Small-Scale Electricity Storage: Future or Folly?

Thorvin Anderson, CFA
Content Director, "Foundations for Commodities" Professional Education Program, J.P. Morgan Center for Commodities (JPMCC), University of Colorado Denver Business School; and Member of the JPMCC's Research Council

This digest article is based on Thorvin Anderson's presentation to the JPMCC's Research Council on September 30, 2016.

Thorvin Anderson, CFA, Content Director, "Foundations for Commodities" Professional Education Program, JPMCC, University of Colorado Denver Business School and member of the JPMCC Research Council, presenting at the September 30, 2016 JPMCC Research Council meeting. Mr. Anderson is also an Editorial Advisory Board member of the *Global Commodities Applied Research Digest*.

Introduction

Recent developments in battery technology have given rise to energy storage devices targeting not just wholesale or grid support operations, but residential buyers as well. While several manufacturers compete in this space, it is Tesla, with its Powerwall, that has commanded the majority of media attention. Billed as a complement to residential rooftop solar installations, the Powerwall offers homeowners the allure of some measure of energy independence, reliability, and cost savings, all with not-too-subtle intimations that use of this storage technology is associated with superior environmental stewardship. This paper examines the Powerwall product, and by implication its competitors, in the context of today's electricity markets to consider the validity of these claims and the prospect of retail electricity storage significantly impacting the electric market.

Current State of the Retail Electricity Market

The wave of deregulation that swept through the electricity industry in the late 1990s brought vibrant wholesale markets to much of the U.S. population. In the large states of California and Texas, and from Illinois across to the eastern seaboard and up to New England, Independent System Operators (ISOs) run the electric grids, and coordinate markets that publish unique prices for sub-hourly intervals, theoretically reflective of the marginal cost to the system of producing the electrical energy. These markets represent a significant step forward in transparency and the ability to optimize asset utilization and capital allocation, compared to the monopolistic regimes that existed before and still dominate in the unreformed regions of the country. But despite the progress in wholesale deregulation, the changes stopped short of bringing retail choice to the majority of Americans. Today, only about a dozen states should even be considered as having any meaningful retail competition, and in many of those, access to a competitive retail market is severely limited. In Texas, the state with the most widespread access to retail choice, roughly 85% of the residents are able to choose their own electric providers.[1] Political pressures at the moment seem to favor a renewed push toward deregulation, however, with 72.4% of Nevada voters approving a measure last November that paves the way for eventual retail choice in that state.[2]

Any view of the retail electric market must acknowledge the non-homogeneity of not only the regional generation mix and resulting prices, but also retail policy environments; a lucrative value proposition for retail customers in one state may not be of comparable value, or even available, for their neighbors in another state. Nonetheless, we can make a few general observations that will be important to bear in mind as we consider the value of electricity storage inside a home.

- Almost all residential customers, in both regulated and choice markets, are currently insulated from real-time pricing. This means that they are separated from the price signal that could communicate to them, say, the true market value of deferring consumption to another hour. In markets that remain regulated, electricity tariffs are set through rate cases and sanctioned by the utility commissions of the respective states. They therefore bear little relationship to the wholesale market value of electricity. Even in markets with alleged "time-of-use" pricing, such as the California utilities have been directed to embrace, price differentials are set by fiat, with roughly drawn "peak" and "off-peak" periods, and are not reflective of dynamic market conditions. This separation of the retail customer from the wholesale market is not exclusive to regulated markets - in retail markets that are almost completely vertically deregulated, most customers choose rate plans which lock in their electricity prices at fixed rates for some term, such as 6 months or a year. The customer typically pays that rate on all kilowatt-hours (kWh) consumed, regardless of the timing or amount.

- Tiered pricing exists in both regulated and deregulated markets, but is typically calculated monthly, not by hour, so smoothing consumption across time periods inside a month is of limited value in avoiding higher-priced tiers. Many regulated utilities set their rates based on tiers of monthly consumption. The lowest price applies to the first tier of kWh, after which a higher price is charged on additional kWh. There may be three or more such tiers, each of successively higher price. If this tiered calculation were conducted over a short time period (such as an hour), a user could use various means to smooth consumption to avoid high-priced tiers, but that is not the way tiered pricing is typically implemented.

