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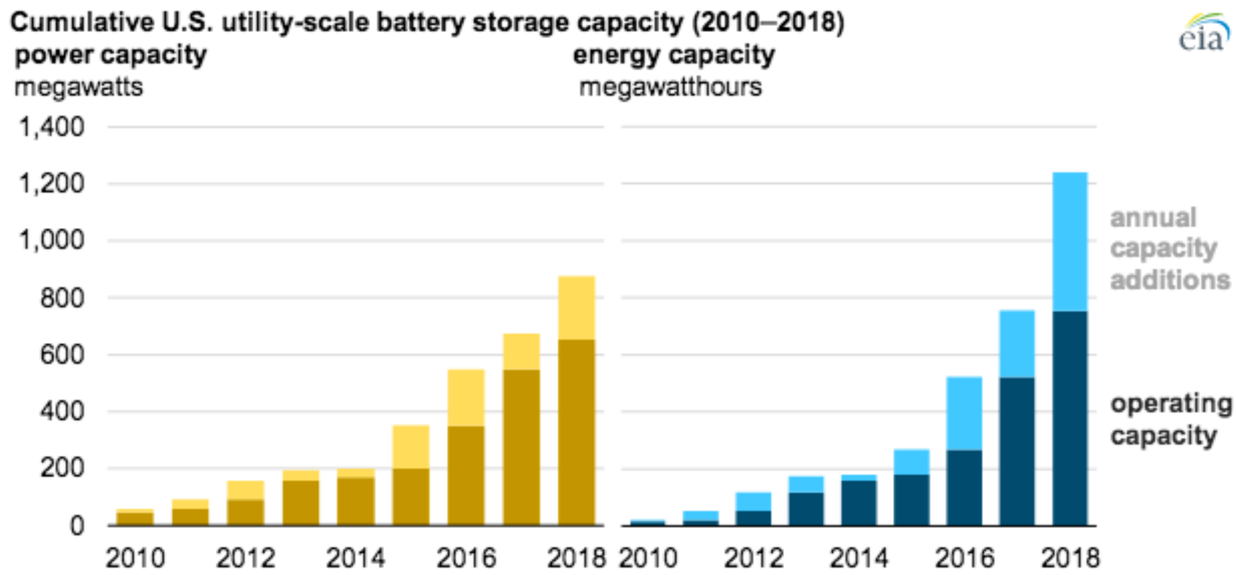
Considerations for risk management and valuation of electricity storage assets

Much has been written over the years about volatility in deregulated power markets and the means with which various enterprises can hedge their exposure. The body of research is growing along with the development of new sources of power generation, especially renewables. But there are other sources of power coming into the market that face a different sort of price volatility and for which standard hedging products are of limited use. These include storage assets – mostly batteries – that have become cost competitive and will be deployed increasingly where they are needed most.

Risk management and valuation of storage assets is very different from that of generation assets. The distinction is akin to those in other energy markets such as oil and gas where storage tanks and caverns have long been utilized to help manage price volatility and can serve as a model for power markets. In this paper, we discuss various aspects of financial risk in those other energy markets and focus on what can be applied to investments in electricity storage.

Batteries have potential to lower power price volatility, if not price itself

Battery storage in power is a relatively new concept, especially at utility scale. Other storage generation capacity – particularly hydroelectric pumped storage – has been in use for far longer and in significant size, but deployment of battery storage is only starting to get underway as production costs decline and integration with the grid improves. At roughly 1,000 MW in total, utility-scale battery storage accounts for only about 0.1% of total U.S. power production capacity. This is likely to change in the years ahead as investment continues to ramp up. There are several projects underway that will double capacity in the next year or so and could continue to do so for the next several years. Still, such assets in total are likely to remain a rounding error when considered relative to existing generating assets.



Regardless of their relative size, the impact of storage capacity on power prices is different from that of generating assets. Power generation *creates* supply, which has the effect of depressing prices in the absence of a corresponding increase in load. The general decline in power prices over the past several years reflects the addition of new capacity in the face of flat or declining demand (notwithstanding reduced capacity from older plants, mostly nuclear and coal generators). A relatively steady decline in the primary fuel for thermal plants – natural gas – has contributed as well.

Storage capacity won't add to the supply of power in the traditional sense. Rather, it simply reallocates power that is produced at one time and allows it to be consumed at another. It is thus a source of *demand* for power in some time periods – typically those characterized by low demand and low prices – and a source of *supply* at others – typically high demand and high prices. Taking advantage of such market opportunities creates value for the owners or renters of storage assets.

