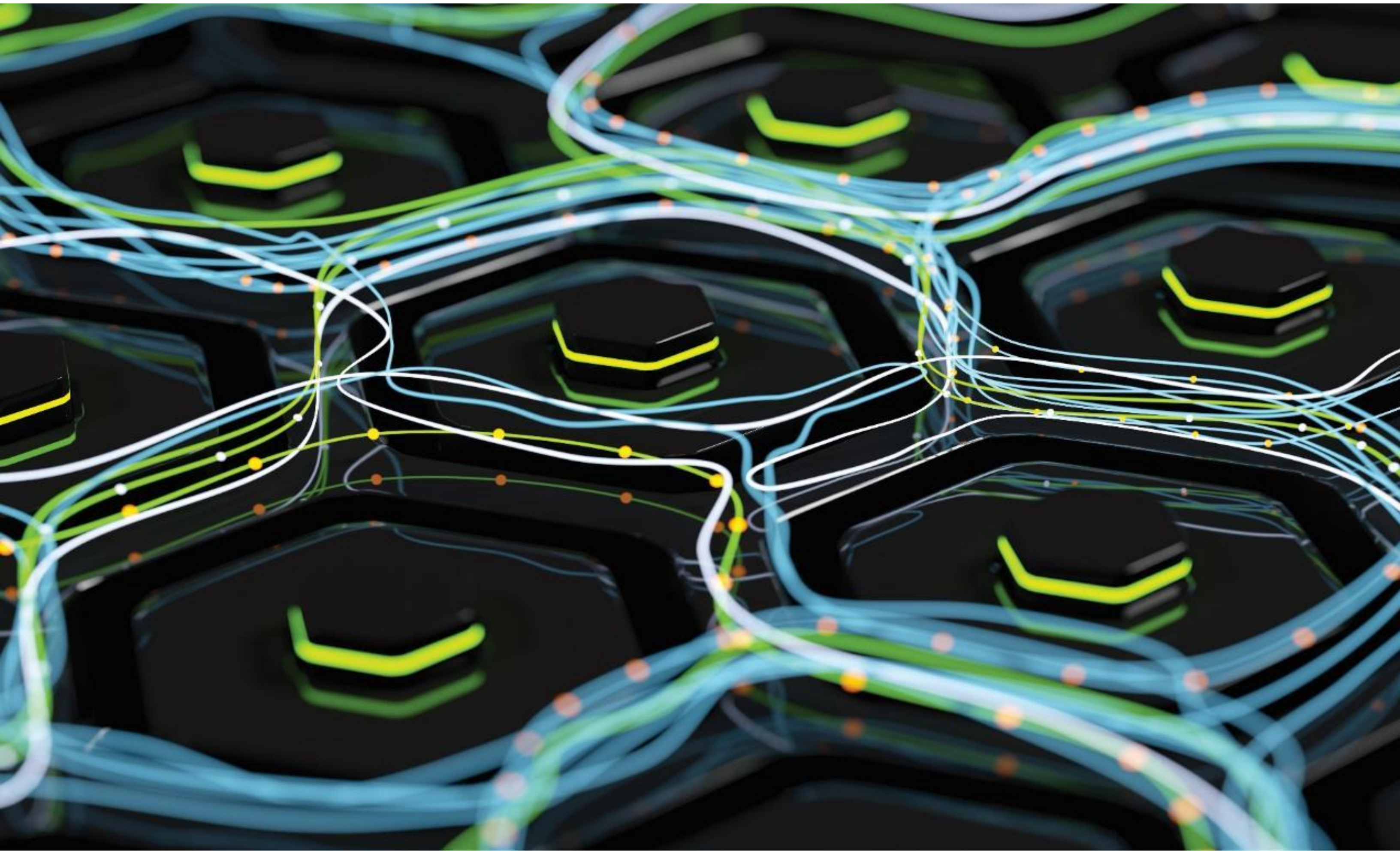
CRA Charles River Associates



Energy and ancillary services value stacking in ERCOT

Historical performance comparison for flexible gas and battery technologies

August 2025

Executive summary

As the electric power markets undergo a significant transition towards intermittent generation in the face of growing demand, electric utilities, developers, and investors must understand the different value streams available to flexible resource additions, which are poised to grow significantly. In this paper, CRA evaluates the performance of six such flexible resources (three gas-fired and three battery storage), using historical energy and ancillary services data from the ERCOT market in its proprietary Energy Storage and Ancillary Service Optimization (ESOP) tool.

Using sub-hourly price data across three historical years, the ESOP model analyzed potential co-optimization of dispatch in the energy and ancillary services markets across the 2021-2023 time period and within different discrete historical weather events. CRA's analysis identified the following major conclusions:

- Overall, the battery storage technologies were projected to generate higher levels of revenue, particularly due to their ability to take part in the ancillary service market when not actively charging and discharging. Roughly 33% of the storage technologies' revenue was projected to come from the ancillary service market, with 60-65% projected to come from energy arbitrage.
- Meanwhile, the lion's share (around 90%) of revenue for the natural gas-fired resources was projected to come from the energy market, and given lower ongoing fixed costs, natural gas resources were projected to generate greater value overall.
- During sustained periods of high prices (such as Winter Storm Uri in 2021), natural gas resources were projected to generate more revenue than batteries, assuming steady availability of fuel supplies. Batteries were at a disadvantage during the sustained high price period, as any charging they undertook was at extremely high prices. As such, the battery technologies would likely rely more heavily on ancillary services revenues during conditions when long-duration dispatchability is at a premium.
- During periods of volatile prices (such as the summer of 2022), both natural gas-fueled resources and battery resources were projected to generate the majority of their revenue from the energy market. Longer-duration battery storage resources showcased their greatest energy market revenue potential during such conditions.
- Resource options that offer modular block size additions can help optimize participation across multiple markets and minimize outage risks.

Overall, while no single technology can offer every desired resource attribute, for a system that values a technology that can provide firm, reliable energy during prolonged periods of grid stress as well as a flexible and fast responding energy resource, RICE and other flexible gas resources will often provide the best value. A system that values operational flexibility and has a high level of intermittent generation that is misaligned with system demand, a battery option may provide higher value by allowing operators to be more active in ancillary service markets and take advantage of volatile price periods.

Introduction

The power generation sector has seen several seismic shifts in recent years: the large scale adoption of hydraulic fracturing technology and the subsequent sustained low gas prices; the growth of wind and solar generation from a fringe contributor into a major energy provider; the widespread retirement of coal resources; the rapid deployment of battery energy storage projects to supplement intermittent generation; and the ballooning growth of large data centers.

This changing landscape has brought about a radical change in how systems are operated. The days of a simple resource stack of baseload, mid-merit, and peaking resources overlaid with a predictable load shape are long gone. Load serving entities must balance grid stability and reliability against the rapid penetration of intermittent generation (both utility scale and behind the meter), large load customers, and a diminished baseload generation fleet.

As a larger portion of grid energy is subject to the uncertainties of wind and cloud cover, the importance of markets for ancillary services have grown, helping to incentivize flexible and fast response resources offering attributes that help maintain grid stability. This challenge can be met by load serving entities and market operators primarily in two ways: battery energy storage systems or fast response gas units.

This analysis examines how these technologies would have historically performed in the Electric Reliability Council of Texas (ERCOT) West and ERCOT South energy and ancillary service markets from 2021-2023. It assesses the aggregate value these resources would have accrued over the examined period and explores performance during specific time periods that are representative of particular market conditions. This paper will lay out how these technologies create value, assess how they perform under various market conditions, and present qualitative considerations when comparing them.

CRA deployed its proprietary Energy Storage and Ancillary Service Optimization model (ESOP) to carry out this analysis. ESOP is an asset valuation tool used to assess the performance of fast-responding resources in changing market conditions and scenarios. ESOP is an optimization model that computes revenues through participation of resources in real time and the ancillary services markets with five-minute level granularity. Given projections of energy and ancillary services prices, ESOP outputs optimal dispatch decisions for storage or other fast response resources (i.e., value stacking strategies) that are unique to (a) the resource’s technological characteristics, and (b) the regional market’s participation rules. Decisions include whether to discharge or charge and by how much, and whether to commit to participate in the energy or ancillary services markets.

ESOP can represent a wide spectrum of fast-responding thermal and storage technologies with a set of parameters–ones that determine the resource performance in value stacking. These performance parameters depict the strengths and shortcomings of each type of technology, which shape unique strategies under the rules of different electric power markets and provide significant flexibility in modeling extant technologies. Optimal strategies can be used by investors to conduct financial calculations for near-term projects but can also support existing asset operators in real-time operations.

Market context

The ERCOT market is currently dominated by natural gas capacity, accounting for nearly 50% of installed capacity, as shown in Exhibit 1. However, as wind and solar installations have grown significantly over the last several years, battery storage additions have outpaced those of natural gas, with nearly 6 GW of new storage capacity added since 2021, compared to 3 GW of new gas, as illustrated in Exhibit 2. The latest interconnection queue for ERCOT tells an even starker story, with nearly all capacity either solar, wind, or storage; natural gas comprises a mere 5% of proposed capacity, as presented in Exhibit 3.

