The Value of Distributed Electricity Storage in Texas

Proposed Policy for Enabling Grid-Integrated Storage Investments

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November 2014

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This report was prepared for Oncor Electric Delivery Company. All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group, Inc. or its clients. As a Transmission and Distribution Service Provider in Texas, Oncor has an interest in the state's regulatory policy regarding whether and how storage assets may be regulated. While Oncor has commissioned this whitepaper, its contents represent the authors' independent view and assessment of the economics of storage in Texas.

We acknowledge the valuable contributions of Jürgen Weiss for peer review and conceptual contributions and of Oncor staff for providing the underlying data and conceptual support that we used to understand and analyze the benefits of integrating storage into their distribution system.

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Executive Summary

Electricity storage is attracting much attention as storage manufacturers begin to announce rapid reductions in the technology's costs, utilities publicize upcoming deployments, and states evaluate new policy initiatives.[1] Interest in electricity storage is driven by a range of potential applications that include avoiding power outages for customers, reinforcing the grid, reducing other transmission and distribution (T&D) costs, shifting power consumption away from costly peak-load periods, balancing intermittent renewable energy resources, and providing ancillary services and emergency response service in the wholesale power markets. While the potential value of these and other storage applications have long been recognized, electricity storage costs have not been competitive with alternative technologies and resources that can provide comparable services. Therefore, electricity storage investments to date have been deployed primarily as demonstration projects.

Due to recent development, electricity storage appears to be on the verge of becoming quite economically attractive. Most importantly, several battery storage manufacturers have indicated that their costs will decrease substantially over the next few years. Public reports now forecast cost declines from the current $700–$3,000 per kWh of installed electricity storage in 2014 to less than half of that over the next three years.[2] Some analyst projections and vendor quotes point to even more significant cost reductions, forecasting that the installed costs of battery systems will drop to approximately $350/kWh by 2020.[3] At these much lower system costs, many innovative applications of electricity storage could be cost effective.

In this context of declining battery costs, Oncor Electric Delivery Company, a Transmission and Distribution Service Provider (TDSP) in Texas, has engaged us to explore the economics of grid-integrated storage deployment in Texas. We evaluate this question first by estimating whether storage could be cost-effectively deployed on the distribution systems in the state from the perspectives of retail customers, wholesale electricity market participants, and the combined system or "society as a whole." We then evaluate whether new public policies supporting electricity storage in Texas would be needed, given the Electric Reliability Council of Texas's (ERCOT's) deregulated market structure, and if so, what policies might be necessary for Texas to

1 For example, see Public Utility Commission of the State of California (2013), p. 2.

2 Navigant notes that current storage costs for a four-hour battery are $720–$2,800/kWh depending on the scale of the battery. According to Sam Jaffe of Navigant Research, battery-only costs are currently around $500–700/kWh with the remaining installation costs due to system costs. Also see Dumoulin-Smith, *et al.* (2014) p. 1.

3 The $350/kWh installed cost projection is based on Oncor's discussions with vendors, consistent with industry sources. For example, Morgan Stanley predicts that battery-only costs may reach $125–$150/kWh in the near future, down from the $500/kWh currently. See Byrd, *et al.* (2014), p. 40. If battery costs are capable of reaching the low costs projected by Tesla Motors Inc., this would imply a battery-only cost of only $110/kWh. See Jaffe (2014) p. 30.

realize the full economic and reliability benefits of grid-integrated, distributed electrical energy storage.

Our analysis shows that deploying electricity storage on distribution systems across Texas could provide substantial net benefits to the state. We estimate that up to 5,000 MW (15,000 MWh, assuming a three-to-one ratio of storage to discharge capability) of grid-integrated, distributed electricity storage would be cost effective from an ERCOT system-wide societal perspective based on a forecast of installed cost of storage of approximately $350/kWh. Our analysis assumes that the storage deployment plan will be developed to capture as much benefits as possible by integrating value from increasing customer reliability, improving the T&D systems, and transacting in the wholesale power markets. Our analysis accounts for the net impact that deploying storage would have on generation investments in ERCOT's "energy-only" wholesale electricity market. The resulting generation investment response sustains market prices sufficient to support the development of the generating capacity necessary to maintain ERCOT's resource adequacy.

We also evaluate the benefits of grid-integrated storage deployed by TDSPs from an average electricity customer's perspective. Our analysis shows that deploying 3,000 MW (9,000 MWh) of storage across ERCOT (with 1,000 MW on Oncor's system) would reduce residential customer bills slightly and provide additional reliability benefits in the form of reduced power outages for customers located in areas where storage is installed. **Considering both the impact on electricity bills and improved reliability of grid-integrated storage, total customer benefits would significantly exceed costs.** However, while beneficial from an integrated, system-wide perspective, an efficient scale of storage deployment would not be reached if deployed solely by merchant developers in the wholesale market, by retail customers, or only for capturing T&D benefits.

Storage investments could not be undertaken at an efficient scale solely by merchant developers in the Texas restructured electricity market because the value that a merchant storage developer can capture and monetize through transacting in the wholesale power market alone is too low compared to costs. For instance, we find that approximately 30–40% of the total system-wide benefits of storage investments are associated with reliability, transmission, and distribution functions that are not reflected in wholesale market prices and, therefore, cannot be captured by merchant storage investors. Even at the low projected storage costs, the opportunity to arbitrage wholesale power market prices and sell ancillary services would not likely attract merchant storage investments at a significant scale. This means that relying only on merchant investors to develop storage in ERCOT would result in under-investment in storage from a state-wide perspective. Moreover, without being integrated in T&D planning and operations, merchant electricity storage would be under-utilized and unable to capture the high additional value offered by targeted deployment within the state's transmission and distribution systems.

Similarly, while individual customers would be able to capture backup-power benefits of storage, they are not likely to directly monetize the larger grid-wide and wholesale power market benefits. Finally, developing storage to capture only the T&D system benefits would likely result in under-investment and under-utilization of electricity storage for wholesale power applications.