Power prices have historically been much more volatile than other energy products such as oil and gas precisely because of the market's *lack* of storage capacity to help balance supply and demand when one side significantly exceeds the other. Power markets also reflect a higher degree of basis risk than other energy markets given limitations on transmission capacity. The main trunk lines carrying power between regions of the U.S. have changed little by comparison with oil and gas pipeline capacity over the past several decades.

The introduction of storage capacity can help alleviate the shortcomings of transportation capacity by providing a source of supply where and when it is needed most. While intuitively this might not seem likely to depress prices over the long term, it does have the potential to smooth out the spikes that occur when capacity is stretched. Thus, the main impact on prices from storage assets should be to lower price *volatility*, which should benefit producers and consumers that value more stability in their revenues and costs. And, to the extent price spikes tend to be most severe during peak demand periods, lower volatility of peak prices will almost surely translate to lower prices overall.

But how does the storage owner get paid for reducing price volatility that others in the market face? How does one value storage assets and, importantly, how do storage owners manage their own exposure to prices? While they may not have long-term exposure to spot prices, they do have exposure to price volatility. What actions can they take to mitigate it? We address these issues below.

Outright prices vs. spreads

Energy hedging can be viewed in two main dimensions. First is the outright price, which is the dimension faced by the vast majority of participants. All producers face risk from declining prices while consumers face risk from rising prices. Each side hedges their exposure by taking opposite positions on forward prices of the commodity. They can do this via fixed-price physical transactions, or via financial hedges; either way the result is similar because the hedge reduces their net exposure.

The second dimension is relative value, or spreads between two or more prices. Companies are exposed to spreads of three main types: basis (location) differences; quality differences such as exist between two similar products; and timing differences between prices of the same commodity at two or more periods of time in the future.

Not all companies are exposed to spread risks, but most of those involved in supply and distribution are exposed to at least one of them. For as long as commodity markets have existed, producers have utilized storage to alleviate their main spread risk: timing differences. Agricultural producers have long been able to defer sale of their product by putting it into storage in anticipation – or indeed by locking in – a higher price in the future. Most energy producers have been able to do the same, except in cases where storing the commodity is especially difficult and, hence, expensive.

In oil and gas markets, where storage capacity has been built and managed actively for many decades, there is a vast industry built around using futures to optimize the value of storage assets. The locations chosen for the most liquid futures contracts tend to be those that are more closely associated with storage and transportation alternatives than with actual production or consumption.

Electric power markets, operating historically on a model of load balancing without storage, have developed differently from the other energy markets. The ever-present need for finely-balanced supply and demand creates incentives for excess production capacity but, without inventories to call upon during demand spikes, there is always the potential for significant price volatility if capacity is fully utilized. However, going forward, storage assets will play an increasingly important role in physical power supply. Utility-scale batteries have achieved significant cost reductions in recent years and the technology needed to incorporate them into grid reliability systems has improved as well.

Management of electricity storage assets, including trading and risk management, should increasingly mirror those of the more developed storage systems in oil and gas markets. For this reason, we discuss some relevant aspects of those markets next.

Whose assets? Whose exposure?

In oil and gas markets, large-scale storage facilities aren't typically built or owned by production companies. Rather, they are logistical assets, like pipelines, that are typically owned by others specializing in that field – historically mostly master limited partnerships (MLPs). Producers specialize in development and extraction and their shareholders prefer that they market their products at posted or index prices, letting others handle the decisions around moving the product to end-use markets or storing them for later use.

We'll discuss the likely ownership of electricity storage assets a bit further on and postulate about where the impact of lower price volatility will be most clearly manifest. Unlike in oil and gas, there is already a greater propensity for storage assets to be owned by electricity producers (generators) and this is likely to continue in the future. Nevertheless, and especially for those facilities that will be owned by independent operators, we address some of the financial risks specific to these assets and practices that have been utilized to mitigate them.

For any new transportation or storage facility to be built, there needs to be a customer willing to pay a fee, or rent, for the capacity for a defined period of time. Even if the owner intends to utilize all of the capacity for its own uses, its shareholders still need to value the asset based on its potential utility to others that understand the costs and benefits of operating a storage asset. Any such customer is only incentivized to pay the rent when there is an opportunity to buy energy when prices are low and sell when prices are higher.