- Transmission and distribution (T&D) cost recovery charges are very significant, but are not levied in a manner that encourages residential customers to reduce their peak demand. Utilities have invested heavily in transmission and distribution infrastructure, and must not only recover those investments, but earn a return on the capital employed. The manner in which this occurs is generally via a $/kWh charge multiplied by the kWh energy consumption of the customer. While this value may be relatively large (approximately half the total $/kWh cost in many cases), making this cost proportional to energy consumed is at best an approximate allocation. The magnitude of transmission and distribution infrastructure required to serve a particular customer is dictated by that customer's *peak* load, not its *average* load. As an extreme example: a customer that draws 1000 kWh ratably in every hour of a month will pay the same in T&D charges as a hypothetical customer that takes the 1000 kWh in total over a month, but takes that energy all in just one hour of the month! Obviously, the delivery infrastructure required to serve the second customer is much greater than the first. Yet, given the equivalence in their T&D charges under current residential pricing schemes, each customer would pay the same.

These three phenomena serve to create informational inefficiencies in the retail markets, and inhibit customers from acting in a manner that is consistent with optimizing the use of the electricity resource, such as through energy storage via a battery. In deregulated retail markets, this may be a matter of market maturity, that participants need additional time to develop relationships and adapt to technology that allows for the communication of price information and market-responsive decision-making.

Given conducive policy and market rule frameworks, true time-of-use pricing might be offered by more retail providers if demanded by the customers, and retail providers may find ways of recovering T&D charges based on maximum usage instead of average usage. In Texas, for example, retail electric providers already offer plans that charge the customers the Locational Marginal Price (LMP) of the wholesale market, by 15-minute interval, plus a service charge.[3]

Given the advanced state of the Texas market, we will use as an example case, data from a particular residential meter in southeast Texas associated with a family of four and a relatively large dwelling. This meter was matched with a hypothetical 8 kW DC rooftop solar installation, which produces a modeled 15.4% capacity factor.[4] As emphasized earlier, retail market features are very location-specific, so conclusions drawn from this example do not necessarily apply across the United States. However, given Texas' progressive policy stance on retail deregulation, it likely represents an aggressive evaluation of the value proposition of residential storage.

Residential-Scale Storage Devices

The unveiling of Tesla's Powerwall product in April 2015, the company's first foray into residential energy storage, created considerable stir. Previous electricity storage mechanisms had stubbornly remained the domain of either utilities (as in the case of pump storage hydro-electric or compressed air energy storage facilities), or the hobbyist electing to go "off the grid" with a custom-engineered system of lead-acid batteries to complement a small generation source. With the Powerwall, Tesla clearly targets mainstream consumers. The Powerwall consists of lithium ion cells packaged into a clean, attractive housing that can be mounted to a floor or wall, either inside a house or outside.

The second generation Tesla Powerwall, announced in October 2016 and scheduled for delivery starting in early 2017, represents a significant improvement over its predecessor and competing products. The original Powerwall was a 6.4 kWh battery with peak deliverability of 3.3 kW. Tesla claims its successor will store 13.5 kWh of electrical energy, with continuous deliverability of 5 kW, and rated to accommodate surges, such as required to start inductive loads like motors, of up to 7 kW. Unlike its predecessor, the Powerwall 2 contains an onboard inverter, eliminating additional purchase of that equipment. Tesla offers its Powerwall 2 for $5500, and lists installation and supporting hardware starting at $1500, for a minimum installation cost of $7000.

No battery is 100% efficient. In other words, more electrical energy must be sourced to charge it than can be recovered during its duty cycle. In the case of the Powerwall 2, Tesla states round-trip efficiency to be 90% with a depth of discharge of 100%. Thus, a full 13.5 kWh can be discharged from the battery, but this requires 13.5/0.9 = 15kWh of energy to charge.