Exhibit 1: Current Texas capacity mix

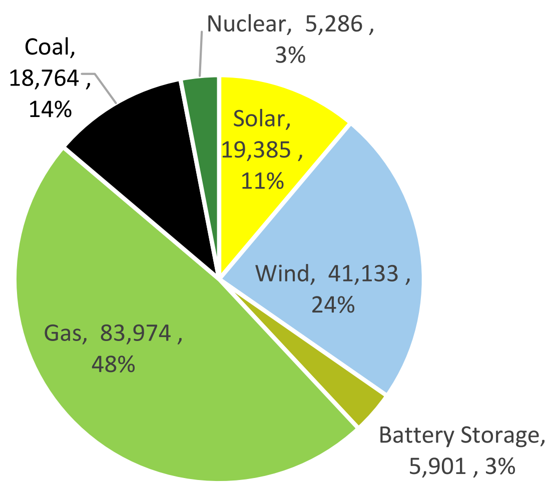


Exhibit 2: Recent ERCOT cumulative capacity additions

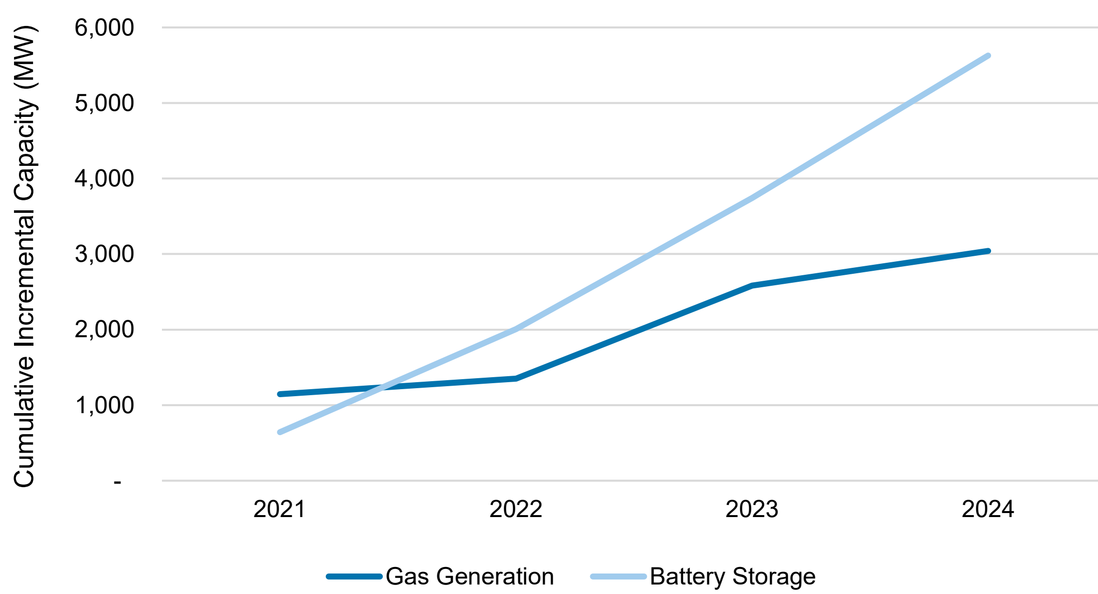
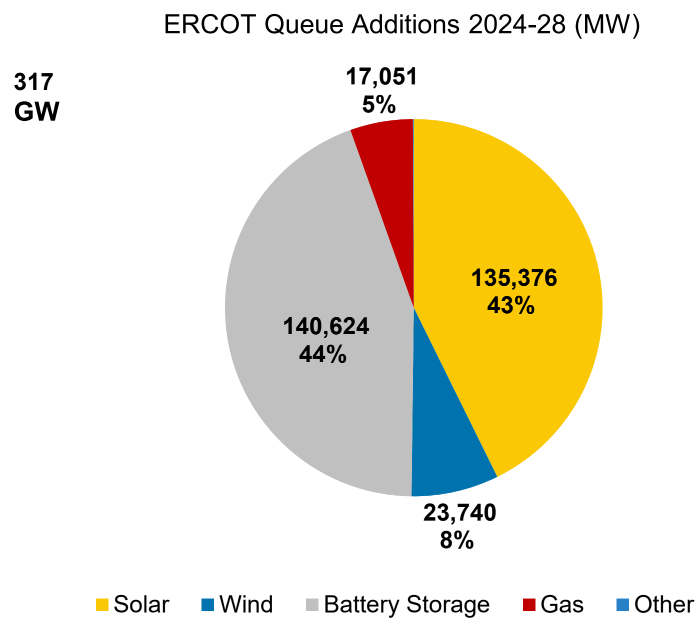


Exhibit 3: 2024-2028 ERCOT queue capacity breakdown



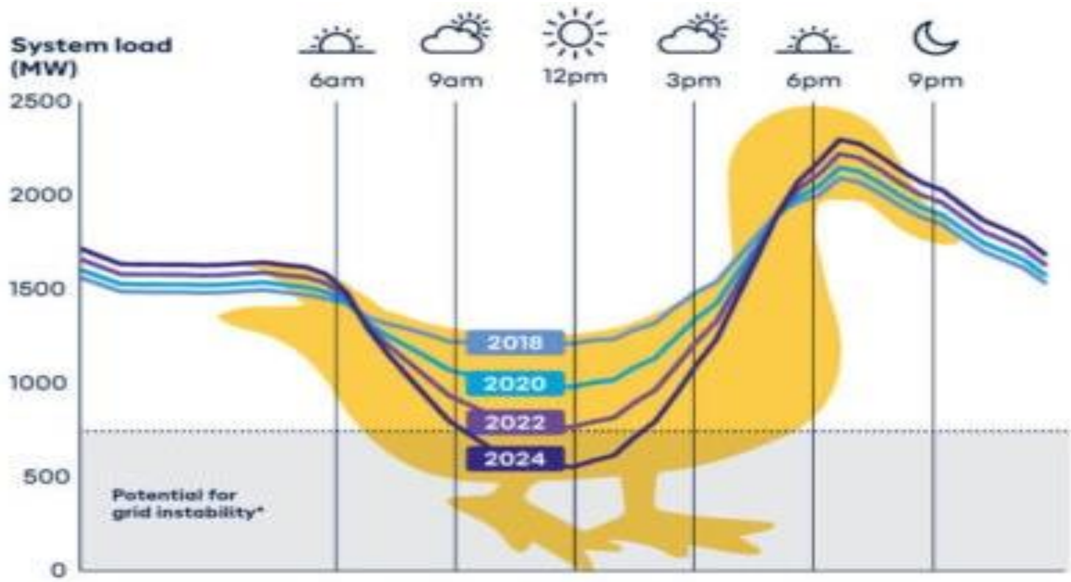
It remains uncertain how much of the capacity currently awaiting in the queue will be built, but developers clearly see a strong value proposition for batteries in the ERCOT market. Strong battery storage growth has also been witnessed recently in two other major markets with high levels of intermittent renewable energy penetration: Australia and California.

In Australia, the first large battery storage unit was constructed in Hornsdale, South Australia. Built in 2017, it is a Tesla, 150 MW/194 MWh lithium-ion facility. Initially, it generated most of its value through frequency support and other ancillary services; its fast response times proved superior to the older gas generators, which had previously served that market. It quickly captured more than half of the ancillary services market and reduced the cost for the frequency control product from $470/MWh to $40/MWh. Its operations brought the local ancillary services prices in line with the national energy market.

Since Hornsdale’s success, more battery storage facilities have been developed in Australia. This influx of new capacity, coupled with growing intermittent renewable energy generation, has shifted battery value streams towards energy arbitrage. The frequency control market is only ~600 MW in size on average and there are now nearly 2 GW of utility-scale batteries that could be competing in that space, driving down prices. There has been a consequential shift of new battery facilities with multi-hour duration to better serve the arbitrage market.

In California, the region’s immense solar capacity (both utility scale and behind the meter) has been both a blessing and curse for the grid. It is a source of low cost, carbon free energy, but when evening demand picks up, solar generation diminishes with the setting sun. This phenomenon creates what is referred to as a Duck Curve, due to the shape of the system’s net demand resembling a duck in the water (See Exhibit 4).

Exhibit 4: Duck Curve



Source: Synergy Electric Co-op

The summer evening period, which sees a combination of strong demand and declining solar generation, creates a significant ramp need. Historically, that need has been met with energy imports and natural gas peakers. However, California has been rapidly increasing its battery capacity, growing from less than 1 GW in 2020, to over 10 GW in 2024. The result in this expansion has been a significant displacement of natural gas generation during the ramping period of the duck curve. A typical April over the past several years would see a peak natural gas generation level between 9-10 GW during the peak hour. In 2024, however, that value was reduced by half, to 5 GW. With more batteries expected to be added to the California grid in the near future, this value could drop even further, especially as California moves towards a zero-carbon grid.

In a rather short period of time, batteries proved to be disruptive to traditional power generators in these two markets. In Australia, frequency control service prices were reduced to the point that battery facilities transitioned to an energy arbitrage strategy for revenue. In California, the rapid proliferation of battery capacity has begun the process of forcing natural gas peakers out of the evening ramping market. With little to no end in sight for new batteries in this market, these trends will likely continue and serve as a window into the future for other markets such as ERCOT.

ERCOT market analysis: Key input assumptions

CRA's analysis of the ERCOT market examined six different technologies with approximately 275 MW of installed capacity each: three thermal peaking technology types and three battery storage technologies of different duration, as summarized in Exhibit 5. Key technology specifications include unit size, efficiency, variable operations and maintenance (VOM) costs, fixed operations and maintenance (FOM) costs, installed capital costs, flexibility to ramp capacity up or down, and storage duration and cycle limits for battery resources. From an overall cost perspective, it is important to note that battery technologies were assumed to receive a subsidy equivalent to 40%

of their capital costs via the Investment Tax Credit (ITC).[1] Natural gas fired plants were assumed to receive a subsidy amounting to $120/kW from the Texas Energy Fund.[2] These subsidies are by no means certain their value has been tracked as a separate value stream.

