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A battery of innovative choices—if we commit to investing

Noah Kittner and Daniel M. Kammen

ABSTRACT
Renewable energy – such as photovoltaics and wind power – is rapidly moving into the mainstream, with global solar capacity set to outproduce nuclear energy capacity for the first time. But a major holdup has been how to store the electricity produced by renewables; consequently, good, cheap, long-lasting battery storage has been the Holy Grail of R&D in this area. But how close are we in reaching this goal? To track progress, the authors have introduced a new, "two-factor" model of analyzing innovations in energy storage that accounts not only for total sales of a particular technology but also for the degree of investment in innovation, measured by looking at the number of new patents issued in energy storage technology.

KEYWORDS
Batteries; energy storage; renewables; R&D; innovation

Imagine a world where we depend on solar and wind power for most of our energy needs. Then imagine nighttime, when our main source of electricity literally falls asleep. Unless our future electricity system represents a giant "super-grid" with millions of tons of wires connecting everywhere from San Francisco to Beijing, we will need some place to put that electricity when the sun doesn't shine and the wind doesn't blow. Enter into the picture battery storage, one of the emerging technology advancements of the 21st century that could revolutionize the way we produce and consume electricity.

Traditionally, battery storage has been hailed as too expensive to make sense for grid utilities and customers. But the economics are quickly changing. With electric cars going mainstream and countries like France, China, and the United Kingdom phasing out gas and diesel vehicles, there has been a surge in demand for lithium-ion batteries – and, consequently, more investment by the marketplace in research and development in this field. At the same time, in places like California, where photovoltaics (PV) now power nearly five million rooftops, grid-scale storage options – both in people's houses and on sites owned by utility operators – are lowering the cost of electricity. Simultaneously, battery storage is a critical technology for electric vehicles (and could conceivably also serve as distributed stationary storage on the power grid).

With all these factors coming together at the same time, the result has been a burst of innovation in battery technology, with storage prices consequently falling faster than PV or wind generation technologies did at similar points in their respective cost trajectories. We modeled where various combinations of solar, wind, and battery storage systems could go and showed how these systems would outcompete fossil fuels on the electric power grid.

But there is a hitch: Public and private investment in research and development will be critical to achieving better energy storage, yet this field is currently underfunded in US federal budget proposals. This could severely impact the United States' ability to find low-cost solutions to clean the American electricity grid and benefit the environment and public health.

Where things stand today

Nowadays, in California, when many households install solar panels on their rooftops, the electric utilities don't have to generate as much power during the middle of the day. They can save energy by turning off some of their conventional generators. But once most people return home from work in the evening and the sun begins to set, California's grid operators face a dilemma – how do you counter the rising demand for electricity when everyone is at home and the sun is generating less electricity for grid use? The setting sun completely changes the operations of the grid within only an hour's time. Natural gas "peaker" plants are often called upon to provide backup and maintain grid reliability to prevent possible outages. But these combustion turbines are often inefficient and dirtier than their combined-cycle gas turbine counterparts.

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Battery storage could replace those peaker plants and respond to changes in sunlight and wind availability within seconds. Lithium-ion batteries, in particular, are maturing because of their presence and availability in consumer electronics, electric vehicles, and on the grid. As Tesla moves to install a "Gigafactory" in Nevada and the largest lithium-ion storage battery in the world in South Australia, the sheer size and scale of the new, innovative combinations of energy storage are changing the investment picture. In fact, the costs of battery storage are dropping so rapidly that California Energy Commission members are currently roiled in debate over whether the NRG power company's Puente natural gas peaker plant should even be built – which speaks volumes about the ability of lithium-ion batteries to provide megawatt-scale levels of flexibility in a grid-scale application.

By way of example, the Tesla Powerwall is advertised as a system that can store electrical energy at around $350 per kilowatt-hour (kWh). This is still out of reach for many customers, but the US Energy Department has set a goal for $100 per kWh battery storage by 2020. This is achievable, but investments on the research and development side are still very critical to enable this transition. On the other hand, the pace of innovation in this area has been staggering; consider that lithium-ion batteries in the early 1990s stored energy at $10,000 per kWh in the early 1990s, or a cost that is nearly 29 times that of today. Imagine if the average car today cost one-29th of what it did in the early 1990s.