In oil and gas, where pricing is almost exclusively done on daily or monthly averages, the most common opportunities to buy, store, and sell forward are those in which the term structure of prices is contango (i.e. future prices above spot prices). Because storage cycles in these markets tend to be measured in weeks or months – as opposed to hours or days – any prospective customer of such a facility will need the price term structure of the commodity to be steeper than the monthly rent in order to utilize the capacity and earn a return on their investment after capital costs.

The oil and gas markets don't always allow such investment and today's relatively flat shape does not encourage investment in new capacity. Nevertheless, there is always *potential* for term structure to steepen at any point in time. At such a time, demand for any such a facility will rise and the storage owner will be able to charge higher rents. Therefore, decisions on whether to build new capacity are more about potential opportunities in the future than they are about whether such opportunity exists in today's market. This means that the storage owner faces uncertainty as to whether such opportunities will ever manifest themselves. Likewise, the owner's customer who leases the capacity has a similar risk if they take on a long-term commitment.

The role of volatility

Recall the distinction above about the two main dimensions of energy risk management: outright prices vs. relative value. For producers and consumers, the outright price is their main exposure. For storage owners and their customers, it is relatively meaningless. Their exposure is in the timing spreads between prices at two or more periods in the future (i.e. term structure of prices).

If there were no volatility of price term structure, then storage owners would have nothing to hedge: either their monthly rents are competitive with the shape of the forward curve or they are not. If they are competitive, then their business is simple: just keep building capacity, buy enough of the commodity to fill the facility (or find renters willing to do the same), and sell futures to lock in the economics. (Incidentally, the same could be said for the outright price exposure faced by producers and consumers: if there is no price volatility then their operation is either successful or unsuccessful at the static price and the only variable is whether to expand operations or close up shop.)

Of course, there is plenty of volatility in prices, both outright and in their term structure. And so there are choices that can be made around operations based on the management of that exposure. Yet even those with the most exposure to energy prices may not consider volatility in their hedging deliberations. If anything, they tend to want to own it, not only in their operating business but also in their hedges even if it makes those hedges more expensive.

Plenty of asset owners, including many oil and gas producers, hedge by simply selling forward swaps. The result of such a sale is a linear offset to the physical commodity ownership. Assuming the volume of the hedge is less than or equal to the volume of expected production (or inventory), then the hedge is only partially effective in the degree to which its performance offsets the physical exposure to the company. Selling (or buying) a swap does not consider the dimension of volatility.

Other asset owners seek to maintain more flexibility from their hedging position and either buy or sell options – or both. These asset owners incur swap exposure, but also volatility exposure. If, for example, a producer chooses to buy options – e.g. a put option – they would most likely then maintain exposure to spot prices for all of their production but also have protection against a price decline of a certain magnitude. Of course, they would have to pay a premium for that enhanced flexibility.

Relatively few energy producers and consumers are comfortable with hedges that take advantage of high volatility because doing so requires that they sell options that their assets provide, most likely capping their upside in exchange for a fixed cash payment. Equity investors tend not to understand such hedging programs well and do not reward management for doing so.

In practice, commodity owners span the range of practices of selling swaps, buying put options and selling call options. In many cases, they combine put purchases and call selling in order obtain pricing flexibility while minimizing premium cost.

Storage owners' greater exposure to volatility

One might think of storage ownership as akin to any other asset ownership. As such, hedging is simply a process of selling forward, utilizing structures described above. But storage operators have a different exposure profile than producers and consumers. In effect, they are more exposed to volatility on an outright basis than they are to prices because higher volatility leads to changes in term structure. Indeed, it is the volatility of the term structure that they are exposed to and most such asset owners understand that hedging involves selling volatility, not price.

Storage owners in oil and gas markets thus tend to manage their exposure by selling options on the spreads to which they are exposed: inter-month futures spreads. They are monetizing their asset's inherent optionality; receiving cash upfront to supplement their operational economics which has historically been important to MLPs as it helps guarantee their ability to make regular distributions. If they sell calls on these spreads (i.e. selling an option that a nearby contract will appreciate relative to a deferred contract), then their hedges would lose money at precisely the time that their physical asset is losing value – an ineffective hedge. But if they sell puts on the spreads, then their hedge will lose money when their asset is gaining value, effectively limiting their upside – an effective hedge.

This isn't the only way that storage owners can hedge their exposure to changes in term structure. They also can choose to enter into a greater (or lesser) share of long-term leases at any time in the useful life of their asset. In practice, this might mean taking on a greater share of long-term leases when the forward curve is most severely contango and lease rates are highest. The risk to their operation at such a time is that the curve flattens; lease rates decline and they are forced to accept lower rents. Having a greater share of long-term leases limits the downside but also limits the upside that would occur if the curve shape were to become even more steep.