Prospective buyers must also be aware of another physical feature of batteries: their degradation over time. The storage capacity of batteries declines with duty cycles, and Tesla's updated warranty explicitly excludes "normal degradation of your Powerwall's energy capacity over time."[5] This means that consumers must factor in a decline in future performance by as much as 40% over 10 years, based on minimum performance guarantees in earlier formulations of the Tesla warranty.[6]

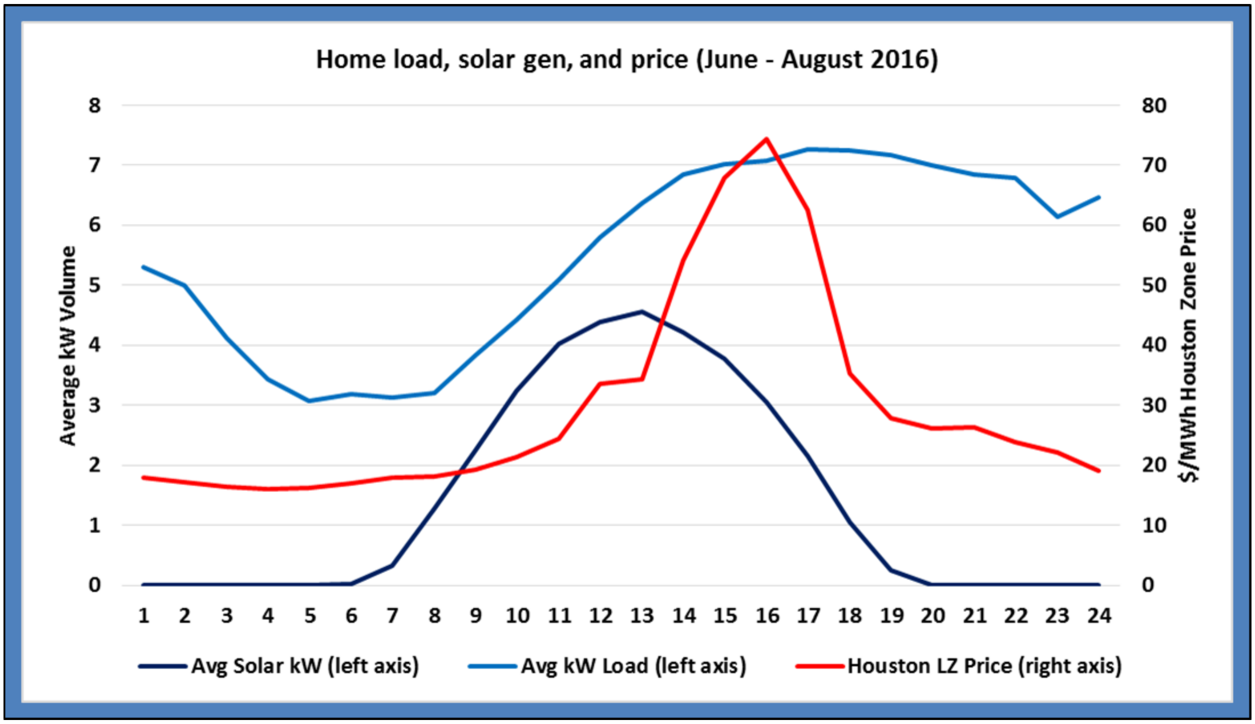
Value Propositions of Small-Scale Storage

Tesla states four "Supported Applications" of the Powerwall 2: solar self-consumption, time-of-use load shifting, backup, and off grid.

The idea of "solar self-consumption" figures prominently in Tesla's Powerwall marketing history. In a reference since removed, the Tesla website originally said the Powerwall "bridges the gap between peak solar and peak demand, allowing you to use your photons when you need them." Indeed, while solar power peaks during the middle of the day, and maximum residential load occurs during daylight hours as well, the respective hours of maximum solar generation and maximum residential demand are, in most cases, not perfectly coincident. This means that, if the solar system of a residence is large enough, its output can exceed the simultaneous consumption of the household. Excess solar generation is typically sent to the grid, and the customer is paid by the utility based on a feed-in tariff.

The diagram below in Figure 1 examines the actual average hourly demand associated with our example meter during the three peak summer months of June – August 2016. This is set against the expected hourly generation from the hypothetical rooftop solar installation. The solar generation peaks at about noon, whereas the electric demand peaks later in the afternoon, around 5:00 PM. We see that, if the solar generation were scaled up large enough, its mismatch with the load would mean excess generation sent to the grid during mid-day hours, and significant deficits during the nighttime hours. Solving this discrepancy is at the core of Tesla's proposed "solar self-consumption."