In contrast, deploying storage in a manner that can capture wholesale market benefits but is also integrated into the distribution system would allow TDSPs to capture high-value applications such as providing backup power and voltage support on distribution feeders with below-average reliability or high-value end uses, reducing wear on critical distribution assets, and deferring some T&D investments. Given that deploying storage on specific locations on the distribution system is important for capturing the full value that storage can provide, a grid-based deployment strategy will be most effective if it is integrated with: (a) the planning of transmission and distribution system investments; and (b) targeted efforts to use electricity storage backup to reduce customers' distribution-system-related power outages. In addition, to capture the full value of distributed storage assets would require that they be dispatched into the wholesale power markets.

Given the significant benefits that storage can bring to the system as a whole, enabling cost-effective investments in electricity storage will require a regulatory framework that helps investors capture both the wholesale market and the T&D system values associated with the storage devices. We envision that such a policy would involve: (1) enabling electricity storage investments to be deployed by TDSPs on their systems as part of T&D planning that seeks to capture T&D and reliability-related values; and (2) allowing independent wholesale market participants to offer the storage devices into the wholesale power market. Specifically, we propose that an effective regulatory framework would involve allowing the transmission and distribution companies to "auction off" to independent third parties the wholesale market dispatch of the electricity storage deployed on the T&D system. This approach would maintain the clear delineation between: (1) the TDSP's role as a T&D service provider and (2) wholesale market participants who transact in the market. The auction proceeds would be used as an offset to retail customers' T&D costs, which include paying for the storage facilities. Such a regulatory framework would facilitate an economically-efficient level of storage investments in Texas, and reduce investment barriers by allowing the storage technology to be deployed when the combined benefits from the wholesale market, transmission, and distribution systems exceed the expected costs by a sufficient margin.

I. Perspectives for Measuring Value of Electricity Storage

When evaluating the benefits of distributed electricity storage or any potential investment, it is important to establish from whose perspective the benefits are measured. From the perspective of a wholesale market participant, the primary question is whether the benefits of merchant participation in the ERCOT electricity market exceed the necessary investment costs. From the perspective of policy makers, it is most relevant to compare the system-wide benefits with system-wide costs. Finally, from the perspective of the transmission and distribution (T&D) provider and ratepayers, it is important to evaluate the benefits that T&D customers would receive in comparison to the costs they would incur.

The definition and significance of these three distinct perspectives are described below and summarized in Figure 1:

- Merchant Benefits are the net profits that a private investor could monetize by participating in the wholesale markets for electric energy and ancillary services. The net merchant value is the most relevant metric from a wholesale market participant's perspective because one would make the storage investment only if one can obtain adequate profit from it. If the capital expenditure of the storage were paid for by electricity customers through regulated cost recovery, the merchant value could be captured and shared with customers to reduce their electricity bills.
- "System-Wide" or "Societal" Benefits are the overall benefits of storage to the electricity system as a whole, regardless of whether those benefits and costs accrue to the asset owner, retail customers, or other entities and market participants. After subtracting the costs of electricity storage, the net societal benefits indicate whether the investment in storage would be in the overall public interest. This system-wide benefits perspective is the most common metric on which policy-makers and regulators rely in making policy choices. It is also the metric used in Texas for evaluating the economics of transmission investment decisions, as codified in the Public Utility Commission of Texas's (PUCT's) decisions.[4]
- Customer Benefits are the benefits that accrue directly to electricity users. In the context of electricity storage deployment, these benefits may include lower electricity bills, improvements in reliability for customers that benefit from storage as a backup power source and from improved power quality due to storage's ability to control voltage. Net customer benefits (after accounting for the costs incurred) are likely to be the most important metric for ERCOT

[4] See PUCT (2012).

Transmission and Distribution Service Providers (TDSPs) and their customers when determining whether a capital expenditure should be made and added to a TDSP's rate base.

We evaluate the magnitude of potential benefits from each of these three perspectives, compared to anticipated costs, when determining whether and how Texas can benefit from electricity storage investments.

Figure 1
Three Perspectives on Measuring the Value of Electricity Storage

Merchant Value	• Profits that a private investor could capture in the ERCOT wholesale power markets • Driven by energy arbitrage value and ancillary service prices • **Importance:** determines: (a) whether wholesale market incentives by themselves are sufficient to attract investment; and (b) the offset to storage costs if deployed by wires company for T&D/reliability benefits
"Societal" or "System-Wide" Benefits	• System-wide benefits, including reduction in production, investment, and outage costs (regardless of whether suppliers or customers benefit) • Also known as "total resource cost" benefits • **Importance:** PUCT transmission policy for "economic" projects requires analysis of net "societal" or "system-wide" benefits
Customer Benefits	• Customer bill savings from reduced wholesale prices, deferred transmission and distribution costs, and rebated merchant value • Increase in realized distribution system reliability (reduced outages) • **Importance:** customers' and distribution utilities' primary interest, also a key metric from a public policy perspective

II. The Value of Electrical Energy Storage

To evaluate the net benefits of electricity storage in Texas, we consider adding storage from the perspectives of wholesale market participants, society as a whole, and retail electric customers. We first consider how a merchant developer may analyze the level of storage investment that would be supported solely by wholesale market participation. We then measure the societal or system-wide benefits by tabulating all potential benefits of storage, regardless of whether suppliers or customers would realize those benefits, and estimate the deployment scale beyond which investing in additional storage would likely start to erode the overall value.

Finally, we estimate the net benefits to retail electricity customers if storage assets were deployed under a regulated framework that would allow the full value of the storage assets to be captured. In this analysis, we assume that customers would pay for the storage investments just as they pay for transmission and distribution investments. Customers would then receive offsetting reductions in retail electricity costs from the storage in the form of deferred T&D investments, refunds from the wholesale market auction proceeds, and reduced power purchase costs. Customers would additionally benefit through increased system reliability from avoided distribution outages, although the improved reliability does not directly affect the customers' electricity bills. Other customer benefits that we have not analyzed include improved power quality and support for customer-side renewable energy usage.