Exhibit 5: Technology specifications

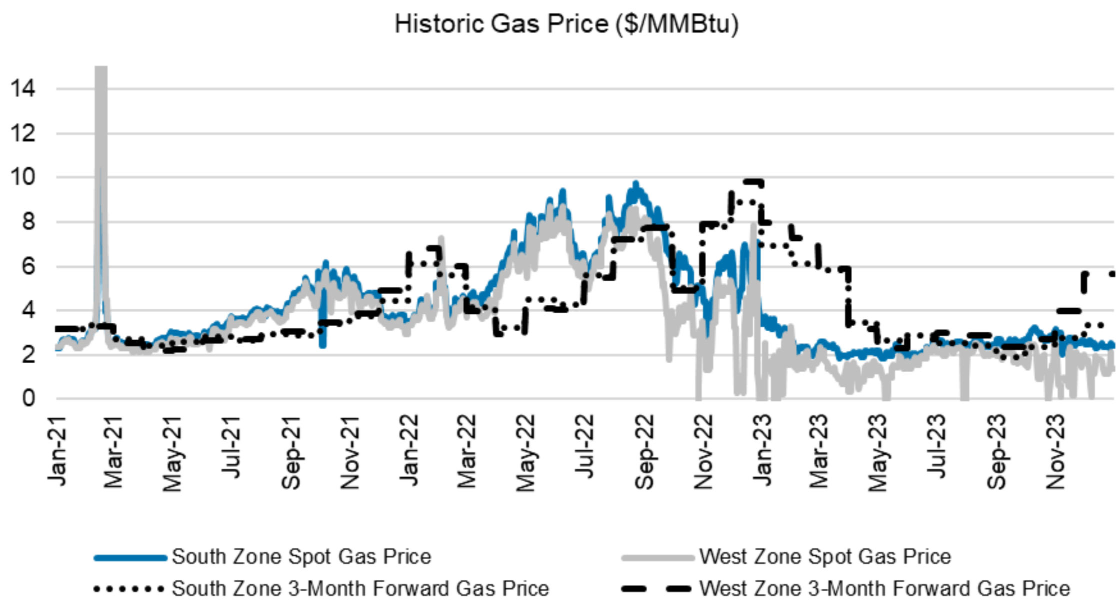
Resource	*Unit*	RICE	Aero CT	Frame CT	4-Hour Li-ion	8 Hour Li-ion	20 Hour Flow
Unit Size	*MW*	25	46.6	288	275	275	275
Block Size	*# of units*	11	6	1	1	1	1
Block Size	*MW*	275	279.6	288	275	275	275
Unit Minimum Capacity	*MW*	2.5	11.65	144	-	-	-
Block Minimum Capacity	*%*	0.9%	4.17%	50%	-	-	-
Heat Rate	*MMBtu/ MWh*	7,359	9,386	9,691	-	-	-
VOM	*$/MWh*	8.45	5.89	7.33	-	-	-
FOM	*$/kW-year*	15	9.89	26.99	43.00	76.86	15.64
Capital Costs	*$/kW*	1,250	1,428	867	1,706	3,070	4,697
Federal Subsidies	*$/kW-Year*	0	0	0	40% ITC	40% ITC	40% ITC
State Subsidies	*$/kW*	$80-$120	$80-$120	$80-$120	0	0	0
Unit Ramp Rate	*MW/Minute*	12.5	30	23	Instantaneous	Instantaneous	Instantaneous
Min Up Time	*Hours*	0.083	1	2	-	-	-
Min Down Time	*Hours*	0.083	1.1	1.25	-	-	-
Battery Efficiency	*% Retained*	-	-	-	85%	85%	70%
Battery Duration	*Hours*	-	-	-	4	8	20
Cycles per year	*#*	-	-	-	200	200	300
Cycles per day	*#*	-	-	-	Not restricted	Not restricted	Not restricted

[1] Note that the ITC is 30% for projects that meet prevailing wage and apprenticeship requirements, with an additional 10% adder available for projects located in “energy communities,” regions in proximity to retired coal infrastructure or in areas with high levels of employment in the fossil fuel industry and unemployment rates higher than the national average. Texas has many qualifying energy communities, so it has been assumed that new storage resources can qualify for a 40% ITC.

[2] Texas Senate Bill 2627 (SB2627) establishes a $7.2 billion low-interest loan program, also known as the Texas Energy Fund (TEF), for new or upgraded dispatchable generation resources of at least 100 MW. Texans voted to create the TEF through a constitutional election on November 7, 2023. The TEF will provide up to $5 billion of state funds for FY25-FY26, which will be eligible for natural gas generators.

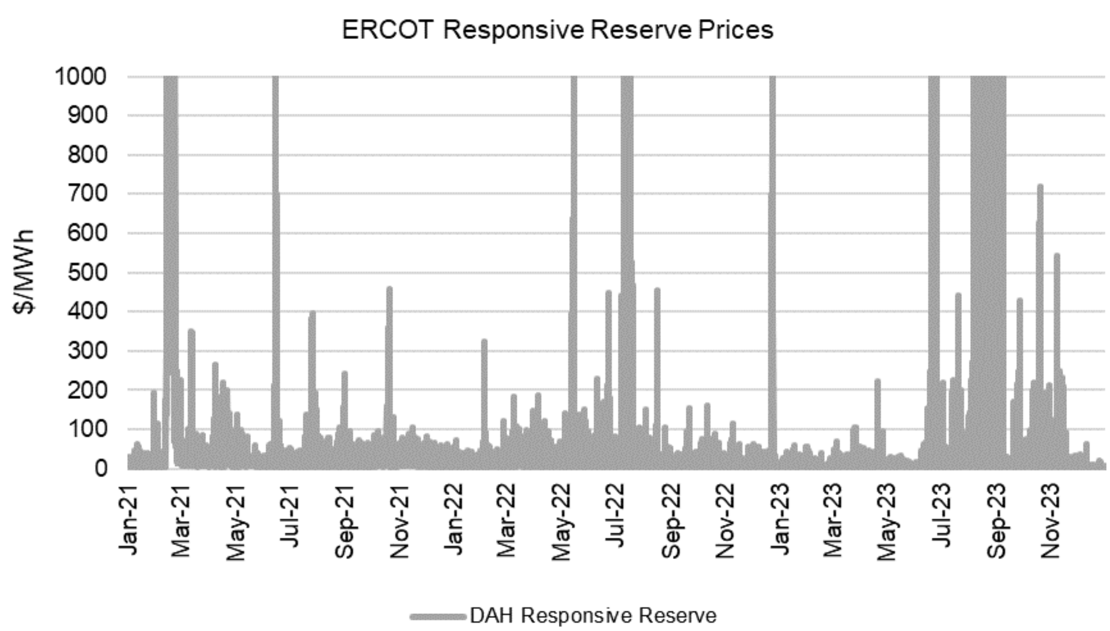
For natural gas prices for the thermal resources, CRA used both forward and spot gas prices for two ERCOT regions, as shown in Exhibit 6.

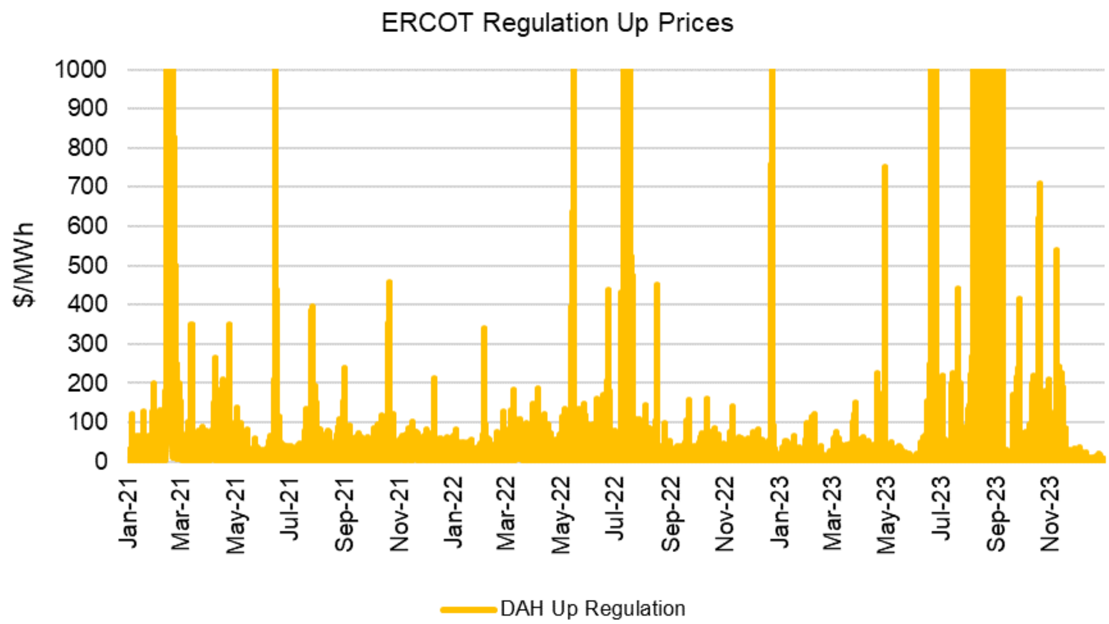
Exhibit 6: Historic natural gas price



Historical actual ERCOT ancillary service prices for responsive reserves and regulation up and down services were used, as shown in Exhibit 7, while historical 15-minute power prices for the ERCOT West and South regions were also used across the historical years of 2021, 2022, and 2023, as shown in Exhibit 8.