To document this historic rate of change and create forecasts, we conducted a sensitivity matrix of different levels of future patent activity and deployment while accounting for knowledge depreciation and patent lag times; we found strong correlations between the level of patent activity and the price of future batteries. (At the risk of greatly oversimplifying, more patents in energy storage technology today ultimately means cheaper batteries tomorrow.) We also looked at the role of investment and concluded that an integrated strategy to increase basic and applied research and development in the materials sciences and related disciplines would be a low-cost strategy to enable a low-carbon energy transition. This means that coherent planning and strategy could yield billions of dollars in terms of avoided costs in future climate change, due to the ability of battery storage technologies to enable higher penetrations of intermittent solar and wind on the grid that are increasingly necessary for climate change mitigation (Creutzig, et al. 2017).

Ordinarily, public research investment and private venture capital money undergoes tough scrutiny before money can be spent on research. The results from the hard work of prior years are not immediately visible. Statistical analysis, however, demonstrates that long-term research and development spending played a critical factor to achieve these cost reductions. In other words, modest investments in research and development could go a long way to unlock the low-cost and low-carbon transformative electricity available from PV, wind, and battery storage.

The two-factor model depicted in Figure 1 highlights the correlated value of both deployment in terms of economies-of-scale and innovation (represented by patent activity) to reduce the cost of battery storage.[1]

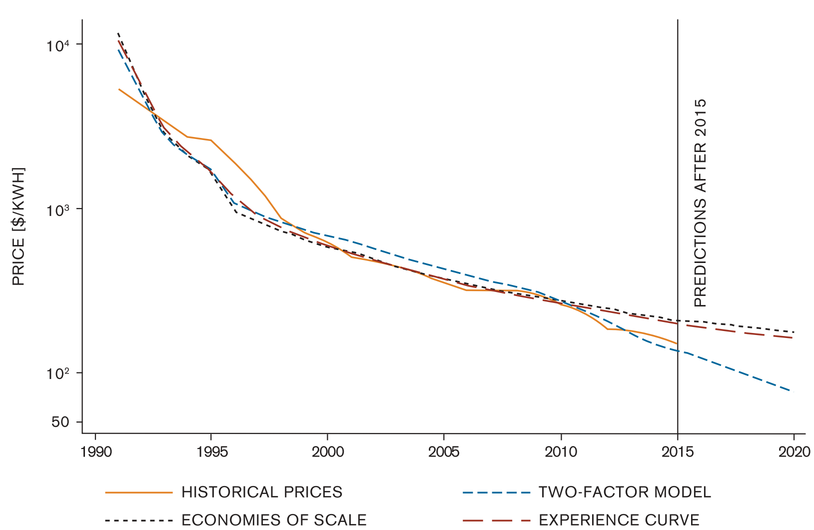

Figure 1. The falling cost of lithium-ion battery storage by comparing historical prices with one-factor models that incorporate economies of scale and experience, and two-factor models that investigate the value of innovation and deployment. Image courtesy of Kittner, Lill, and Kammen (2017).

One example of the power of battery storage lies in the underestimated potential of PV. Installations of solar panels have dramatically outpaced expert predictions over the past decade (Creutzig, et al. 2017). But to fully make use of that electricity in a significant way, we need to invest in research that can reduce the cost of storing that energy in such a way that it allows us to use solar or wind electricity whenever we want.

The future

The potential for cost reductions is astonishing. But the current US administration has committed only a tiny fraction of the budget to research and development – and private venture capital funds have also lagged behind previous years. In fact, the Trump administration has proposed budget cuts up to 57 percent for energy research and development (Anadon, Gallagher, and Holdren 2017). The Trump administration's theory is that the private sector can pick up the slack for public investment; however, a growing body of economic research suggests that this is not the case (Anadon et al. 2016). More likely, the United States will cede leadership on the opportunity to gain significant market shares and likewise surrender pioneering development in electric and autonomous vehicle technology. Countries like Japan and Germany made significant headway on solar panels. For the United States to lose out on playing a leadership role through a lack of investment will signal a lack of interest by the nation in cleaning up its power grid, even while China has taken significant steps – including its future ban of internal combustion engine vehicles and its commitments to drastically reduce greenhouse gas emissions over the next decade.