A. Merchant Value

To estimate the level of storage investment that might be attractive to wholesale market participants, we estimate the net revenues that storage could earn from the ERCOT wholesale power markets.[5] We simulate the net profits earned from charging during low-price periods, discharging during high-price periods, and participating in ancillary services markets for operating reserves. These simulations reflect 2020 equilibrium market conditions in the ERCOT "energy-only" market with wholesale market prices that are sufficient to support all necessary new generation investments.[6]

Figure 2 presents our estimate of expected merchant value and costs at varying levels of storage deployment in ERCOT. The top of each bar shows the total market value that merchant investors could earn in ERCOT's energy and ancillary services markets. To compare this merchant value against storage costs, we report two potential benchmarks for the installed costs of storage. The lower benchmark cost of storage is $350/kWh, consistent with vendor quotes and other industry projections for the year 2020, and the higher benchmark cost is $500/kWh presuming the projected cost reductions do not fully materialize. We then annualize these investment costs (in levelized real-dollar terms), based on recovery of investment costs over a 15-year period at an 8.0% after-tax weighted-average cost of capital (ATWACC), which is consistent

5 If certain retail electricity customers are also interested in deploying electricity storage on their premises, we assume that they too would be interested in capturing the values associated with transacting in the wholesale markets. Thus, the merchant value we estimate in the report is the value that any storage investor should be able to capture via participating in the wholesale market either through direct or third-party participation.

6 We use the Polaris Systems Optimization (PSO) market simulation tool to conduct this study using fuel price, market pricing, and generation mix in Texas for the year 2020. We calculate expected realized system costs and wholesale energy and ancillary-service revenues as a weighted average of simulated results under 2012 and 2011 weather conditions, with 2012 weather assumed to reflect a "median" weather case and 2011 to reflect an "extreme" weather case. The model results presented reflect equilibrium conditions in ERCOT's "energy-only" market at each level of storage deployment analyzed. Specifically, we presume that (1) adding storage reduces energy prices, which then (2) triggers a supply-side response that reduces the amount of additional generating plant additions, until (3) the combined amount of generation and storage investments yields market prices that reflect long-run equilibrium conditions under which a new natural gas combined-cycle ("CCs") plant can fully recover its investment costs, which is assumed to be equal to a levelized cost of new entry (CONE) of $149/kW-year.

with the cost of capital of a merchant generation investment.[7] As another comparison point, we also report the annualized investment costs using a regulated TDSP's 6.3% ATWACC, assuming a 15-year life of the battery and a 30-year life for the balance of plant components. Such a comparison of annualized costs and benefits is equivalent to a net present value analysis, normalized for the life of the investment.

The results, summarized in Figure 2 below, show that the wholesale market benefits of storage alone are limited in comparison to storage costs. This discrepancy between benefits and costs is also consistent with the fact that private investments in storage have been minimal to date: the wholesale market value that can be captured is well below current storage costs, which still exceed $500/kWh. However, if storage costs drop to the $350/kWh benchmark used in this study, it is possible that a modest amount of storage could be attractive purely on a merchant, wholesale-market basis. However, as Figure 2 shows, the aggregate merchant value is well below storage costs at any larger scale. This is because the wholesale power price difference between peak and off-peak periods (on which merchant investors rely) diminishes quickly as storage deployment increases.[8]

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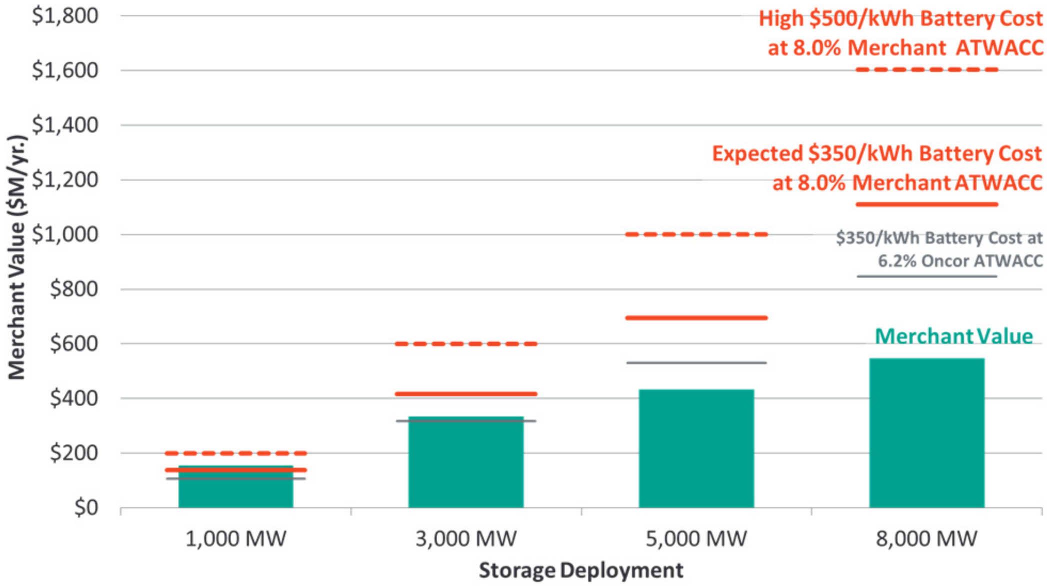
7 We also account for fixed operations and maintenance costs of 1% and 2% respectively, for both the "expected" and "high" battery cost points. Oncor provided capital and fixed cost assumptions as well as the planned three-hour discharge period and other technical assumptions based on discussions with vendors. The 8.0% ATWACC reflects the estimated cost of capital of merchant generation investments as reported in Newell, *et al.* (2014). To the extent the cost of capital of merchant storage investments exceeds those of merchant generation investments, the annualized cost of storage would be higher as well.

8 Note that we estimate a relatively more gradual decline in merchant value compared to many other studies estimating the value of storage. This is because we also account for the partially offsetting generation "investment response" effect such that wholesale power prices remain high enough to attract needed generation investments as explained in a prior footnote.

Figure 2
Merchant Storage Value that Could be Captured by Wholesale Market Participants



Sources and Notes:

Merchant value represents the margins that a merchant investor would receive by participating in ERCOT's energy and ancillary services markets; assuming storage with a 3-hour discharge capability, 85% round-trip efficiency, and no other variable operations and maintenance (VOM) costs. Storage costs of $350/kW-y are based on battery vendors' estimates of $200/kWh as quoted to Oncor, plus an Oncor-estimated installation cost of $150/kWh, plus fixed operations and maintenance costs equal to 1% and 2% of investment costs for the "expected" and "high" cost levels.