Exhibit 7: Historic ancillary service prices




ERCOT Regulation Up Prices
$/MWh
1000
900
800
700
600
500
400
300
200
100
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Jan-21
Mar-21
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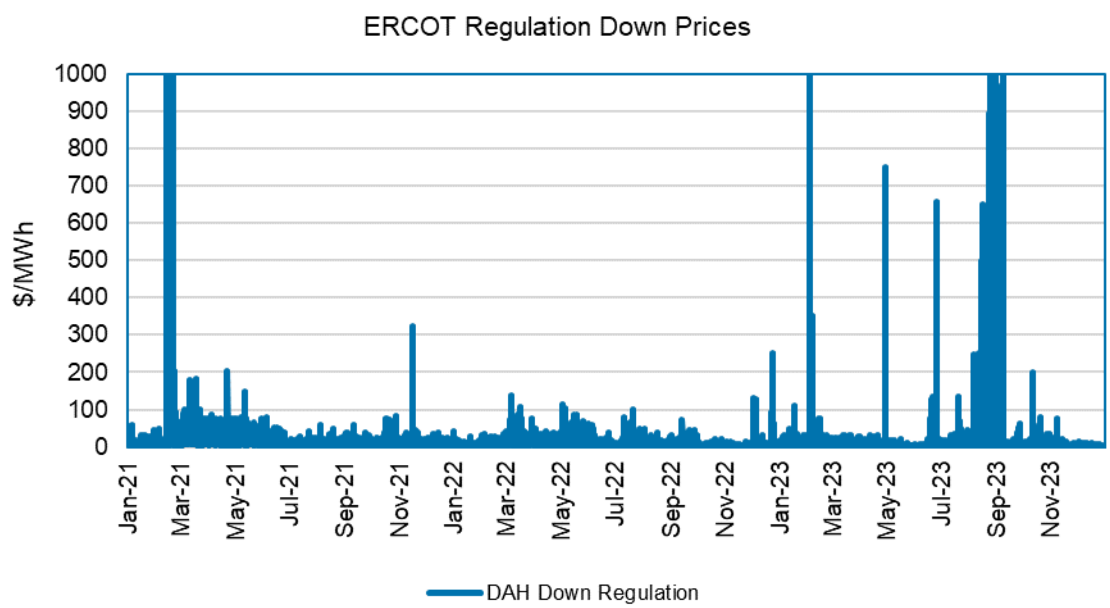
DAH Up Regulation


ERCOT Regulation Down Prices
$/MWh
1000
900
800
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Jan-21
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May-22
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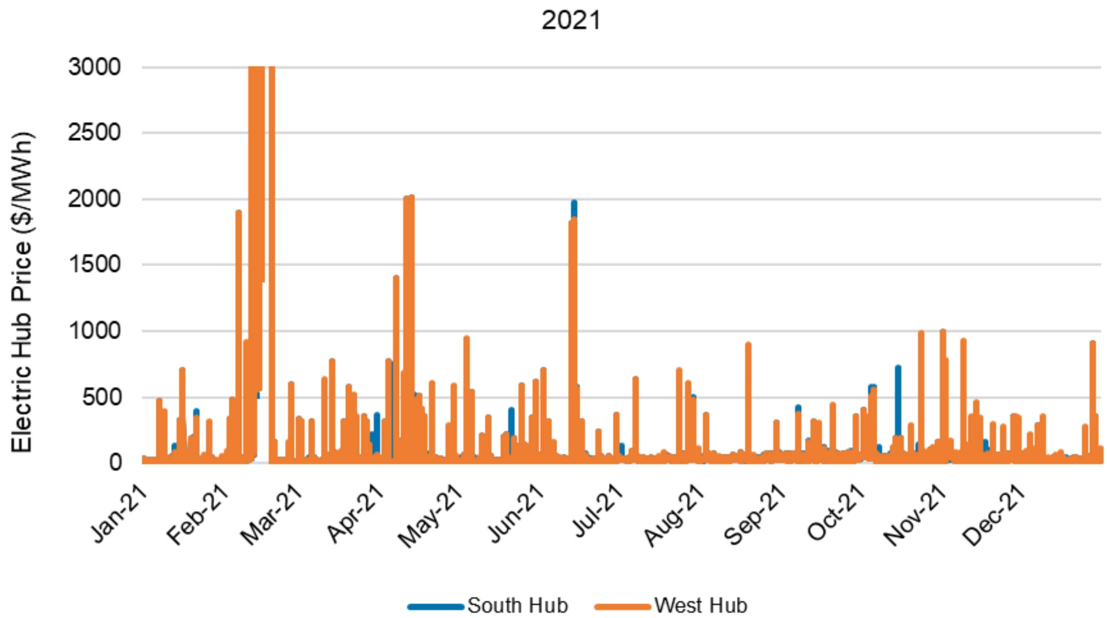
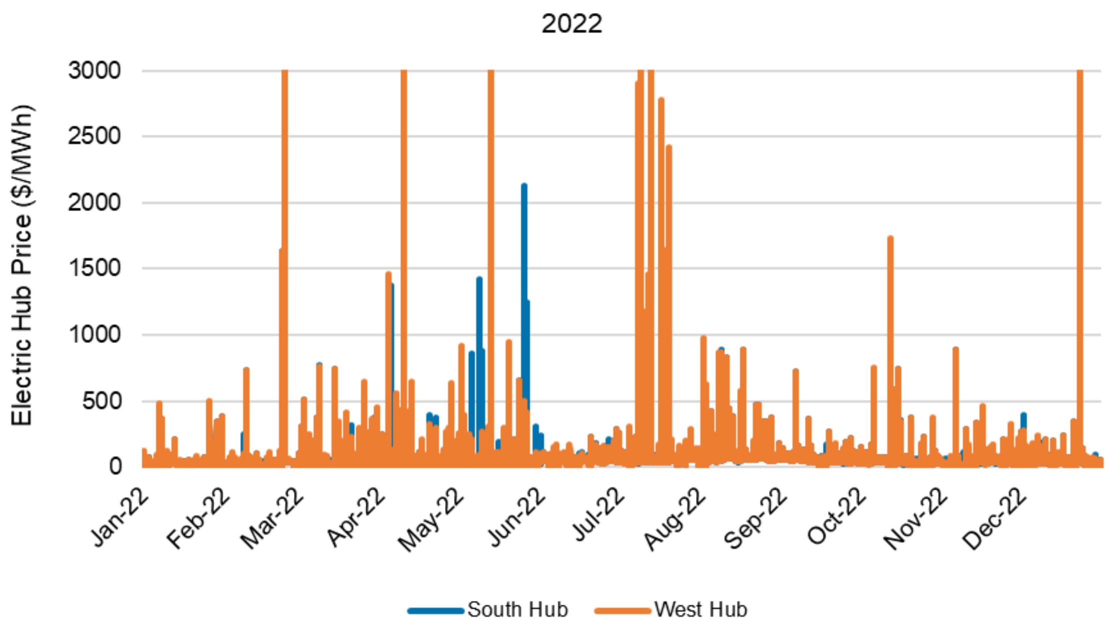
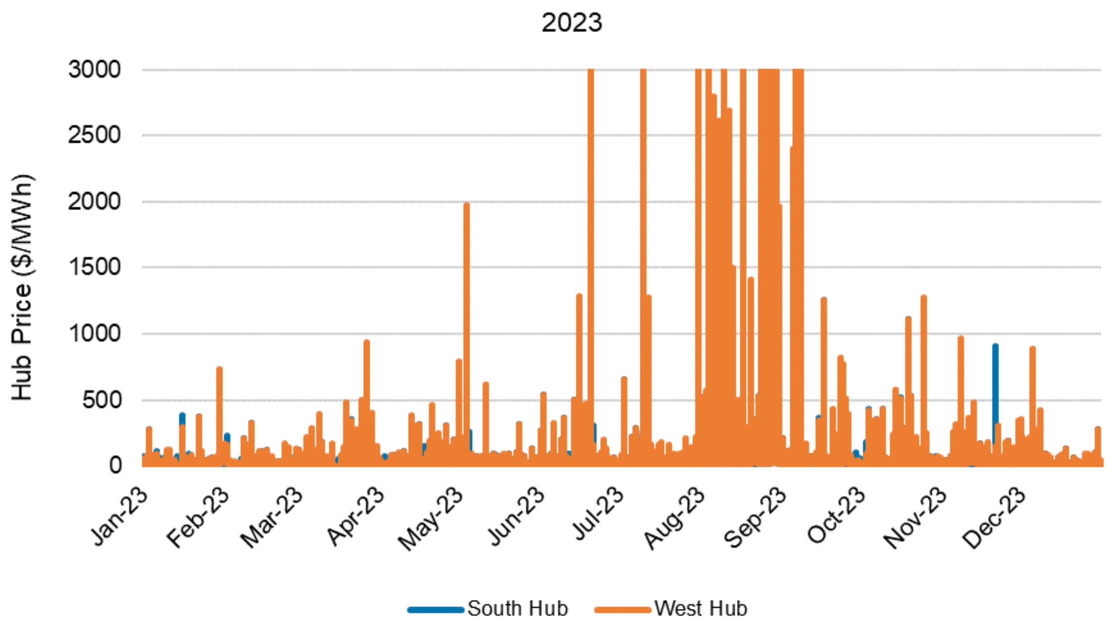
Nov-23
DAH Down Regulation

Exhibit 8: Historic 15-minute electricity prices







Historical data considerations

Due to extreme market conditions in February 2021, data from this month was ignored in the core value calculations. During this period, when Winter Storm Uri hit Texas, both power prices and ancillary service prices experienced sustained spikes. In the case of energy prices, the price cap ($9,000/MWh) was reached for several consecutive days. Given these outlier conditions, and the fact that market reforms have been instituted in response, the conditions caused by Winter Storm Uri, and the resulting revenues and costs for candidate technology options, would not be indicative of technology value. However, the analysis separately examined how the various technologies behaved during this extreme event.