Their customers, the lessees of storage, have the opposite exposure and may seek to enter into long-term leases when curves are flat and spot lease rates are relatively low. It should be noted that trading companies that enter into long-term leases rarely commit beyond a few years. If they did, they would have to consider building their own assets, an activity that few consider to be a core competency. Since most storage assets are expected to provide decades of service their owners face significant long-term merchant risk.

Power storage's unique characteristic – high frequency

As with storage owners in oil and gas markets, owners of new utility-scale storage assets in the power market have exposure to the term structure of prices (as opposed to outright prices). There is nevertheless a key distinction between the exposure of oil and gas storage assets versus power storage assets. The former is focused on timing spreads that are generally at least a month apart because that is the frequency of standard pricing contracts. Power storage assets, by contrast, can take advantage of far more frequent pricing differences, including those based on hours and minutes of a given day.

This is not to say that oil and gas storage is limited to monthly injections and withdrawals; we know that inventories rise and fall every day. But the ability for those involved to hedge their commodity price during such operations is based mostly on monthly prices. There are some exceptions to this, including weekly and daily contracts for differences (to the monthly indices), but even in those cases the deferred leg of any storage hedge tends to be executed against a monthly index price.

With the power market's higher frequency of price discovery (down to 5-minute intervals), there is a completely unique opportunity for battery storage: the ability to cycle in and out and hedge the pricing using intra-day market pricing. Given the relatively short holding periods most battery owners consider for accumulating and discharging power it is safe to say that the higher-frequency market opportunities – hourly – are the main attraction of battery development.

The simplest manifestation of this opportunity is in the daily difference between peak and off-peak prices. Depending on the season and geographic region, such differences can be anywhere from slight to severe. But even when severe, such differences have a somewhat predictable component (reflected in futures prices) and a less-predictable component that is most clearly reflected in day-ahead and real-time markets where weather and other short-term demand inputs are most relevant. Owning storage assets enables the owner (or lessee) to take advantage of both the predictable and less-predictable components of intraday volatility.

Coupled with generation, or standalone?

Storage assets are developed in one of two general ways: coupled with generation assets or as standalone units. The financial risks around each type of installation are very different and worth analyzing separately. Those that are coupled with generation assets – especially renewables – are the easier to conceptualize because the storage assets have the potential to lower the intermittency of the generation assets. This is akin to storage assets owned by producers of any other commodity that give the producer the ability to sell at market prices or store and sell in the future.

Intermittency of renewable generation is a key component of their financial risk. In addition to ordinary merchant price fluctuations, and associated basis risk, the generation output of the asset determines whether or not it meets or exceeds prior financial performance expectations. Intermittency is the chief differentiator in the modeling of renewables' performance relative to thermal-generation asset performance. Having battery storage, especially of sufficient size to fully offset the intermittency of the generation asset, effectively puts renewables on a similar playing field with thermal generation assets. Take away the intermittency, and each will contribute power to the market as ratably as conditions warrant. This is why many of the storage assets being built today are coupled with generation assets.

On a broader scale, batteries have the potential to make a significant difference in the intra-day imbalances of supply and demand that are increasingly evident in places like California where solar PV capacity has grown significantly. That capacity has led to significant surpluses of generation in midday even as reserve margins tighten during peak demand periods earlier and – especially – later in the day.

Cost declines in battery storage systems have made them more competitive just in the past couple of years and their financing, development, and deployment is growing commensurately. These cost declines have also led developers to pursue battery storage projects on a standalone basis. Understanding the economics of such assets is very different from those that are coupled with generation and can perhaps best be thought of like their analogs in oil and gas storage. The market will pay rent for the utilization of storage. The question is how much will it pay?

What is the appropriate rent for long-term storage assets?

Unlike oil and gas markets where the shape of monthly futures prices and their associated volatilities dictate the value of storage assets, electricity futures do not easily imply the value of batteries. As discussed in previous sections, the value of batteries on a standalone basis should reflect the volatility of prices not only over the course of months and days, but also hours and minutes. Futures aren't denominated in those increments. Nevertheless, we can apply some of the basic elements of lower-frequency analysis to help us derive a similar framework for higher-frequency asset valuation. And, as we'll see, even such a conceptual framework leaves room for interpretation. This is an evolving science.