B. System-Wide Societal Benefits

Our analysis of system-wide benefits shows that that the estimated total incremental value of storage would exceed incremental costs up to approximately 5,000 MW (or 15,000 MWh) of storage deployment in ERCOT if the cost of storage declines to $350/MWh. Beyond 5,000 MW, the incremental value of installing additional storage facilities falls below its cost, reflecting the fact that the incremental benefits decline with increasing storage deployment. If the cost of storage falls to levels below $350/MWh, distributed storage investments above 5,000 MW would likely continue to yield net societal benefits.

We estimate these net benefits based on four components of storage value from an annualized, system-wide societal perspective: (1) avoided distribution outages; (2) deferred transmission and distribution investments; (3) production cost savings; and (4) avoided generation investments. These estimated annual benefits of storage are then compared with the range of annualized storage costs. These annualized costs of storage are estimated assuming a T&D utility's cost of capital, with component costs depreciated over 15 to 30 years, depending on the life of the components.

- Avoided Distribution Outages. Deploying storage on the distribution system can help avoid distribution outages that customers experience from time to time. The causes of these distribution outages can range from storms to unexpected equipment failures. To use storage to reduce these outages in the most effective and efficient manner, a distribution utility would install the storage devices at certain distribution locations, or feeders, where the storage equipment can be used to avoid the most costly outages. We use historical outage patterns to simulate a storage deployment targeted at feeders with lower than average reliability, recognizing that it is difficult to predict future outage patterns. We value the estimated quantity of avoided outages at typical ranges for the value of lost load (VOLL) of different customer classes. We assume that the VOLL for commercial and industrial customers is approximately $20,000/MWh, while the VOLL for residential customers is approximately $3,000/MWh.[9,10]

- **Deferred Transmission Investments.** Deploying storage close to load, in a distributed manner, also means that the storage can be discharged during peak system periods to serve load. If targeted to specific locations, such peak-shaving applications will reduce the pace (and/or magnitude) of future transmission investment needs. To most accurately evaluate the potential effect of deferred transmission investments, one would need to conduct a detailed transmission planning effort for varying levels of storage deployment. We have not conducted such a transmission analysis. Instead, we assume that the benefit of future transmission investment deferrals is approximately equal to the average annual transmission cost for every unit of reduced peak demand. This average cost is approximately $36/kW-year, consistent with the current average annual transmission cost per kW of summer coincident peak (CP) load in ERCOT.[11] We

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9 A 2013 study done on behalf of ERCOT found VOLLs ranging from $3,000/MWh to $53,907/MWh for commercial and industrial customers and $0/MWh to $17,976/MWh for residential customers, see London Economics International (2013). The weighted average VOLL that we estimate across all simulated outages is approximately $13,200/MWh, or somewhat above the $9,000/MWh assumed VOLL that the PUCT and ERCOT use for wholesale market pricing purposes, see ERCOT (2014).

10 Specifically, we analyzed five years of detailed outage statistics at each Oncor substation and feeder and estimated the number of outages that could have been avoided if Oncor had storage assets distributed on the feeders to maintain customer power supply during outage events. We assume a targeted but imperfectly-optimized storage deployment strategy by selecting locations to install storage at feeders with high outage frequencies first. We then calculated the customer interruptions that could be avoided, observing storage unit capacity and energy limitations, and assuming only 50% of the theoretically avoidable outages can actually be avoided due to the (with hindsight) imperfect placement of storage installation on the feeder and dispatch, deployment, and technical limitations. We estimate that 3,000 MW of storage installed on select feeders on Oncor's system could improve Oncor's System Average Interruption Duration Index (SAIDI) metric by 10 percentage points.

11 We measure peak load reductions for transmission cost deferral purposes based on realized ERCOT system peak, accounting for the fact that at higher levels of storage deployment each incremental unit of storage reduces peak load by a declining amount because storage is energy-limited and the load duration curve has become flatter. Transmission costs reflect the transmission rate applicable to one class of customers in Oncor's system as of 2014 ($2.840117 per 4CP kW), escalated with inflation to

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recognize, however, that the actual future costs of incremental transmission needs may be below or above the current level of average costs. Because the relative magnitude of deferred transmission and distribution investments may vary by location and over time, we combine deferred transmission and distribution investments when reporting results.

- **Deferred Distribution Investments.** Distributed deployment of storage can also be used to reduce peak load growth on distribution feeders and thereby defer some of the ongoing distribution system investment needs. While overall distribution system spending will increase with the deployment of distributed storage devices, the estimated deferred investments represent a partial offset to those cost increases. Again, as a substitute for conducting a full distribution system needs assessment with and without storage, we assume that each kW of discharge capability from storage can defer one kW of distribution load and average distribution cost.[12] We estimate the value of those distribution deferrals in two ways. First, we worked with Oncor to develop an approximate estimate of the number of higher-value distribution investment deferral opportunities that might exist, for example by installing a modest amount of storage to defer a major substation or transformer upgrade.[13] We assume that the highest-value distribution investment deferral opportunities would be pursued first. Second, for all additional battery deployments, we use a lower $14/kW-year value based on Oncor's average annual distribution investments and annual load growth in 2014. As noted, we combine deferred transmission and distribution investments when reporting results.

- **Production Cost Savings.** To estimate the system-wide value that storage creates in the wholesale market, we estimate the degree to which storage can help shift electricity production from higher-cost to lower-cost resources. We simulate the

Continued from previous page

2020 nominal dollars. This 2014 transmission rate is in line with the transmission rates applied to other customer classes and in other distribution systems across ERCOT, see PUCT (2014).

12 Unlike transmission costs, which we assume are driven primarily by ERCOT coincident peak loads, we assume that distribution system costs are driven by non-coincident peak loads on each feeder so that each MW of storage would reduce distribution feeder peak loads by one MW.

13 The highest-value opportunities are in locations where relatively large distribution upgrades are required on feeders with modest or low load growth. Because incremental distribution investments (such as transformer and substation upgrades) are quite large, a modest-sized storage asset that is sufficient to meet a modest increase in load can have large economic value. We estimated the potential value of such deferrals for a selection of upgrades for which Oncor identified and provided cost and load growth estimates, and then estimated the total potential deferral opportunities available based on historical distribution investment data. We anticipate that the annual distribution investment on the Oncor system would increase relative to the recent past few years for which we have investment data. Thus, the estimated value of distribution investment deferral benefits is likely to be conservatively low.