Key findings and results

Overall, the battery storage technologies were projected to generate higher levels of revenue.[3] Their ability to take part in the ancillary service market when not actively discharging allows them to capture more ancillary service value, while the lion's share of revenue for the natural gas-fired resources was projected to come from the energy market. However, due to higher capital cost and fixed cost expectations, the battery resources were projected to generate lower total value. This is presented in Exhibit 9, which summarizes projected revenues and costs for the various 275 MW blocks of each technology option, and Exhibit 10 through Exhibit 15, which show the detailed revenue and cost components for each technology.

[3] It should be noted the ESOP model assumes perfect foresight of market prices in terms of facility operations, and an actual plant operator would be unlikely to realize the full potential value, particularly given competitive dispatch and system operator calls within the ERCOT market. Nevertheless, the analysis can still provide a relative value comparison of the various technologies.

Exhibit 9: Technology revenues and costs[4]

Millions $ - Net Revenue	West 4-Hour	West 8-Hour	West 20-Hour	West RICE Spot	West Frame Spot	West Aero Spot
2021	-37.83	-102.82	-79.73	-19.28	-25.46	-27.60
2022	-18.24	-83.08	-55.92	13.93	2.69	-0.74
2023	14.26	-49.12	-24.46	44.09	39.45	37.13
Total	**-41.91**	**-234.92**	**-160.00**	**38.75**	**16.69**	**8.79**

Millions $	West 4-Hour	West 8-Hour	West 20-Hour	West RICE Spot	West Frame Spot	West Aero Spot
Energy Revenue	146.49	187.64	183.90	234.68	198.58	205.07
Reserve Revenue	55.58	48.82	52.15	18.75	14.53	20.06
Reg Up Revenue	34.23	34.88	35.29	9.42	5.97	9.56
Reg Down Revenue	17.46	18.29	16.26	2.23	1.18	2.06
FOM Cost	-137.96	-246.59	-50.18	-48.13	-82.68	-57.90
Fuel Cost	0.00	0.00	0.00	-68.61	-52.76	-59.57
VOM Cost	0.00	0.00	0.00	-23.90	-14.56	-13.08
Charging Cost	-24.69	-37.99	-30.28	0.00	0.00	0.00
Capital Cost	-166.51	-299.64	-458.38	-94.78	-62.77	-106.50
Subsidy	33.49	59.69	91.23	9.10	9.10	9.10
Net Revenue	**-41.91**	**-234.92**	**-160.00**	**38.75**	**16.59**	**8.79**

[4] Across the board, the resources that operated in the West Zone generated slightly higher total value than those that operated in the South. Further, the natural gas resources that dispatched on spot gas prices instead of forwards, generated slightly higher value. The graphics showing technology revenues and costs for gas technologies will display the values for the West Zone and spot gas for simplicity. Results from the Southern Zone or using natural gas forwards resulted in total net revenues that were several million dollars below the West spot gas results.

Exhibit 10: Detailed revenue and cost components for 4-Hour battery operating in ERCOT West

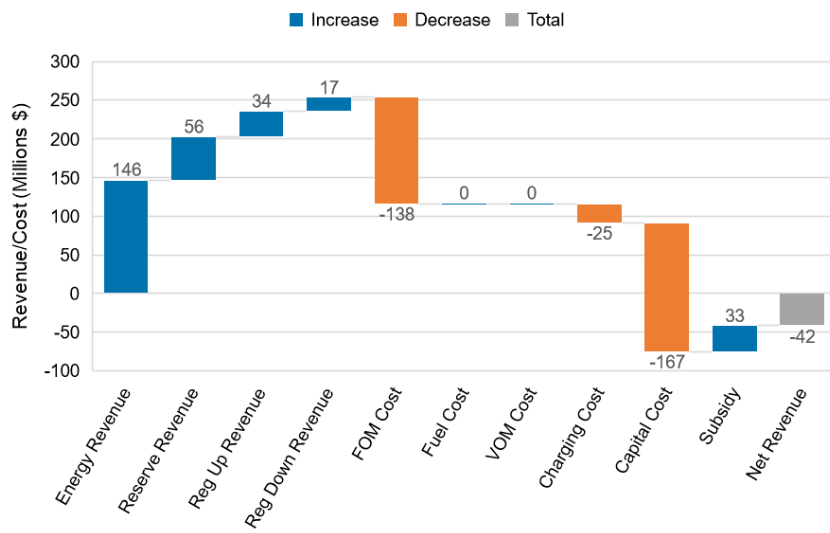


Exhibit 11: Detailed revenue and cost components for 8-hour battery operating in ERCOT West

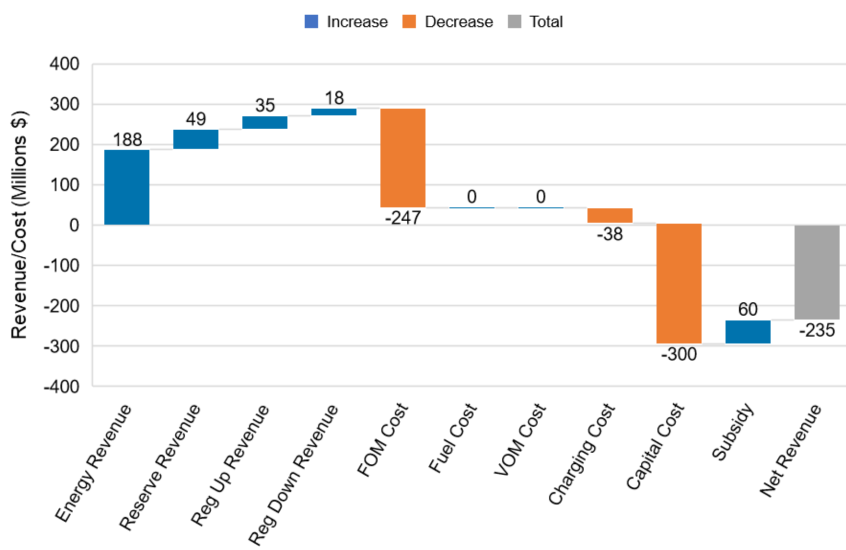


Exhibit 12: Detailed revenue and cost components for 20-hour battery operating in ERCOT West

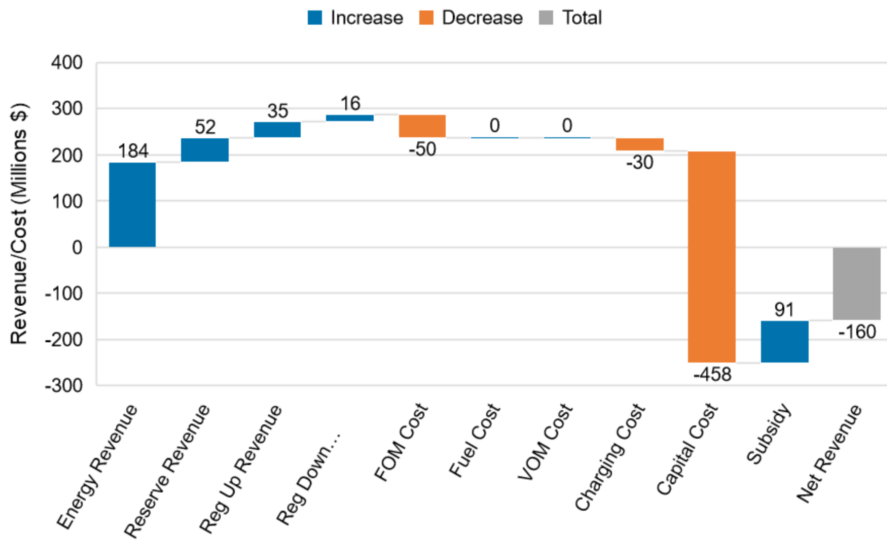


Exhibit 13: Detailed revenue and cost components for RICE operating under West spot gas prices

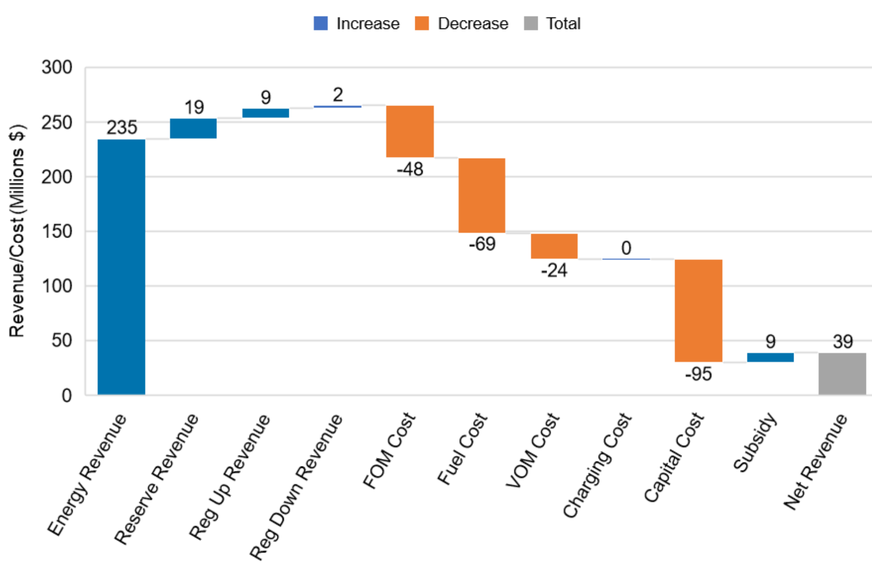


Exhibit 14: Detailed revenue and cost components for Aero operating under West spot gas prices