At a high level, for any given commodity each forward price has its own individual volatility that can be calculated over some historical period of time. Historical volatility is a simple calculation of the standard deviation of returns over time (typically daily). As for the future, any options that trade on those forward prices will dictate an *implied* volatility based on the premium (as well as other fixed variables such as time to maturity, interest rate, etc.). Of course, the volatilities of various forward prices (e.g. September 2020, December 2020, or June 2021) are similar to each other. Futures prices rise and fall together over any period of time. But they do not rise and fall by the same amount and the degree to which various futures prices for the same commodity (i.e. the forward curve) rise and fall together is a key concept in storage valuation.

If all futures prices rise and fall by the same amount all of the time there would be no need to trade any individual tenors as changes in the spot price would dictate changes in the futures price. Of course, they don't rise and fall by the same amount all of the time and when their movements deviate significantly from each other there is a low degree of correlation. If they move completely independently of each other, there is no correlation.

In practice, forward curves for all energy contracts – including oil, gas, and power – reflect relatively high correlation because the factors driving prices are similar throughout the year, even for the most seasonal products. The most volatile contracts tend to be the spot contracts, and price changes in those contracts are propagated across future contracts at a declining rate so that long-dated futures (years ahead) display comparatively little price change.

Such futures price behavior – with declining realized volatility of long-dated futures contracts – has direct impact on options' implied volatility (typically highest in the front of the curve and declining into the future). With few exceptions, the implied volatilities of two or more contracts in the future tend to be very similar to each other. Exceptions include the most seasonal contract differences; for example March vs. April in natural gas, or June vs. July or August in power.

For oil and gas storage, valuation requires understanding how options markets assess the likelihood that futures prices can move apart from each other and allow an opportunity to store product profitably. From our prior discussion, we know that if correlation breaks down then there is a greater likelihood that storage will be in demand by arbitrageurs seeking to take advantage of wider price differentials.

Understanding options on price differentials – as opposed to the more common options on an individual price – can shed some light on such a likelihood. Differential options, or spread options, are valued based on the difference in implied volatility of two or more relevant futures and the covariance of those futures. But the valuation requires an adjustment to the longer-dated future's implied volatility to make its expiration equivalent to the shorter-dated future's expiration. And because we know there is a steep term structure to option volatility, such an adjustment isn't a straightforward interpolation.

Moreover, covariance itself isn't perfectly observable. Rather, it is subject to interpretation depending mostly on the historical period one chooses for such a calculation. For most energy commodities there are long periods of high covariance punctuated by short periods of low covariance. How one weighs the average likelihood of each introduces subjectivity.

Conceptually, and subject to these caveats, spread option prices rise when implied volatility rises in one contract vs. another, as well as when the market's assumptions about covariance decline and prices are deemed more likely to move independently of each other. If a trader deems such a likelihood to be higher than implied by current market prices, then he or she might buy that spread option to take advantage of the possibility that a physical storage opportunity will arise. The premium for that option has direct bearing on the value of the storage asset and can be monetized by its owner.

In practice, there are many other factors to consider in taking on a storage commitment, including cost of transportation into and out of the storage site, excess capacity of competitive sites, and various aspects of seasonality. As such, an alternative approach is to calculate from historical data the degree to which price differentials deviate from some long-term trend and apply more of an actuarial probability of those deviations occurring in the future. This is akin to estimating the volatility of the spread itself rather than going through the process of estimating individual price volatilities and covariance. Of course, there are limitations to the utility of this approach as well, not least of which is the degree to which the market fundamentals of the future will resemble those of the past.

Implications for shorter-term storage assets, including batteries

Valuation of longer-term storage assets has direct implication for shorter-term assets such as batteries, though the relevant market data may be quite different. Electricity futures prices today can be traded for monthly averages of daily intervals: peak, off-peak and in combination (around the clock). Those intervals are several hours in duration, each occurring only once per day. Options on futures also trade against each of these time intervals.

One could utilize a spread-option or actuarial approach to estimate the likelihood that peak prices in any given month or strip of months will deviate from off-peak prices in that same month or strip. The relevant price indexes in this analysis would be futures for the peak and the off-peak periods. For example, the market may assess covariance as high – implying low likelihood that peak and off-peak prices deviate significant from each other in a given month. A trader could then consider entering a position either financially (buying a spread option) or physically (taking on a lease) on the belief that prices will behave more independently, opening up an opportunity for storage injection during one period of the day and dispatch in the other period. Importantly, the option value and the lease rate are driven by the same estimation and the owner of the storage asset can apply such a valuation to available capacity throughout the asset.