ERCOT wholesale energy and ancillary services market in 2020 to approximate the charging and discharging pattern of the storage consistent with resulting wholesale energy and ancillary service prices.[14] The storage dispatch and resulting production cost savings also consider the 15% "round-trip efficiency loss" associated with the charge-discharge cycle of the storage facility. Production cost savings are expressed as the reduced costs for fuel, variable operations and maintenance (O&M) costs, and demand response deployment costs on an ERCOT-wide basis.[15]

- **Avoided Generation or Demand-Side Capacity Investments.** Because electricity storage facilities can be discharged to reduce load during peak-load conditions, deploying storage will reduce the amount of future generation or demand-side resource investments. To estimate this potential value, we assessed the extent to which deploying storage would reduce generation investment needs. Specifically, we assume that the marginal resource investment has costs similar to a natural gas combined-cycle (CC) plant. As we add storage to the system (which tends to reduce the wholesale market prices during peak-load conditions and increase them during off-peak periods), we also simultaneously reduce natural gas CC additions to restore the market prices and revenues necessary to support new generation investments. We assume a levelized annual cost of new CC generation investment of $149/kW-year.[16]

The combined value of these benefits exceeds the costs of storage by a substantial margin across a range of deployment levels, as shown in Figure 3. In the top chart, we report the total annual costs and benefits of deploying increasing levels of storage and show that that the total benefits exceed the costs even at a relatively high ERCOT-wide storage deployment level of 8,000 MW. The chart also shows that the net benefits in absolute dollars are maximized at a deployment

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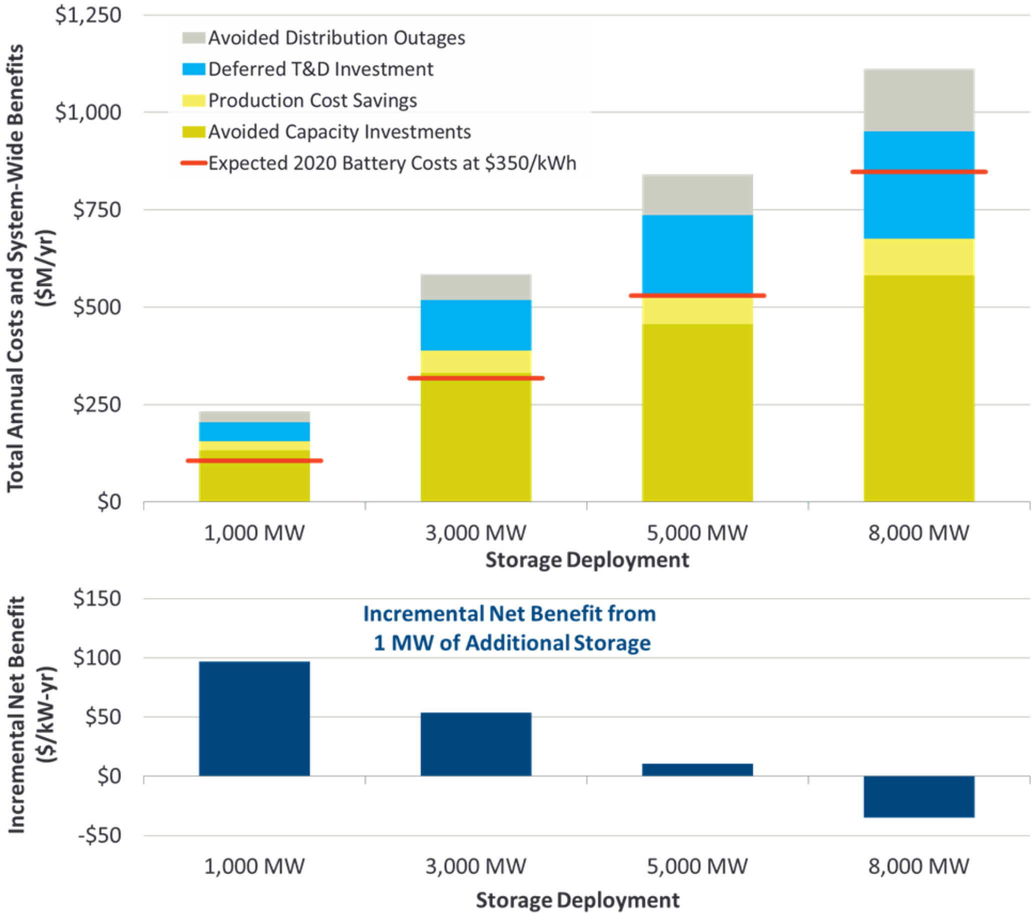
14 We conduct an hourly simulation model consistent with ERCOT's day-ahead wholesale market. We do not attempt to estimate the potentially higher value that might be realized if storage were able to capture additional value from shorter-term price fluctuations in the ERCOT real-time market. The hourly market simulation also considers the ability of electricity storage to provide ancillary services.

15 We calculate a relatively modest quantity of production cost savings when compared to other studies estimating the value of storage. This is the case primarily because we also account for the impacts of generation investment in response to the storage deployment. The increasing level of storage certainly facilitates a substantial amount of load shifting and production cost savings. We account for the fact that lower peak loads will also reduce the need for conventional generation investment. In turn, reduced future generation investments keep prices relatively high. Thus, the net impact on production costs and wholesale power prices is much more modest than in static studies that do not consider generation investment response. By considering investment response, our simulation results maintain market prices that support investment in necessary additional generation resources.

16 The study assumptions are adapted from a CONE study for PJM with necessary adjustments for ERCOT, see Newell, *et al.* (2012) and Spees, *et al.* (2011). Updated estimates apply escalation rates derived from Newell, *et al.* (2013).

level of approximately 5,000 MW, after which the total net benefits begin to decline due to the diminishing return from investments.

Figure 3
System-Wide Annual Benefits Compared to Expected 2020 Storage Costs
Top: Total Benefits and Costs, Bottom: Net Incremental Benefits



Sources and Notes:

The Expected 2020 Battery Costs are based on Oncor's 6.3% ATWACC, with 15- and 30-year assumed lifetime for the battery and balance of plant respectively.