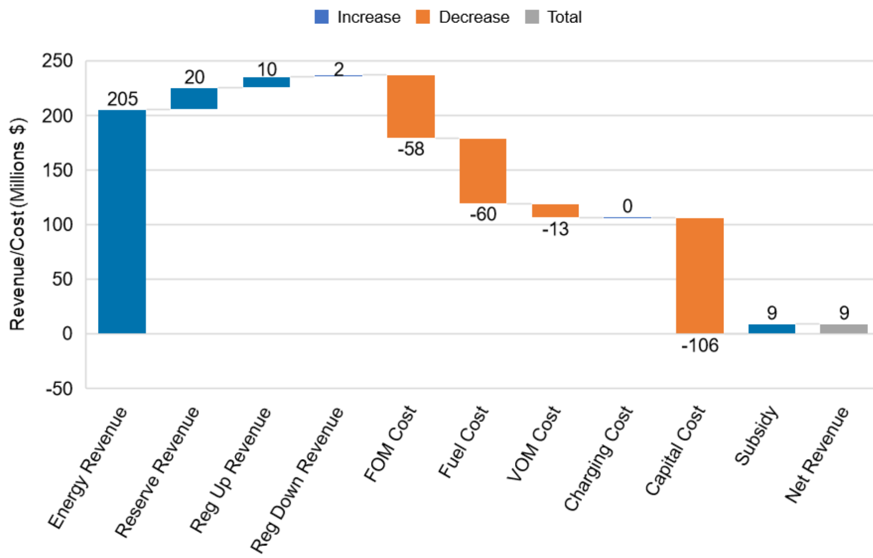
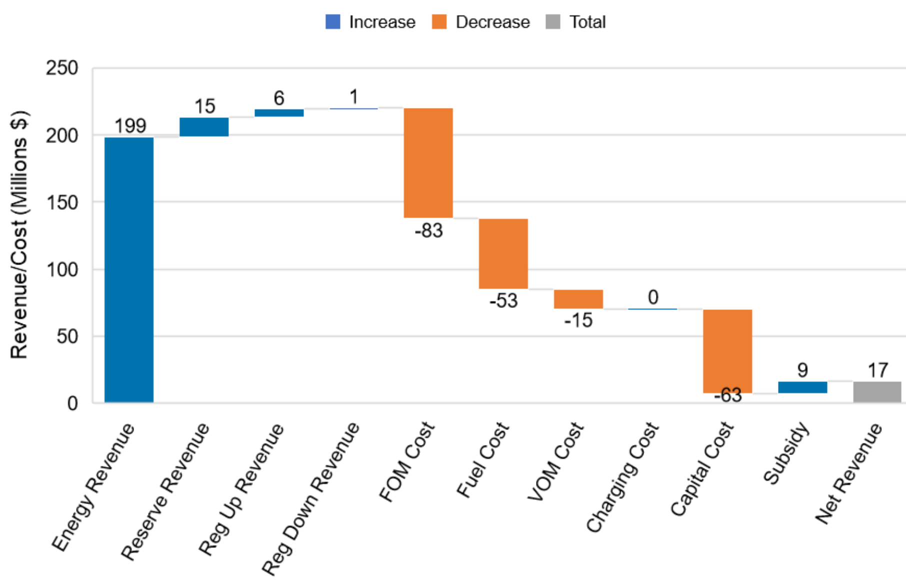


Exhibit 15: Detailed revenue and cost components for Gas Frame operating under West spot gas prices



For the most part, the natural gas fired technologies were projected to receive the vast majority of their revenue from the energy market, with ancillary revenue fluctuating between 0% and 20% over the years. This is shown in Exhibit 16 through Exhibit 18.

Exhibit 16: RICE revenue share by market, under spot gas prices

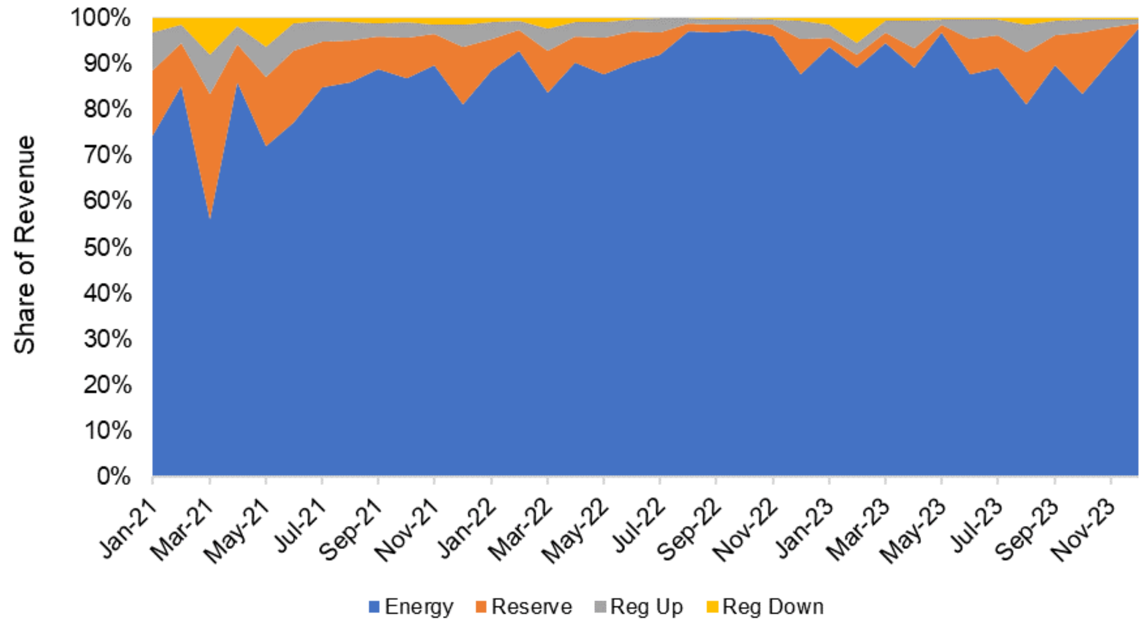


Exhibit 17: Frame revenue share by market, under spot gas price

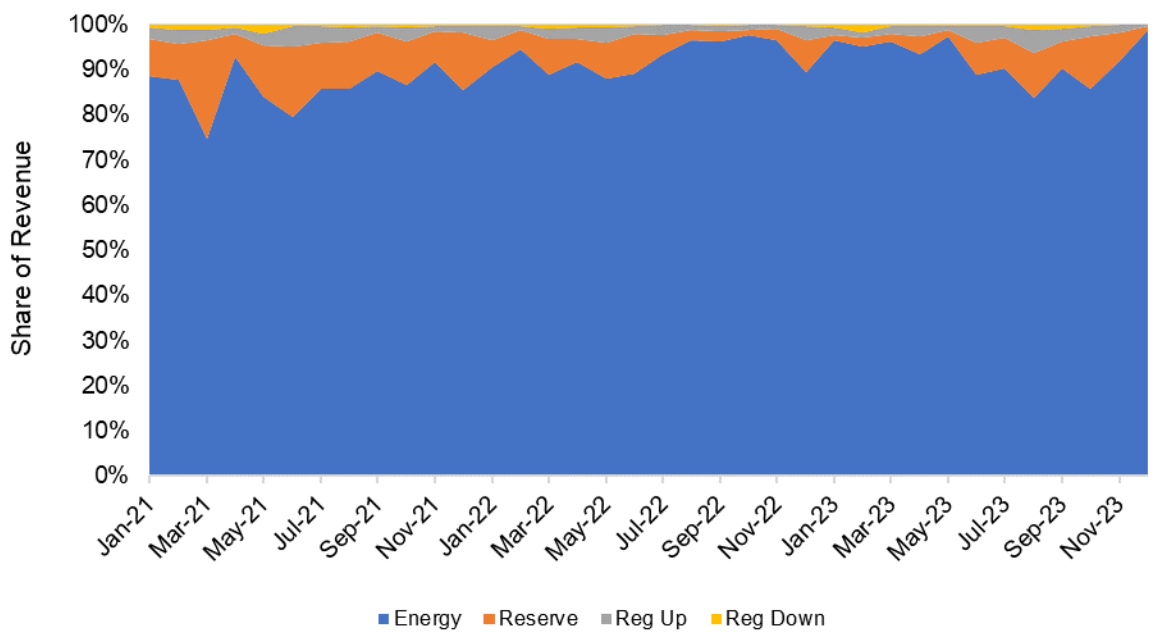
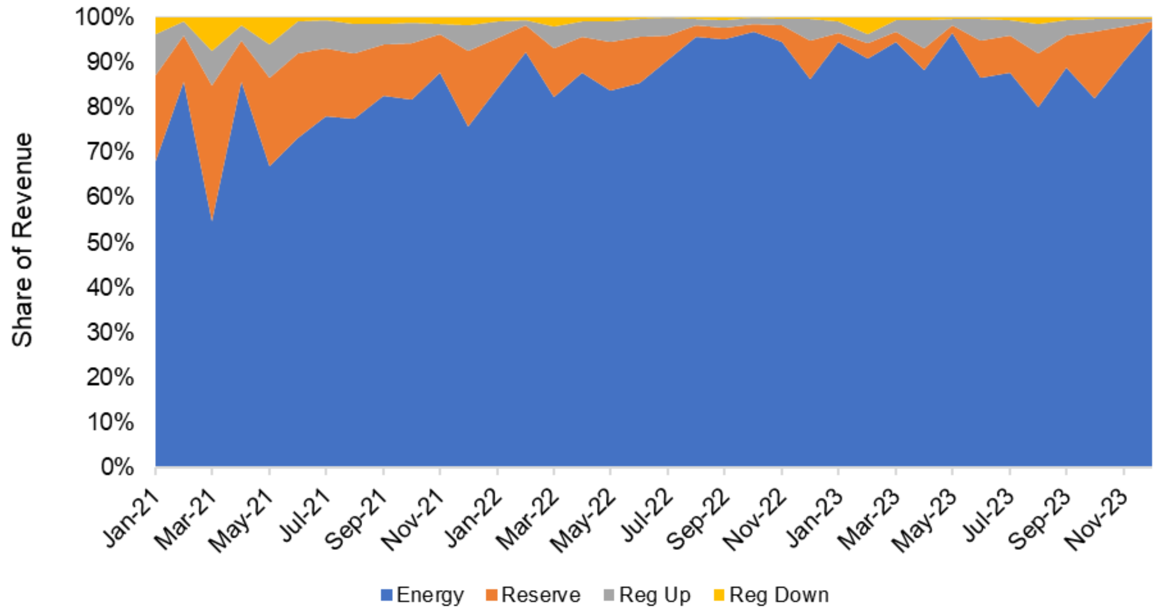


Exhibit 18: Aero revenue share by market, under spot gas price



Battery technologies, however, were projected to have a more diverse revenue stream, with only 60-65% of revenues coming from the energy market. This is in part due to batteries' ability to provide ancillary services when not in a state of operation, providing a lower cost threshold to generate profit in these markets than a gas resource would. This flexibility allows batteries to be more active in ancillary markets. The battery technologies' share of revenue is shown in Exhibit 19 through Exhibit 21.

