benefit the environment will go elsewhere, along with thousands of research jobs. Scientists working at our national labs and at small companies will likely move to China, Japan, or South Korea, where they can find funding for their work. If we surrender all that brainpower, we may never catch up.

Much of the problem stems from short-term thinking among business and political leaders. Big U.S. industrial companies are very good at supply chain management, manufacturing, and cost reduction, but struggle to foster a culture of innovation. U.S. battery companies are mostly stand-alone entities. They do employ Ph.D.s and research teams, but they aren't focused on generating breakthrough technologies. They are often tasked with near term goals such as incremental improvements for existing products to help the company meet quarterly earnings targets.

Meanwhile, several leading Asian electronics companies have built battery innovation into their vertical structures, designing products that integrate their own new technologies, which creates a market for them and supplies steady research funding. Companies like Samsung, Panasonic, LG and Amperex Technology (ATL) employ thousands of researchers, dwarfing the staffs at their U.S. counterparts.

On the government side, the U.S. did supply stimulus funds for renewable energy companies during the Obama administration. Although well intentioned, the urgent focus on creating manufacturing jobs incentivized some dubious choices that did not end well. Several promising small ventures expanded too quickly in order to qualify for federal support, instead of incubating their innovative new products. In the aftermath, public support for clean tech funding dwindled. In countries like China, Japan and South Korea, government support is much more consistent, encouraging longer-term research and development.

And yet, there may still be time for the U.S. to compete. To be sure, it's very tough to directly challenge large, established companies that have already depreciated their equipment and have tremendous manufacturing experience. The cost of lithium ion technology is rapidly declining -- which was an unanticipated and an exciting development. It couldn't have come at a better time.

Tesla plans to expand its production of electric cars to 500,000 a year and Volvo recently committed to an all-electric or hybrid fleet in 2019. Demand for electrified transportation is surging. All of this is great for the consumer, but it's extremely difficult for U.S. battery manufacturers to compete in such an environment.

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But we could win with step change technology – innovation that offers a huge advantage in terms of performance. One such possibility is the development of rechargeable lithium metal batteries, which are expected to double the energy density of competing Li-ion batteries (half of the weight and size for an equivalent energy content). Commercialization of this technology domestically would give U.S. manufacturers a significant competitive advantage.

The U.S. Department of Energy and a number of industrial outfits have been looking at grid storage and batteries in particular for a long time. Today, the U.S. is not a significant competitor in the lithium ion market. Even Tesla's Gigafactory, which builds car batteries in Reno, Nevada, uses cell technology developed by Panasonic in Japan.

For the U.S. to be a major player in any clean tech field, it's going to take renewed, reliable government commitment to the development of emerging technologies, plus increased investment from big industrial companies. Industry collaboration would help incubate new products and build integrated supply chains to compete with Asian companies. Funding from patient investors, such as Breakthrough Energy Ventures, can augment government support.

Without additional support, the U.S. will be relegated to second-tier status in an enormous and strategic industry. We can choose to bolster our economy by investing in energy innovation and tomorrow's technology, or we can watch other countries build entire new, clean tech businesses and reap huge economic rewards. It's not too late to catch up, but it will be if we don't act soon.

Better Batteries Are Just the Beginning



DR. HENRY "RICK" COSTANTINO

CHIEF TECHNOLOGY OFFICER,
GROUP14 TECHNOLOGIES

Early in my career I worked in the pharmaceutical industry, developing advanced drug delivery systems for complex therapeutics such as peptides and proteins. For example, I advanced a technology to reversibly open the tight junctions of nasal mucosal cells, allowing for the safe and rapid permeation of large-molecular-weight drugs across those surfaces. This was a significant breakthrough, which helped our partners in the biopharmaceutical industry to develop more convenient and effective dosage forms for the drug in their development pipeline.

You might ask: what does improving drug delivery have to do with building better energy storage systems? Plenty, it turns out.