The bottom chart in Figure 3 shows the incremental value of adding one more unit of storage to the system at the indicated scale of total storage deployment.[17] As the chart shows, these incremental benefits of adding storage exceed the incremental costs for the first 5,000 MW (15,000 MWh) of system-wide storage deployment. The net benefit of incremental investments is approximately $100/kW-year at a deployment level of 1,000 MW (3,000 MWh) of storage. As more storage is added, the incremental benefit per unit of storage decreases. These results show

[17] These incremental benefits are lower than the average benefits when considering the total benefits across the cumulative quantity of storage added because the benefits of the last unit added decline as the storage deployment level increases.

that, from an ERCOT system-wide perspective, the *incremental* societal benefits of storage exceed the incremental costs of investing in additional storage facilities up to a total deployment level of about 5,000 MW (or 15,000 MWh). This is consistent with the finding that total net benefits of storage are maximized for a system-wide deployment level of 5,000 MW.

C. Customer Benefits

While net societal benefit is the appropriate metric for forming policy decisions, regulators and utilities also need to be concerned about the benefits and costs to electricity customers. When storage investment is funded through a T&D utility's regulated rates, retail customers will be paying for the investment.

This section of our report analyzes costs and benefits from the perspective of electricity customers and assesses whether they too receive net benefits. While not all of the economic benefits are directly accruing to retail customers, we use impacts on average customer bill to assess the "value" of storage from a customer perspective. If customer bills decrease or reliability increases due to the storage investment, then customers benefit from the investment. However, if customer bill increase by more than the value of reliability improvements, then customers are worse off.

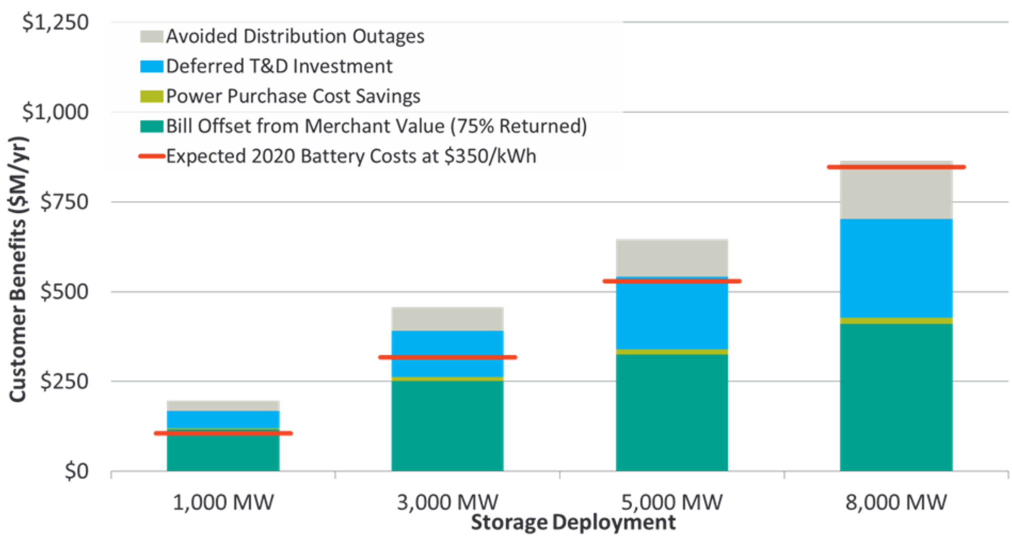
The net benefits of storage from a customer perspective are summarized in Figure 4. From a customer's perspective, most (but not all) of the benefits we estimate from a societal perspective are realized. Benefits realized by customers include the value associated with deferred transmission and distribution investments (explained in the prior section), which help offset the costs customer incur by paying for the storage. Improved reliability and power quality are also direct benefits to customers, although these benefits do not affect customer electricity bills. In addition, customers would also benefit from two additional benefit categories that will reduce customer electricity bills:

- Power Purchase Cost Savings. Since the use of storage can reduce power purchase costs by reducing power purchases during system peaks (net of purchases during off-peak periods), this value will directly affect customer bills. However, after considering the market price impacts of generation investment response, we estimate that power purchase cost savings are quite small across a wide range of storage investments.
- Customer Bill Offsets from Storage Merchant Value. We envision that installed storage facilities will be used by independent third-parties to participate in the ERCOT wholesale energy and ancillary services markets. The value of this wholesale market participation would be obtained as an offset to customer bills through an auction process as discussed further below. If storage were deployed by T&D utilities with the investment costs recovered through regulated retail rates, we envision a regulatory framework under which retail customers who pay for the storage assets would also receive a portion of the merchant revenues earned in wholesale markets. For the purpose of our analysis, we assume that

retail customers would be able to benefit from approximately 75% of the value that independent market participants would obtain in ERCOT's wholesale market, with the remaining 25% kept by the independent entity who contracts for the right to use the storage facilities for participation in the wholesale market.[18]

Figure 4 summarizes these customer benefits and compares them to costs for the simulated 2020 market condition. The stacked bars represent the values that the customers would obtain while the red horizontal lines reflect expected storage costs at $350/kWh. This analysis shows that the customers are likely to experience significant net benefits even as the cost of the storage investments is recovered through regulated retail rates. We estimate that net customer benefits are maximized between 3,000 MW and 5,000 MW of ERCOT-wide storage deployment.

Figure 4
Estimated 2020 ERCOT-Wide Customer Benefits and Storage Costs



Sources and Notes:

The expected 2020 battery costs are annualized based on Oncor's 6.3% ATWACC, with 15- and 30-year assumed lifetime for the battery and balance of plant respectively.