Exhibit 19: 4-Hour battery revenue share by market, operation in ERCOT West

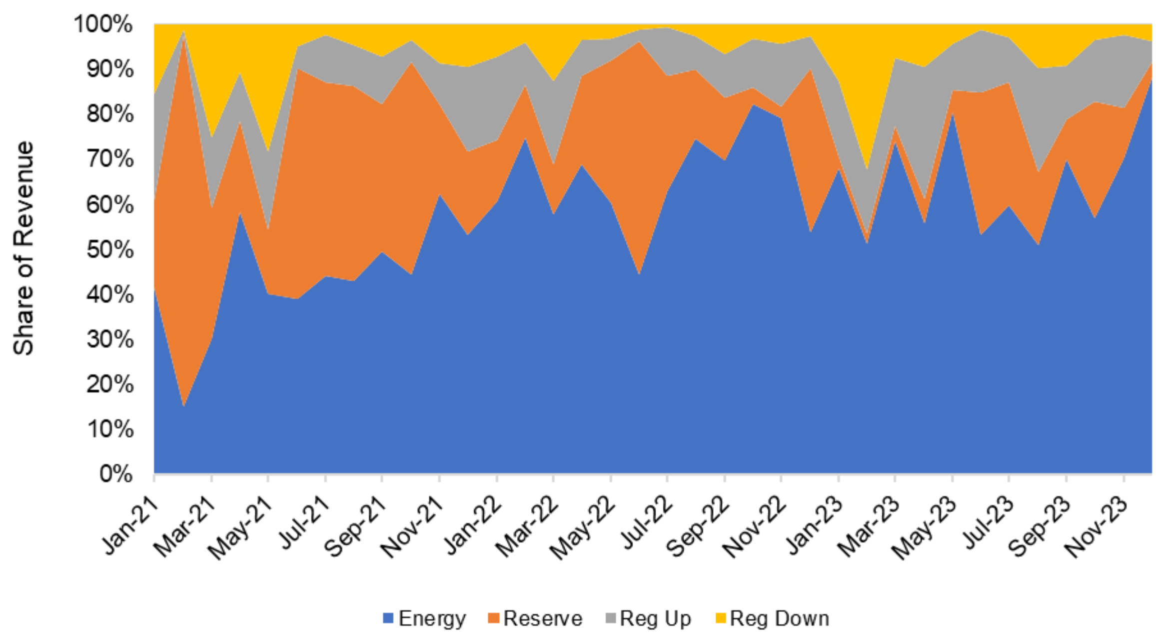


Exhibit 20: 8-Hour battery revenue share by market, operation in ERCOT West

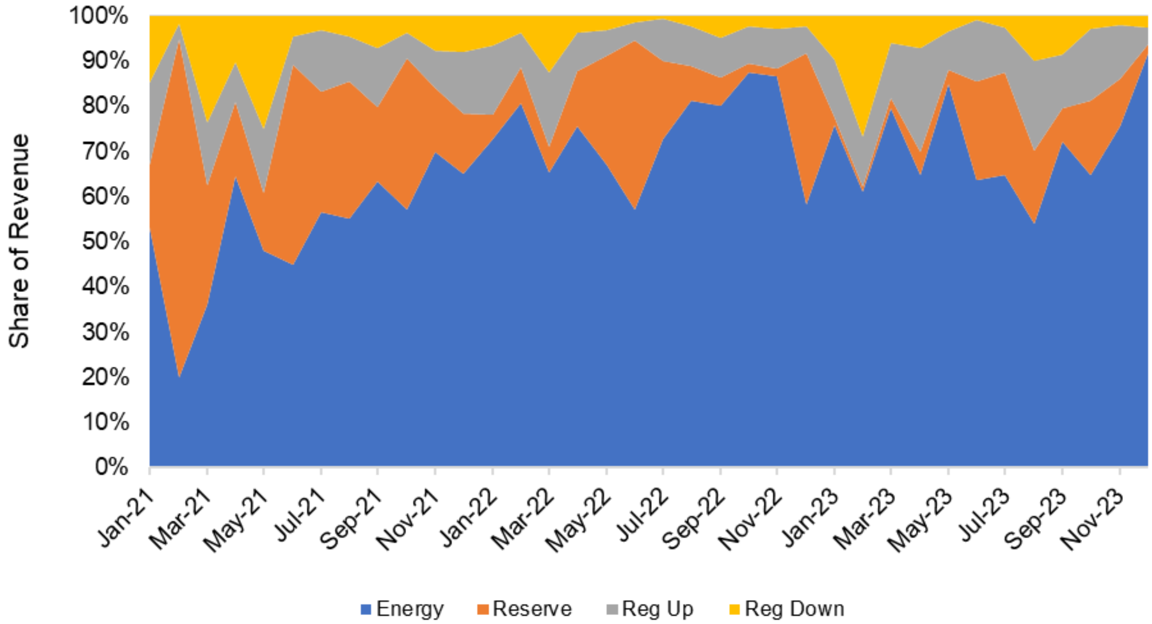
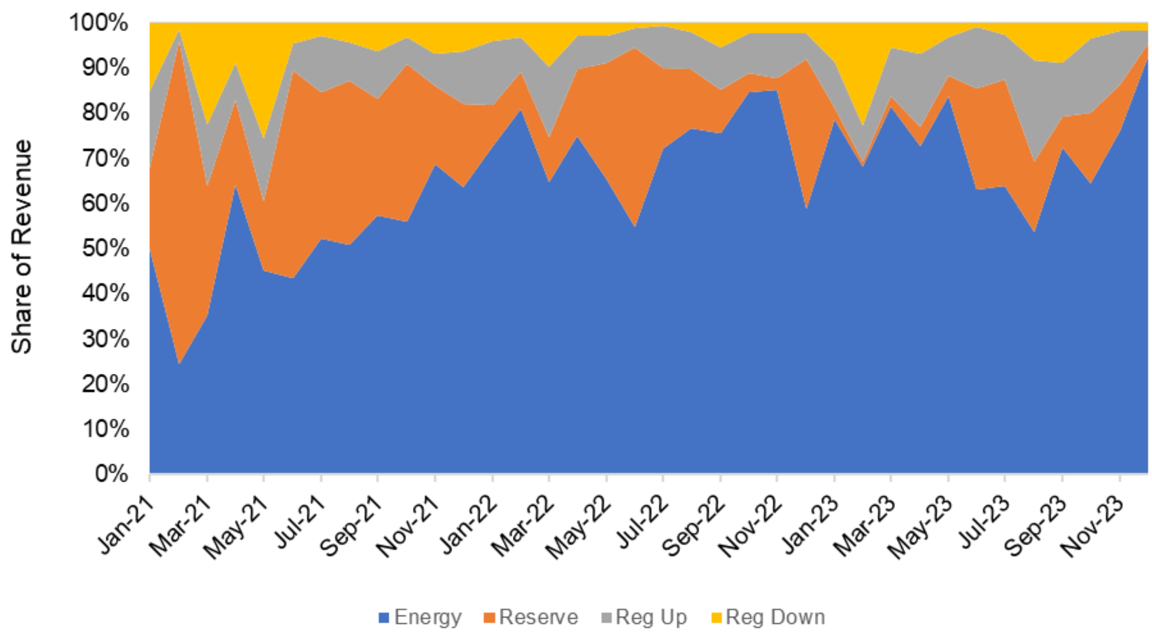


Exhibit 21: 20-Hour battery revenue share by market, operation in ERCOT West



Discrete event analysis

CRA also examined revenue, cost, and total value projections for the six technologies analyzed during three weekly periods that represented significantly different market behavior:

- February 2021: Winter Storm Uri, which resulted in sustained prices at or near the market price cap (see Exhibit 22).
- July 2022: A period with extreme spikes driven by hot weather, with lower price periods interspersed (See Exhibit 23).
- May 2023: A period with relatively stable prices (See Exhibit 24).