In the pharmaceutical world, you need devices that reliably deliver precise drug dosages at the desired time to the correct site of action. Moreover, the drug formulation needs to remain stable over a prescribed time frame – a two-year shelf life, for example. The therapeutic benefit depends on proper formulation, storage and delivery. When you compare drug delivery with energy delivery, the challenge is conceptually very similar. We need to provide electrical energy in the correct form and in an extremely stable and reproducible way to power the next generation of vehicles and consumer electronics.

Our main goal today is to increase the energy density – or the power stored – in battery materials, so that our partners can produce reliable, longer-lasting batteries that expand the range of electric cars or ameliorate the time and frequency for charging our personal electronic devices, especially cell phones. Just as drug makers need support from researchers to make their product more effective, battery producers need

improvements in battery materials and components to make better batteries. Fortunately, energy researchers can operate much more nimbly than drug developers, who build products that affect people's health, and are therefore subject to rigorous protocols and multi-year processes mandated by the federal government. By contrast, we in the energy field conduct our tests on mechanical devices, not human subjects. I can test a new concept for a battery material in the lab in mere days to weeks. If I can make enough of that material quickly, I might have a customer testing it on a related device in a matter of weeks to months. Compared to pharmaceuticals, energy storage technology can be developed, tested, and commercialized at a remarkably rapid pace.

The therapeutic benefit depends on proper formulation, storage and delivery. When you compare drug delivery with energy delivery, the challenge is conceptually very similar. We need to provide electrical energy in the correct form and in an extremely stable and reproducible way to power the next generation of vehicles and consumer electronics.

That also means that battery improvements can be made relatively inexpensively, especially if those improvements comprise a platform technology compatible with existing energy storage systems. This situation reminds me again of my experience developing a nasal drug delivery platform, wherein the intent was to provide compatibility with existing and future pharmaceuticals. Likewise for energy storage, those new and improved battery materials meant as a “drop in” for current battery systems will not require existing battery makers to “start from scratch” with a whole new technology. We’re seeing steady incremental gains in energy density today by upgrading materials and components, without requiring a huge investment in a new production infrastructure. Those performance improvements open up new possibilities for battery-driven products and systems, including some that aren’t even on the drawing board today.

And that’s where things could get really interesting. When we develop new materials to deliver higher energy density at a lower cost per energy storage unit, it leads to lighter, smaller, and cheaper lithium ion batteries. That in turn could enable development of new miniature devices, wearable computers and other mobile technology.

Again, we can look to the pharmaceutical industry as an example. New drugs are approved to treat specific health issues. But researchers may also find new indications for that drug long after it’s been developed. Even venerable aspirin, originally used to relieve pain and fevers, continues to find new uses in the 21st century.

At G14Technologies, we’re working on breakthroughs that could drive similar innovation for decades to come. Power storage and distribution systems will play a critical role in the global transition to safe, reliable renewable energy – lowering costs, easing air pollution and reducing fossil fuel consumption. To meet this need, we are developing a rationally-designed, high-performing silicon-carbon composite material to augment conventional graphite in lithium ion anodes. It’s hard to know exactly which applications and which manufacturers will lead the energy storage market into the future. Fortunately, we don’t have to know. We’re working with different battery companies across a variety of applications, all with the same overall goal - to improve energy delivery.

Energy Storage Breakthroughs Are Coming – and They Will Be Game Changers



JUN LIU

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The U.S. power grid delivers more than \$400 billion worth of electricity every year on aging, inefficient equipment that badly needs upgrading. The system is vulnerable to storms and natural disasters, struggles to meet peak demand, and is stifling the growth of clean renewable energy. We can solve many of these problems, and save billions of dollars each year, by improving our ability to store electricity. The good news is we are very close to some major breakthroughs. But to finish the job, we need a final push of research and development, with support from the technology sector, utilities and government policy makers.