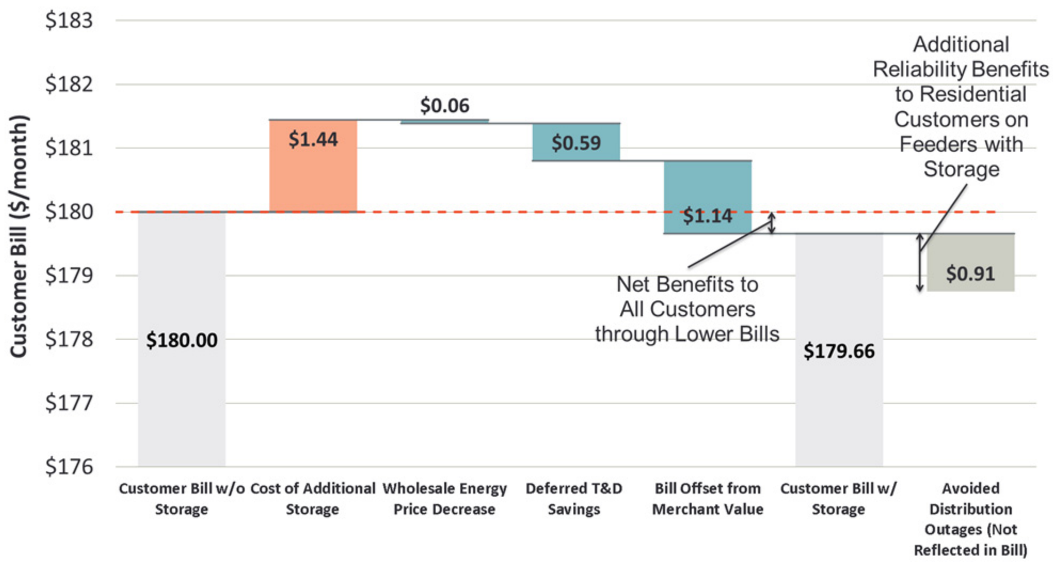
To take the analysis of customer impacts a step further, Figure 5 below illustrates how a typical Oncor residential customer's bill would be affected by the deployment of 3,000 MW (9,000 MWh) of ERCOT-wide storage—assuming that 1,000 MW of that storage were deployed on Oncor's system and the remaining 2,000 MW were deployed in other distribution systems across ERCOT.

We start with a typical residential customer's monthly bill, which is estimated at $180 in 2020 (based on forecast wholesale power prices without storage) as shown in Figure 5. Deploying 3,000 MW (9,000 MWh) of storage on an ERCOT-wide basis (at a storage cost of $350/kWh) is estimated to increase Oncor's average monthly residential bills by $1.44 as shown by the orange

18 This 25% net revenue sharing assumption is approximately consistent with typical net revenue sharing levels for third-party demand response providers. See Newell, *et al.*, (2013) pp. 52-55.

bar of Figure 5. These higher residential customer bills are then offset by a number of benefits shown as blue bars. The first benefit bar shows a minor cost reduction due to a slight wholesale energy price decrease, followed by larger bill reductions from deferred transmission and distribution investments, and the 75% of merchant value assumed to be credited back to ratepayers. As a result, deploying 3,000 MW (9,000 MWh) of storage on an ERCOT-wide basis would slightly reduce Oncor's typical residential bill.[19] In addition to a small residential customer bill reduction, customers located on feeders with storage would also realize meaningful reliability improvements (as shown by the grey bar) and power quality benefits (not quantified).

Figure 5
Impact on a Typical Customer Bill in 2020 Assuming 3,000 MW of Storage Installed in ERCOT (1,000 MW Installed on Oncor's System)



Sources and Notes:

We assume that Oncor installs 1,000 MW out of 3,000 MW of storage deployed on an ERCOT-wide basis, with storage costs and wholesale-market proceeds reflecting the same proportion of installations. Oncor customers realize deferred transmission and distribution investment benefits based on the 1,000 MW installed on Oncor's system. The avoided distribution outage value shown is for a typical residential customer on a feeder with storage. Customers not located on a feeder with storage would not realize these reliability benefits.

As indicated by the grey bar on the very right of Figure 5, we estimate that residential customers realize an approximately $0.91/month of additional value through avoided distribution outages, even though that value would not be reflected directly in the customer's bill. Considering that the VOLL for commercial customers (estimated at $20,000/MWh of lost load) is significantly higher than that of residential customers (estimated at only $3,000/MWh) the equivalent reliability value for commercial customers would be approximately seven times higher than that shown in Figure 5.

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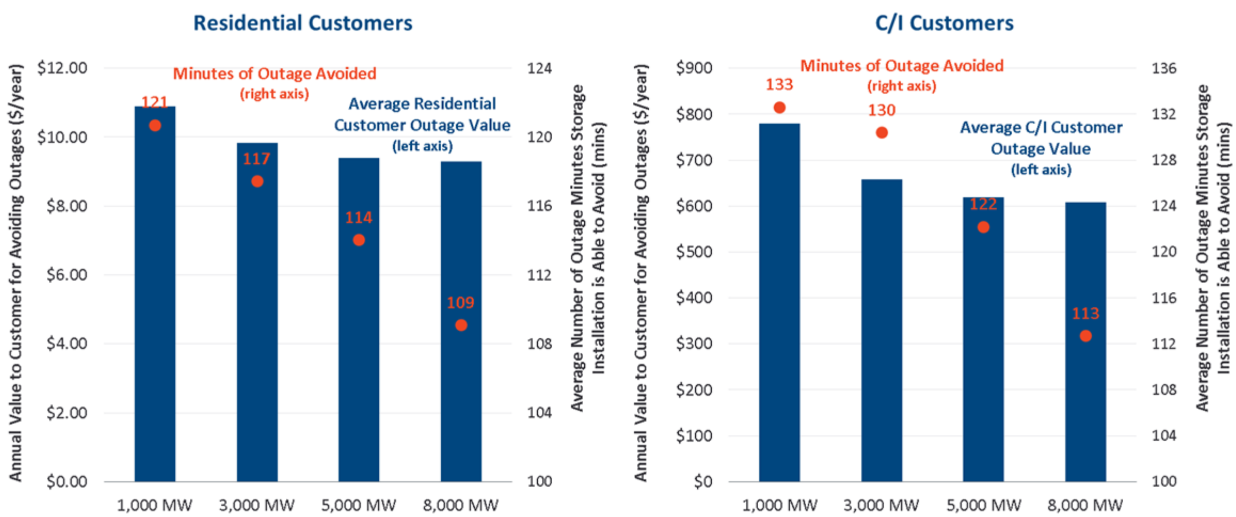
19 Note that the cost comparison that we are reporting here reflects the cumulative cost and benefit impacts to a residential customer comparing a no-storage case to a case with 3,000 MW of storage. This residential bill impact estimate reflects *cumulative* costs and benefits, not the incremental bill impact of adding one more unit of storage.