Figure 1



To examine the economic merits of solar self-consumption, energy market practitioners employ a simple technique evaluating the relative value of two schedules of energy flows via determination of a ratio variously termed the "covariance ratio," or "uplift ratio," among other names. Effectively this covariance ratio consists of the ratio of the weighted average cost to serve divided by the average price. Put mathematically, this may be represented as:

Covariance ratio = E(P * Q) / (E(P) * E(Q)), where

P = Interval price and

Q = Quantity consumed

This ratio captures the covariance of price and quantity, ascribing a higher value to data sets in which high prices correspond with high volumes, and a lower ratio to data sets in which price and volume do not exhibit such strong positive covariance. A load with a high covariance ratio will be more expensive to serve on a $/kWh basis than a load with a low covariance ratio. Correspondingly, an intermittent renewable generation source (such as solar) with a high covariance ratio will be more valuable than one with a low covariance ratio (such as wind generation, which typically offers higher volumes during low-priced nighttime hours).

In our example data, the covariance factors of the load and solar generation, as evaluated against Houston Zone Price with 15-minute granularity, are shown on Table 1.

Table 1

Full Period June - Aug 2016:

	Weighted Avg	Average	"Covariance Ratio"
Home Load	$ 34.13	$ 29.55	1.16
Solar Gen	$ 42.09	$ 29.55	1.42

Covariance Ratios:

	Home Load	Solar Gen
June - Aug	1.16	1.42
June	1.17	1.39
July	1.10	1.32
August	1.18	1.55

We see that the solar product, with a three-month covariance ratio of 1.42, is considerably more valuable than the load, with a covariance ratio of 1.16. In other words, using an energy storage device to shape the solar generation to make it match the shape of the home load would destroy value, not add value. It should be noted that residential loads have widely varying covariance factors, and these may be much higher in conditions that do not require nighttime air conditioning. Nonetheless, the concept still remains – solar generation's delivery of energy purely during the daytime period when prices are relatively high gives it a high relative value compared with almost any load that actually exhibits nighttime demand.

If we are inclined to dismiss the idea of "solar self-consumption" on the basis of the logic above, we might modify the objective by embracing Tesla's second Supported Application: time-of-use load shifting. Instead of forcing solar generation to match on-site consumption profile, we might make use of the market (which few residential customers can outside of places like Texas) to minimize demand during the highest price hours by discharging the battery, and recharge during the lowest price hours. This is effectively the same as an activity that wholesale traders optimizing the battery might consider: simply buying during the low-price hours to charge battery and selling into the market during high-price hours.

Turning once again to our data set of summer 2016 15-minute prices, we see that the average daily spread between the cheapest and the most expensive 15-minute interval was $0.15/kWh, a value intentionally made aggressive by selection of summer months. Setting aside physical charging and discharging constraints, let us suppose that the Powerwall battery could be fully cycled within two 15-minute periods (the cheapest for charging and the most expensive for discharging.) Accounting for the 90% efficiency, but neglecting any degradation effects over time, a single duty cycle per day capturing $0.15/kWh EVERY DAY on the full volume of the battery leads to a simple break-even term of more than 10 years. Including degradation, even with optimistic performance decline assumptions, will make this break-even term even longer.

Tesla's third Supported Application is to use the Powerwall to supply backup electricity in the event of a grid outage. With 5 kW of continuous power generation, the Powerwall has sufficient capacity to power a flat screen TV, a tea kettle, the compressor of a refrigerator/freezer, and several light bulbs. However, assuming average draw equal to just half of that 5 kW, or 2.5 kW, the battery's charge would last only 5.4 hours. Consumers may compare this performance to the alternative offered by a quality portable inverter generator. For example, for $4500 the Honda EU7000iS offers comparable peak and continuous AC output, but the gasoline generator will operate for 6.5 hours at 100% of its 5.5 kW rated load, and 18 hours at ¼ of its rated load.[7] The portable generator has the additional advantage of repeating these run times with each 5 gallon can of gasoline available, which proves an advantage to consumers potentially facing outages of greater duration, such as hurricanes. The Tesla Powerwall therefore seems best positioned to serve as a backup for applications in which short-durations are the most likely/problematic, or in the event that use of a gasoline generator is excessively inconvenient or prohibited. Additionally, it may prove an effective solution to small proprietors in Third World countries, where electric grid mismanagement frequently causes routine outages of short duration.[8] For example, a small convenience store owner may find value in a battery system that keeps refrigeration and lights running during such outages, to prevent spoilage and allow for continuation of business.