In this example, the instrument traded is for the monthly average and therefore the opportunity from owning the option or the storage lease would pertain to every day of the month. But battery storage owners or lessees aren't likely to utilize their asset only on such a ratable, daily basis. They will also seek opportunities in more random price deviations that occur in day-ahead and real-time markets. Those investing in storage assets do so without knowing when those opportunities will arise but believing that they will arise with some regularity, however random their timing may be.

Day-ahead and real-time markets in power can also be utilized by the storage owner or lessee and these markets may be the most relevant to the decisions around charging and dispatching of the asset. However, unlike futures, there are no liquid options markets for day-ahead and real-time markets (though future development of battery storage assets might well prompt market participants to develop such short-term option markets as they could facilitate more transparent value for the assets in the same way that monthly-average options have done for longer-term storage assets in oil and gas).

Another consideration specific to power: Capacity and ancillary services

We have proposed the importance of option markets to valuation of storage assets. But it should be noted that power storage systems also have value beyond the ability to capture market price volatility. Various power markets will also compensate providers for a *commitment* to dispatch on demand via capacity payments and other ancillary services. This income can account for a significant portion of the returns of power asset owners.

Without storage devices, electricity markets have depended on the readiness of excess capacity to be called upon to dispatch on very short term. Now, with batteries increasingly available to serve that function, there is the potential to earn additional revenue from grid operators.

Ancillary revenue complicates the task of valuing storage assets, but the impact on asset valuation could be limited. First, those capacity payments are relatively static, especially over short periods of time, and unaffected by the day-to-day volatility that is likely to drive the energy component of revenue. If a storage owner elects to participate in the capacity market – and commit to dispatching when requested – then their income will be supplemented by a relatively constant factor in addition to its market-based charging and dispatching operations. Ancillary income may be greater than market-based (energy) income, but its variability is likely to be considerably less.

If the asset owner or lessee elects to participate in capacity auctions, the commitment to dispatch upon request might well limit the inherent optionality of the asset. But assuming the call for dispatch would take place during high-demand periods then there is a reasonably high likelihood that it would be seeking to do so anyway. It is possible that it might otherwise choose not to dispatch, but during a high-demand period it is unlikely to want to charge the battery opportunistically. In other words, the capacity commitments should be positively correlated with its market-based activity and the two revenue streams can be thought of as broadly additive.

Second, storage owners and their customers can always choose to maintain the full flexibility of their options and avoid the commitments that come with standing ready to dispatch at market prices. There isn't a clear preference yet among storage owners as to their participation in capacity markets. Of course, as in generation, there are significant regional differences the materiality of capacity payments. Those that chose not to participate (e.g. in ERCOT) would only be subject to the market-based valuation approach discussed above.

Third, in any event, capacity payments will be subject to downward pressure as battery storage capacity grows over the long term. Greater supply of storage capacity will, in time, solve a portion of the system's age-old challenge of balancing supply and demand – just as it has done in other energy markets for many decades. Even with a modest amount of utility-scale storage available today there are limits on ancillary income available, and as that income stream is compressed further its relevance to battery owners is likely to decline over time.

In conclusion

Battery storage is only just beginning to affect the daily operations of U.S. power markets. With declining costs and improving technology – plus a number of state mandates in their favor – it seems safe to assume their deployment will grow as long as they can provide a valuable service to the markets in which they operate. The salutary effects on load balancing could provide benefits to all participants, especially where such imbalances are most severe due to the rising share of intermittent generation.

A share of battery assets will be integrated with new, mostly renewable, generation capacity. Owners of those assets may choose to view them as part of a larger, more dependable, renewable energy provider. As such, those owners may not need to apply the concepts discussed here regarding battery storage as a standalone capability although they should still understand them.

For developers and owners of standalone storage, these concepts should be relevant to valuing the asset as a merchant enterprise, perhaps with ancillary income as well. It may be a bit early to consider the sort of leasing and physical trading activity for batteries that currently exists in oil tanks and natural gas caverns. But these markets aren't entirely different from each other, aside from the limited storage capacity that has typified the power market until now.

The frequency of the cycling is certainly different and the mechanisms for buying and selling physical power differ from other energy markets; indeed, they differ across regional power markets. Still, storage assets have commonalities that can be useful for modeling their operations, income, and long-term valuation. We have attempted to list a few of those commonalities here in the hope that they provide some useful concepts for developers, merchant owners, and their customers.