Our analysis shows that targeted and carefully-planned storage deployment on the portion of the distribution network with the lowest reliability can significantly decrease the costs of power outages. As shown in Figure 6 below, deploying the first 3,000 MW of storage is conservatively estimated to reduce power outages experienced by residential customers on the targeted feeders by approximately 120 minutes per year, including partial mitigation of storm-related outages. For residential customers, this outage reduction is worth about $10/year based on an estimated VOLL of $3,000/MWh.[20] For commercial and industrial (C/I) customers who typically place a much greater value on avoided power outages, the value of reducing power outages is much higher. Based on the estimated VOLL of $20,000/MWh for C/I customers, recognition that the average C/I customer is approximately ten times the size of the average residential customer, and an estimated average annual outage reduction of approximately 130 minutes, a reliability value of approximately $700/year would be realized for the average C/I customer.[21]

Figure 6
Avoided Annual Distribution Outage Value and Outage Duration by Customer Class



Sources and Notes:

Results are based on our analysis of five years of Oncor outage data, with all of the storage deployed on Oncor's distribution system. The average duration of outages avoided declines with storage deployment because early installations are targeted to the worst-performing feeders. Residential value is based on a standard residential consumer using 1,300 kWh/month and a VOLL of $3,000/MWh. C/I value is based on an average customer size of 12,700 kWh/month and a VOLL of $20,000/MWh.

III. Analytical Findings and Implications

The most important question that Texas policy makers may ask is: "Would adding distributed electricity storage in ERCOT produce net benefits for the state, considering the impacts on both investors and electricity customers?" We estimate that if the installed cost of distributed electricity storage falls to $350/kWh, ERCOT as a whole is likely to benefit significantly from

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20 Assumes average residential consumption is 1,300 kWh per month.

21 Assumes an average commercial or industrial customer consumes 12,700 kWh per month.

storage deployment. While the incremental benefits per unit of storage diminish as more storage is added to the system, increasing net benefits are realized until approximately 5,000 MW (or 15,000 MWh) is deployed.

Texas policy makers may also ask: "Why not leave it to the market to make the storage investments?" Our analysis shows that merchant investors, who would only invest in storage if the revenues received in the market would more than pay for their investment costs, would not capture sufficient value of storage to merit investment of significant scale. Based solely on wholesale market participation, merchant developers would under-invest in electricity storage. Moreover, any merchant electricity storage facilities deployed would be under-utilized and not capture the high value offered by targeted deployment within the T&D systems. If electricity customers are left to make the investment themselves, their interests in avoiding power outages would be well-aligned with the T&D utilities' interests, except that the TDSPs will be in a much better position to select and deploy the storage to capture other benefits, including T&D cost reductions and, through third-parties, capture the wholesale market value of the storage assets.

Alternatively, one may ask: "Why wouldn't the transmission and distribution utility go ahead and install storage, if deploying storage can reduce T&D costs and customer outages?" Based on our estimate of benefits associated with deferred T&D investments and the value of improved distribution reliability, we find that those values alone do not justify deploying storage at a system-wide efficient scale. Thus, as with merchant investors, if storage investment is focused only on T&D benefits without capturing benefits of wholesale power market participation, T&D utilities will similarly under-invest in storage and under-utilize storage compared to a deployment that would maximize net benefits on an ERCOT system-wide basis.

In contrast, if the full value of wholesale-market and T&D-related electricity storage can be captured, we estimate that ERCOT system-wide benefits will be highest for a distributed storage investment level of about 5,000 MW (or 15,000 MWh) when the installed storage cost is about $350/MWh.

IV. Policies for Enabling Economic Storage Investments

As discussed, electricity storage offers benefits that span the restructured wholesale market and regulated T&D systems. However, neither merchant investors nor regulated wires companies can independently capture sufficient benefits to justify investing in storage to maximize ERCOT-wide benefits under the current policy framework in Texas. We therefore propose that Texas policy makers consider establishing a regulatory framework that will allow the state to capture the full value of deploying grid-integrated electricity storage. We propose a policy model that allows the TDSPs to make the investment in electricity storage and recover the associated investment costs through regulated rates as long as: (a) a significant fraction of the value of these storage assets is associated with transmission and distribution system benefits that are not captured through wholesale market participation, and (b) the incremental system-wide benefits are expected to exceed costs by a sufficient margin. In addition, regulations would maintain a clear delineation between the regulated TDSPs and wholesale market participants.

Under the envisioned policy framework, the TDSPs will continue to be only transmission and distribution service providers with no wholesale market participation. To maintain the delineation between regulated and market activities, the TDSPs will “auction off” the wholesale market value of distributed storage, enter into arms-length contractual relationships with independent third parties who would then schedule the charging and discharging of the storage devices to maximize revenues from the wholesale market. The auction proceeds would be credited back to reduce the regulated rates of the TDSPs’ retail customers who pay for the storage investments.

Under this proposed regulatory framework, the benefits of storage associated with improved system reliability, deferred transmission and distribution investments, and participation in ERCOT’s wholesale energy and ancillary services market can all be captured simultaneously while aligning market participants’ and customers’ interests with those of the T&D utilities making the storage investments. We believe this approach would solve the barriers created by fragmented value streams that will otherwise lead to under-investment in electric energy storage.

List of Acronyms

CC	Combined Cycle
C/I	Commercial and Industrial
CONE	Cost of New Entry
CP	Coincident Peak
DOE	Department of Energy
ERCOT	Electric Reliability Council of Texas
GRR	Generator Revenue Reduction
kWh	Kilowatt-hour
MW	Megawatt
MWh	Megawatt-hour
O&M	Operations and Maintenance
PCS	Production Cost Savings
PSO	Polaris Systems Optimization
PUCT	Public Utility Commission of Texas
SAIDI	System Average Interruption Duration Index
T&D	Transmission and Distribution
TDSP	Transmission and Distribution Service Provider
VOLL	Value of Lost Load
VOM	Variable Operations and Maintenance

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