The power system is complex, with 707,000 miles of high-voltage transmission lines, 55,800 substations and 6.5 million miles of local distribution lines. This sprawling infrastructure is governed and regulated by multiple independent authorities and agencies, which makes it difficult to agree on modernization strategies – and who should pay for them.

A simpler alternative would be to expand power storage capacity, which would make the whole system more efficient, more reliable and less expensive. It would also reduce the need to build costly new power plants.

Storage can serve many functions, which we can divide into two categories: short-term duration and long-term duration. Short-term needs include stabilizing the flow of power while plants are ramping up or down, and regulating power frequency to customers, which keeps electrical devices working properly. These changes need to happen in seconds or minutes, and can be managed by a fast-discharging lithium-ion battery.

Long-term duration needs include aligning the supply of power with the demand, which tends to peak during the day, especially on hot days, and taper off at night. Storing excess power for release during consumption peaks can reduce power outages, increase reliability and lower costs. Known as “peak shaving”, this process reduces the amount of energy purchased from a utility during peak hours, when the costs are highest. It also creates a market for power produced during low demand periods, which is otherwise wasted or sold at a loss.

Long-term storage also lowers the cost of renewable power sources by eliminating the problem of intermittency. Solar panels don’t produce power at night, and windmills are idle when the wind is calm. Even hydropower, which runs more consistently, sees significant waste. Much of the excess power produced today has to be dumped.

Storing that power, and selling it at prices comparable to coal or gas fired generation, would remove a bottleneck that has delayed the mass-scale introduction of renewables. In a study by PNNL, we found that new renewable power generation needs to be accompanied by storage for 10 percent of that capacity. Cost effective storage at that level could pave the way for renewables to provide 20 to 30 percent of power generation in some regions.

A storage breakthrough will bring many other benefits. Electric cars will charge faster. Neighborhood substations could store and deliver electricity at peak times and during blackouts. It’s even possible that some homes equipped with solar panels could store enough power to operate independently from the grid.

That breakthrough – a viable, affordable storage system that can accelerate renewables, boost efficiency and resiliency, is very close. And the market will be huge. Consider, for example, that even one potential market segment – emergency breakers that provide backup power to homes and businesses – is worth billions and billions of dollars.

Big U.S. industrial companies are very good at supply chain management, manufacturing, and cost reduction, but struggle to foster a culture of innovation.

Most power storage today is handled by lead-acid batteries, which were invented in 1859. This is the battery in most cars and it's the cheapest battery available today. But lead-acid batteries have two problems. One is environmental. Lead is highly toxic, and thousands of tons of it are released to the environment from industry, despite widespread battery recycling. Another problem is that a lead-acid battery will die after a couple of winters and need to be replaced. You can't keep recharging them over long periods of time.

Power from lead-acid batteries cost roughly \$150 per kilowatt hour. Our calculations show that for larger scale applications, the cost needs to be around \$100 per kilowatt hour on a battery that also lasts up to ten years. Newer types of batteries can almost do that, including lithium-ion batteries and redox flow batteries. They can last thousands, even tens of thou-

sands of cycles. Lithium-ion batteries still cost more, but that cost is coming down rapidly. Today, it ranges from \$200 to \$400 per kilowatt hour and we are reasonably optimistic that lithium-ion batteries could hit about \$150 or so per kilowatt hour in the next few years. That would be a game changer. Lithium-ion batteries could replace lead-acid at that point.

Better storage could also reduce the hundreds of billions of dollars spent on grid controls and equipment required to manage voltage and frequency of power sold to industrial customers. Modern batteries could meet much of that need for far less money, creating a huge potential new market.

Unfortunately, technology is not the only challenge to modern power storage systems; several non-technical challenges must also be addressed. Everyone knows that implementing new architecture on the grid will bring big benefits, but they also require investment. Deciding who should pay for those investments is a very complicated issue. Should it be the customer, the municipality, or the utility? The regionalization of the U.S. power grid allows for flexibility at the local level, but makes it more difficult to build consensus for nationwide projects. Different places have different needs. Choosing the right path will require research to understand which system upgrades will provide the best value.