Tesla and lithium-ion batteries are not the only examples of storage advances. Berlin plans to install a 120 megawatt flow battery underground to support wind and solar efforts. (Flow batteries are essentially two liquid tanks separated by a membrane that could provide longer duration storage than conventional lead-acid or lithium-ion batteries. The amount of storage capacity depends on the volume of the tanks; therefore flow batteries are less constrained than vehicle batteries.) California has enacted the first "energy storage mandate" policy on the grid, requiring utilities to procure 1.325 gigawatts of storage by 2020. And diversity of options for storage exists beyond lithium-ion batteries; in the future, we may see distributed small-scale flywheels on systems to inject short bursts of power, combined with vanadium-redox flow batteries that provide multi-hour storage with the potential to power office buildings during peak demand periods.

There is an important evolution happening in battery storage at this moment. The combination of innovations in battery storage for electric vehicle use, powering our vehicles with electricity instead of fossil fuels, and grid-scale storage could enable low-cost solar and wind to become ubiquitous across the world, regardless of geography. This happens due to the portability of different scaled storage devices and the new opportunity that battery storage provides. We can control battery storage through computer programs and make solar and wind electricity dispatchable – meaning that one could turn solar and wind power on and off, just like a light switch.

If we can use solar and wind electricity without having to think about whether it's nighttime or whether the wind is blowing outside, then we can completely phase out fossil fuels from our economy. This presents a low-carbon electricity option that is simply better than coal or natural gas. With batteries that are programmable, energy storage can respond within seconds. And with the potential for a fleet of electric vehicles to participate in the electricity market using vehicle-to-grid technologies, vehicles may serve dual purposes. Batteries enable personal transportation and grid stability that presents intermittent solar, wind, and hydroelectricity as equally or more reliable than conventional electric power systems. This is an area where innovations and investment in distributed mini-grids could shift the landscape toward decentralized energy systems that interact and participate within the existing centralized network. This is already happening from pilot-scale micro-grids in Southeast Asia and sub-Saharan Africa to integrated large-scale battery storage in the United Kingdom and Australia (Alstone, Gershenson, and Kammen 2015; Kittner, Gheewala, and Kammen 2016).

No one said this will be easy. It will take concerted R&D efforts similar to the US SunShot program for PV – a program which, incidentally, actually exceeded its goals for producing electricity from sunlight for residences. (Instead of producing it at times of peak consumption at the target of 15 cents per kWh by 2020, electricity is now produced in 2017 at 6 cents per kWh. In others, at less than half the price, and three years earlier than hoped [Energy.gov 2017].) Why couldn't the same research effort be made for energy storage? As research from our group and others suggests (Schmidt, et al. 2017), storage is a diverse and rapidly evolving field where investments are generating financially viable options; we just have to embrace innovation and investment in deployment and transformational low-carbon technology. The under-investment in innovation is hardly new. Indeed, we have researched and written about it for almost two decades (Margolis and Kammen 1999; Nemet and Kammen 2007; Kammen and Nemet 2007).

What is different today, however, is how close we are to achieving true, "baseload renewables" for both distributed on- and off-grid applications. This progression from expensive renewables and storage to inexpensive renewables and rapidly declining storage prices is transformative; it opens worldwide markets for companies in the United States and elsewhere that choose to focus on reliable, distributed energy.

The pathetic irony of current conversations about cutting US Energy Department and Environmental Protection Agency budgets is that just as the clean energy sector is poised to alter the global energy landscape, all the work that the US research and development community has done to lead this revolution will be lost.

Note

1. The forecasts are based on ordinary least-squares regressions and we used Bayesian Information Criterion to compare one-, two-, and multi-factor models. Though raw material prices have accounted for a statistically significant portion of the price reduction observed through the wind power industry, the diverse material composition of battery storage hedges this relationship. For instance, our analysis found very weak correlations between the price of lithium and the price of cobalt on the price reduction in battery storage, in accordance with other researchers (Ciez and Whitacre 2016), which suggests that perhaps other factors are at play. A possible factor for future research is the impact of government subsidies on battery manufacturers and the resulting price declines, as electric vehicle technologies mature.

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