Tesla's last suggested Supported Application is for off-grid use, when customers, either by choice or necessity, are not connected to a broader electric grid. Storage eliminates the need for a constant source of generation, such as wind, electricity, or gasoline engine. The Tesla Powerwall, and its competitors, present what may be the only energy storage approach aside from reverting to earlier technologies such as lead-acid batteries, and enduring their drawbacks. Nonetheless, any prospective off-grid customer would be wise to understand that the off-grid cost of energy may be several times what is available on-grid. An analysis by *Forbes* concluded that average cost for solar plus Powerwall energy would likely be on the order of $0.30/kWh, or roughly 2-3 times the rate available from the grid, depending on location.[9]

Conclusion

In short, the naïve interpretations of the Tesla Powerwall's value propositions don't pencil out with supportive economics under present market conditions. However, the technology is intriguing and alluring, leaving us to speculate on what changes might rehabilitate the economic viability of products like this. These changes might include:

- Dramatic change in system price. Declines in the cost of lithium-ion batteries gave rise to the use of lithium technologies in stationary energy storage. For example, IHS Markit forecasts declines of more than 50% on the installed cost of large-scale battery systems.[10] Comparable price declines for small systems could significantly swing economics in favor of residential systems.

- Changes in electric market fundamentals, residential tariffs or electric market design.

    - The continued penetration of solar generation in states such as California causes significant system instability and price dislocations between the ending hours of solar generation and the daily peak consumption. If market design allows, solutions could arise whereby owners of distributed storage are allowed to address these problems and profit from their contributions in a way that is not possible now.

    - Utilities may succeed in attaining highly punitive feed-in tariffs that don't offer value to small-scale solar producers through net metering. If excess solar generation is ascribed a value low enough, homeowners could see value in buying battery capacity to recover that undervalued electricity.

    - Utility changes to time-of-use pricing that matches price more accurately to real wholesale conditions will give more residential customers transparency into market conditions, and may allow them to use their combination of load and a battery for arbitrage opportunities.

Endnotes

1 https://www.electricchoice.com/map-deregulated-energy-markets/

2 https://www.ecova.com/blog/2016/11/nevada-electricity-deregulation-ballot-measure-passes-long-road-still-ahead/

3 http://www.voltep.com/

4 http://pvwatts.nrel.gov/pvwatts.php

5 https://www.tesla.com/sites/default/files/pdfs/powerwall/Powerwall_Warranty_USA_2-0.pdf

6 https://www.solarquotes.com.au/blog/new-powerwall-warranty/

7 http://powerequipment.honda.com/generators/models/eu7000is

8 http://www.iiste.org/Journals/index.php/JETP/article/viewFile/20792/21184

9 http://www.forbes.com/sites/christopherhelman/2015/05/01/why-teslas-powerwall-is-just-another-toy-for-rich-green-people/#539c63814879

10 http://press.ihs.com/press-release/technology/price-declines-expected-broaden-energy-storage-market-ihs-says

Author Biography

THORVIN ANDERSON, CFA
Content Director, "Foundations for Commodities" Professional Education Program, JPMCC, University of Colorado Denver Business School

In addition to his position at the JPMCC, Thorvin Anderson is also the president of Razor Commodity Advisors, LLC. He has spent seventeen years in the commodities space, both in industry and on Wall Street, with firms ranging from Koch Industries and Calpine Corporation to Bear Stearns and J.P. Morgan. Thorvin specializes in fundamental commodity market analysis and the valuation of complex structured transactions, such as wind offtake agreements, power plant tolls, load serving obligations, hydro-electric entitlements, natural gas storage, and gas asset management agreements (AMAs).

Actively involved in commodities education throughout his career, Thorvin has orchestrated and led multiple training programs focused on introducing participants to key concepts in commodities. At J.P. Morgan, Thorvin initiated and managed a rotational program to recruit and develop junior talent in a cross-disciplinary manner. He graduated from Stanford University with a B.A. in Economics in 1997, and received his CFA Charter in 2006.

Thorvin is also a member of the JPMCC's Advisory Council and its Research Council. In addition, he serves as a member of the *Global Commodities Applied Research Digest's* Editorial Advisory Board.