But whatever upfront costs are required, they will be dwarfed by the payoff from our investment. We are very close to achieving a cleaner, more reliable, and less expensive power system. We've made great strides in reducing the costs of renewable energy generation. It's time to do the same with our power storage technology.

Time to Pick Up the Pace of Battery Innovation



DANIEL T. SCHWARTZ
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Consistent improvements in energy storage technology are bringing us ever closer to the day when clean, affordable electricity from renewable sources becomes the dominant source of energy in our economy. Incrementally, energy storage is becoming cheaper and better all the time. But we need to pick up the pace of innovation.

Sustaining innovations in battery chemistries, and in manufacturing capabilities, are pushing down lithium-ion battery prices by 14 percent a year, on average. Costs came down 19 percent in 2016 alone. But to reach the tipping point – where performance and economics ensure our vehicle fleet, homes, and businesses are all “battery powered” will require more rapid and disruptive innovation.

The greatest impact will come through improvements in materials and manufacturing. For example, there is a global race to develop new classes of electrode materials that can truly bend the performance-to-price curve for the next generation of Li-ion batteries. Some of these new materials can work with existing electrolyte chemistries and battery components, and are manufactured using similar equipment, so they plug right into the existing supply chain and infrastructure. This is the fastest way for materials innovations to reach the market. Looking farther out, new manufacturing method — producing more complicated three-dimensional architectures, for example — will have compounding impact on the power and energy capabilities of batteries.

Each battery application — whether established portable electronics markets, growing electric vehicle and building energy management markets, or emerging grid-scale energy storage market — brings a different balance of market risk vs. technology risk. Among the newer markets,

vehicle electrification has a clear technology roadmap and price-performance metrics. While electric car sales account for just 1 percent of the overall U.S. market today, carmakers expect strong consumer demand for well-designed, affordable electrics in coming years. And as the price comes down, and range increases, consumers will get a better product for their money; electric vehicles are quieter and have extraordinary acceleration, to name just two enhancements.

Truly enabling two-way flow of electricity between vehicles and the grid will require improved battery informatics – a validated and automated method to know a battery’s current state of health, along with the predictive algorithms that enable us to decide the impact a certain charge or discharge process will have on the battery’s future usable life.

On the other hand, large regulated utilities often exist in a business climate that does not allow them to invest in grid-scale energy storage, even when it would improve the performance of renewable energy sources being demanded their customers. So, today, vehicles market appear to be lower risk than the grid,

where the connections between customer demand, state or district policy, and pricing makes for a confusing and fragmented market. Of course, both the grid and vehicles come with challenging technological requirements (including safety). The high energy and power density needed for transformational electrified vehicle propulsion systems increases their technology risk for delivering truly transformational all-electric vehicles that meet current fossil fuel vehicle performance expectations and price.

While all true, much of what we are discussing represents a set of dichotomies driven by our fossil energy past — vehicles vs. grid, market risk vs. technology risk — not the fully electrified energy future.

Whether we choose to upgrade storage systems for the electrical grid or to power vehicles, or both, our success will depend critically on our ability to fully integrate the two. A major challenge in two-way electricity flow between vehicles and the grid (called V2G) is that every charge-discharge cycle of a Li-ion vehicle battery causes a small amount of degradation that shortens its life — that costs the owner money — but the charge and discharge cycle can make the owner money on a transactive smart grid. How does the vehicle owner decide the real-time market price that makes it worth selling some of the vehicle energy back to the grid?

Truly enabling two-way flow of electricity between vehicles and the grid will require improved battery informatics — a validated and automated method to know a battery's current state of health, along with the predictive algorithms that enable us to decide the impact a certain charge or discharge process will have on the battery's future usable life.

Let's imagine a world that has integrates electric vehicles and a transactive smart grid, where a trusted battery informatics technology works in a fully automated energy market place. If the

fluctuating renewable source, such as a wind or solar farm, has a drop in production, the grid would send out a price signal offering to buy energy. Let's say the offer is for \$0.50 per kilowatt-hour because that is what a back-up diesel generator would cost to operate for this purpose. Every car in the fleet that is plugged in could review the offer and determine its value.

A Chevy Bolt sitting in a cool garage may say "sure, I will take that deal for 10 kW-h, because I'll make \$5.00, but the degradation will cost me only \$1.00 in reduced lifetime, and my owner's Outlook calendar shows she is on vacation, so I'll be able to recharge at low prices before she'll need a full battery." A Nissan Leaf may say "no deal," because it is sitting in the direct sun, so the degradation rate for the hot battery would cost \$6.00 in reduced lifetime.

This would be a great business model for a vertically integrated company with a suite of products including solar generation, electric vehicle and battery manufacturing, as well as home and grid energy management systems — exactly the set of businesses Tesla is committed to building. This kind of micro-transactional energy future would help improve the economics of electric cars, battery makers, intermittent green power production and wholesale distribution. But it will only happen with major innovation and investment in informatics for batteries and the grid.

Current research and innovation into storage technology and Li-ion batteries will sustain incremental performance improvements for the foreseeable future. But to make the rapid gains necessary to truly disrupt our current energy production and distribution system, we'll need to make targeted investments in materials, technology and information systems that lead to compelling changes in the economics of electric and renewable energy.

Q&A with John Chen



JOHN CHEN,
MANAGING GENERAL PARTNER,
PHOENIX VENTURE PARTNERS

How will the U.S. lead in energy storage innovation?

I see the U.S. as the leader for energy storage research and innovation for at least the next decade, from anode and cathode chemistries to novel separators, electrolytes and cell and pack design and management. But manufacturing of energy storage solutions has left the U.S. and is firmly in Asia, increasingly China. As a result, the U.S. will continue to play a pivotal role in shaping how the industry evolves and, therefore, downstream markets like automotive, consumer electronics, and Internet of Things. The U.S. is generating key intellectual property and has created a vibrant startup ecosystem which will contribute to the economy. However, I don't see the U.S. as a major leader in manufacturing of energy storage – with isolated exceptions, like Tesla.

What would be the downside of the U.S. not being a leader in the global energy storage market?

The energy storage market is going to be experiencing rapid growth due to automotive and grid storage and if the U.S. does not maintain a leadership position in at least the innovation front end, the country will completely miss out on a major growth driver.

What is Tesla doing right and what would it take to replicate it?

Tesla has been successful in changing market perception of EVs as uncool or sacrificing performance and stimulated both the demand side and supply side for EVs. Tesla has done a phenomenal job on design, engineering, creating a viable charging infrastructure to support their cars, and innovating around the battery pack so that performance and lifetime are

maximized and meet customer expectations. The decision to invest in the GigaFactory was also a very smart move to bring down costs of the major component of the EV. But I would not say that this strategy is earth shatteringly innovative. It's basic supply chain management and achieving manufacturing economies of scale.

What would grid defection enable, if it were to increase?

For the foreseeable future grid defection will remain a niche opportunity. If grid defection does occur, certain companies and technologies which serve this market will obviously benefit. But grid defection is just one of many drivers impacting the energy storage market.

How will the next generation of electrode materials for Li ion batteries be deployed?

The answer to this question depends on how disruptive and new the next generation of electrode materials is, whether it be cathodes or anodes. If the new electrode material represents an incremental improvement, which is compatible with existing manufacturing processes and works in concert with the balance of the system, (i.e. anodes, separators, electrolytes etc., such as LiCoO₂ -> NMC), then I can imagine the path of least resistance would be as a drop-in replacement. However, if the next generation represents a major change in the overall battery chemistry such as Li Sulfur, new manufacturing processes and likely new separators, electrolytes etc. will have to be developed in parallel, increasing the barrier to adoption.

The energy storage market is going to be experiencing rapid growth due to automotive and grid storage and if the U.S. does not maintain a leadership position in at least the innovation front end, the country will completely miss out on a major growth driver.

Who will be the first market adopters of new technologies: grid storage, consumer electronics, or vehicle electrification?

This is a hard question. It depends on exactly what the new technology is, e.g. electrodes capable of faster charging vs. higher capacity vs. longer cycle life vs. safety. Grid storage would favor high reliability solutions with a low \$/Whr or \$/W and high capacity. Consumer electronics would favor fast charging, high cycle life and higher energy density. EVs would favor safety, higher voltage, low \$/Whr, good cycle life and high capacity. The challenge is that each of these markets is conservative when it comes to adopting new, unproven materials technologies for energy storage.

Will the energy storage approaches for the developing world leapfrog technology used by the first world, similar to what happened with mobile phones in some cases?

I do not believe the leapfrogging effect will be as pronounced in energy storage as compared to mobile phones. The difference in penetration and drive to adopt renewables and electric vehicles is not so great between developed and developing nations. Both markets started from a grid centric infrastructure which only differs in reliability between the developing and developed world. So there isn't as much of an environment for leapfrogging. That said, the degree to which leapfrogging takes place will vary from country to country. If the U.S. falters on its commitment to sustainable energy, countries like China may in fact leapfrog the U.S. in energy storage.

How will energy storage on the grid evolve relative to vehicle electrification? Are they separate or interconnected markets?

When it comes to energy storage on the grid for vehicle applications, the market and consumers will adopt distributed energy storage solutions at the point of use, which may often also be part of an overall energy storage solution for renewable energy buffering like solar as well. To leverage energy arbitrage, these distributed solutions will most certainly also be interconnected to the grid in one market.

There is a natural synergy between residential solar and EVs or vehicle electrification. Furthermore, I'd say that multiple renewable or more sustainable power generation at the home/point of use ranging from solar, to wind, to CHP, etc. with energy storage solutions which are physically co-located and also interconnected from a market perspective is a natural evolution of what is happening and will constitute one distinct market. As for large-scale commercial renewables, i.e. solar farms, wind farms, etc., it is not practical that energy storage solutions will be connected to or physically co-located with residential energy storage/EVs/residential renewables and this will be a distinct market and observe different rate and pricing structures as well. Of course, both residential and commercial energy storage will feed into the same physical grid but will have to be distinct markets. The sheer differences in magnitude of power and energy flows and daily variation across the two markets will necessitate that they be regulated differently, also. However, I could see the potential integration of commercial scale renewables with commercial transportation, electrification of commercial shipping by rail or trucks, and large utility-scale grid storage solutions.

Conclusion



RICK LUEBBE
CO-FOUNDER AND CEO
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Reflecting upon the rapid advancement of energy storage technology today, I am reminded of the ancient Indian parable of the Blind Men and an Elephant. Each blind man touches just a part of the elephant, and describes this new complex thing from the experience of the one part. Lacking cooperation, none of the blind men can ever reach a true understanding of the elephant's nature.

Energy storage innovation is both a huge economic opportunity, and a critical bottleneck limiting our society's ability to transition to a renewable energy economy. We must and will continue to think, create, inspire, and in the Edisonian tradition, perspire to make energy storage technology better and better.

The lesson to be learned, of course, is that all viewpoints should be considered, and that cooperation is required to understand a complex issue. Certainly, energy storage is a complex problem, and there are numerous industrial and academic efforts, each trying to understand a different aspect. Consider the variety of viewpoints presented in this publication, Technology and Innovation in Energy Storage. Each chapter provides a different and valuable perspective about

the intersection of materials science innovation, start-up activity, manufacturing challenges and opportunities, and how they all impact market dynamics for energy storage and battery development.

Our panel of experts provided significant insight. Some of the highlights for me included:

Daniel T. Schwartz on improvements in materials and manufacturing:

The greatest impact will come through improvements in materials and manufacturing. For example, there is a global race to develop new classes of electrode materials that can truly bend the performance-to-price curve for the next generation of Li-ion batteries. Some of these new materials can work with existing electrolyte chemistries and battery components, and are manufactured using similar equipment, so they plug right into the existing supply chain and infrastructure. This is the fastest way for materials innovations to reach the market. Looking farther out, new manufacturing methods – producing more complicated three-dimensional architectures, for example – will have compounding impact on the power and energy capabilities of batteries.

John Chen suggesting greater interconnectedness in the future:

When it comes to energy storage on the grid for vehicle applications, the market and consumers will adopt distributed energy storage solutions at the point of use, which may often also be part of an overall energy storage solution for renewable energy buffering like solar as well. To leverage energy arbitrage, these distributed solutions will most certainly also be interconnected to the grid in one market.

Jun Liu predicting energy storage breakthroughs will create benefits beyond electric cars:

A storage breakthrough will bring many other benefits. Electric cars will charge faster. Neighborhood substations could store and deliver electricity at peak times and during blackouts. It's even possible that some homes equipped with solar panels could store enough power to operate independently from the grid.

Doug Morris advocating closer connections between material science innovators and manufacturers:

To accelerate commercialization of these new technologies, startup companies need smaller batches of raw materials that are currently expensive and difficult to obtain from suppliers based in Asia. Larger original equipment manufacturers (OEMs) like Apple and Samsung can generally get what they need at scale. But for many others, developing a new cell can be so difficult and so expensive that they end up settling for the next closest thing they can find. That usually means their product won't perform as well as it could. If we were able to produce cells in the United States that could enable product manufacturers to get special sizes and special chemistries more freely, a tremendous boost in access to new and innovative new technologies would occur.

Steve Visco's call for greater innovation at U.S. battery manufacturers:

Much of the problem stems from short-term thinking among business and political leaders. Big U.S. industrial companies are very good at supply chain management, manufacturing, and cost reduction, but they lack a culture of innovation. U.S. battery companies are mostly standalone entities. They do employ PhDs and research teams, but they aren't asked to come up with new ideas. They are asked to help the company meet quarterly earnings targets.

And my colleague, Dr. Rick Costantino, comparing energy storage materials innovation to the pharmaceutical industry:

In the pharmaceutical world, you need devices that reliably deliver precise drug dosages at the desired time to the correct site of action. Moreover, the drug formulation needs to remain stable over a prescribed time frame – a two-year shelf life, for example. The therapeutic benefit

depends on proper formulation, storage and delivery. When you compare drug delivery with energy delivery, the challenge is conceptually very similar. We need to provide electrical energy in the correct form and in an extremely stable and reproducible way to power the next generation of vehicles and consumer electronics.

The contributors to this gallery are all brilliant in their fields, and deeply experienced in the energy storage industry. And each have different angles on the collective technical and innovation activities, challenges and impacts the energy storage industry faces. Like the blind men in the parable, each contributor has direct experience with an element of a huge and complex new thing (the evolution and progress of energy storage) and all describe their part with great detail and accuracy. Yet only when taken together do their interpretations illustrate the challenges we face as we push the edges of energy storage technology.

Energy storage innovation is both a huge economic opportunity, and a critical bottleneck limiting our society's ability to transition to a renewable energy economy. We must and will continue to think, create, inspire, and in the Edisonian tradition, perspire to make energy storage technology better and better. I don't know if our future will be a series of small but continuous innovations like the miracle of compound interest, or if we will experience huge disruptive advancements like the discovery of electricity. I am certain though, that our energy technology will continue to advance because of the incredible effort every day from all of the scientists and engineers committed to this challenge. As Thomas Edison said: "To have a great idea, have a lot of them."

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