Exhibit 22: February 2021 hourly energy prices for a week

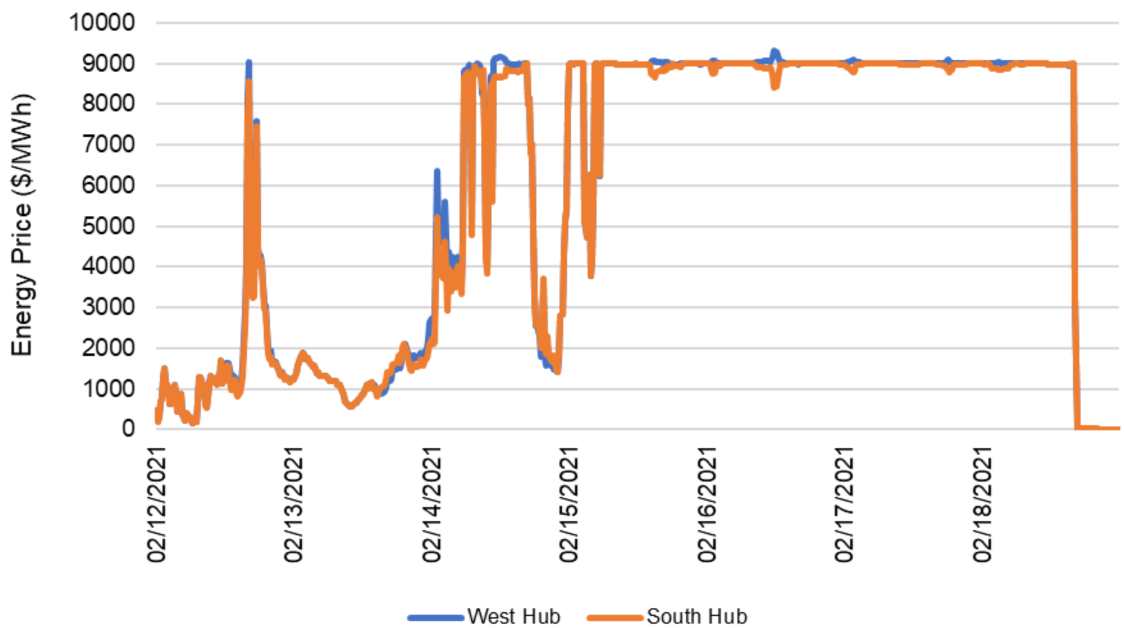


Exhibit 23: July 2022 hourly energy prices for a week

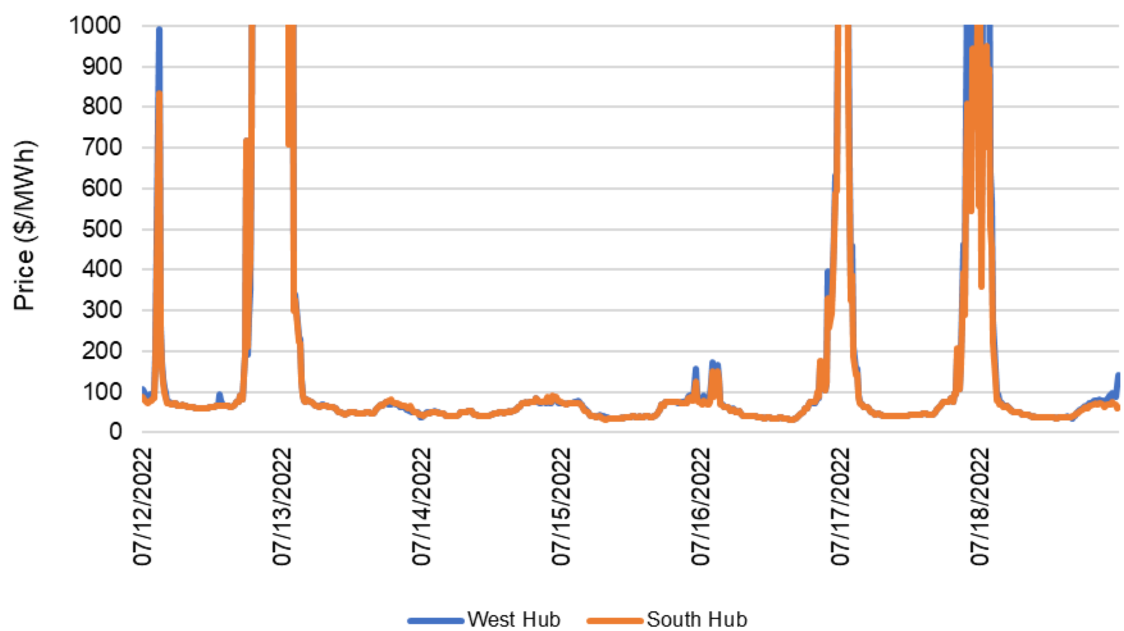
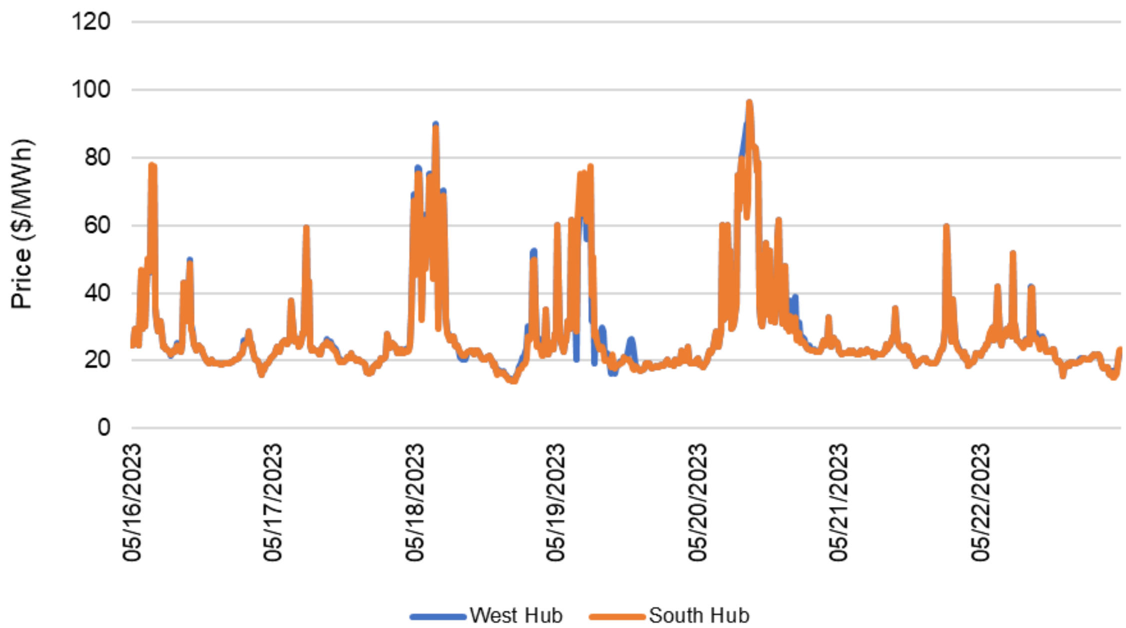


Exhibit 24: May 2023 hourly energy prices for a week



Extreme weather event: Winter Storm Uri (February 2021)

Over this period of sustained high prices, the natural gas units were projected to generate more revenue and, after taking into account charging costs; VOM; fixed costs; capital costs; and fuel costs, slightly more net revenue (See Exhibit 25). Although facing high fuel costs, the units were still able to generate slightly more value. The vast majority of the revenue generated (~90%) came from energy sales. It is worth noting that to achieve this in the real world, these technologies would need access to a firm fuel supply. For example, in the event of natural gas supply issues, the resources' ability to generate energy from non-pipeline fuels, such as ammonia and onsite fuel oil storage, would allow these technologies to perform even in harsh conditions such as Winter Storm Uri.

Batteries were at a disadvantage during the sustained high price period, as any charging they undertook was at extremely high prices. As such, the battery technologies garnered most of their revenue (70-80%) from ancillary services. Instead of daily cycling, with the batteries nearly emptying during high price periods and charging during low price periods, the batteries did little charging during the sustained high price period and contented themselves with either meeting ancillary service demand or, in the case of the 20-hour battery, slowly drawing down its charge over the course of several days (See Exhibit 26).

Exhibit 25: Net revenue by technology for February 2021 sample period

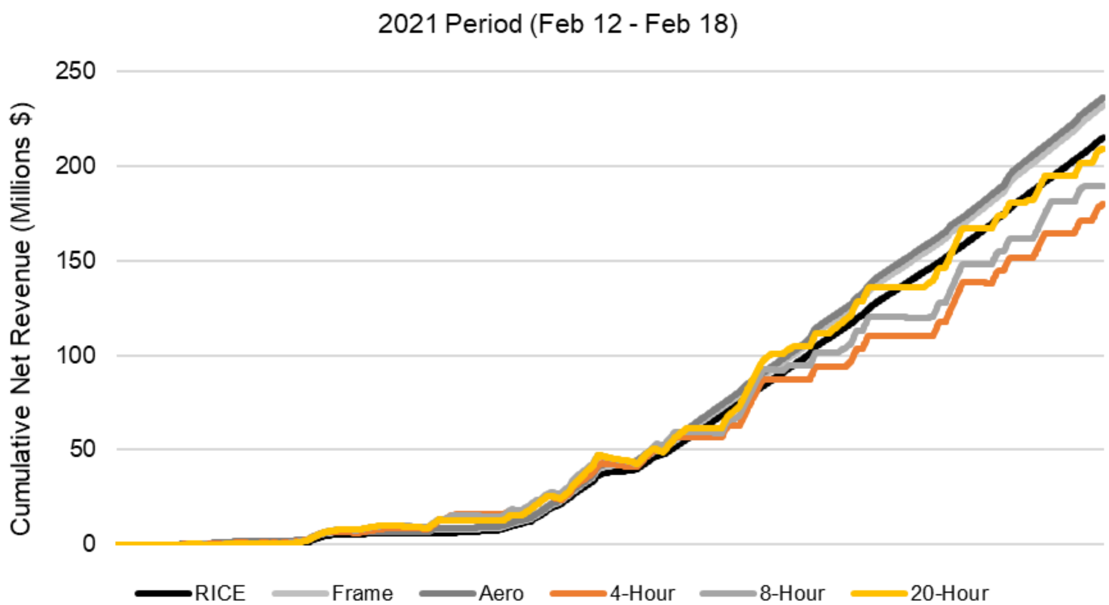
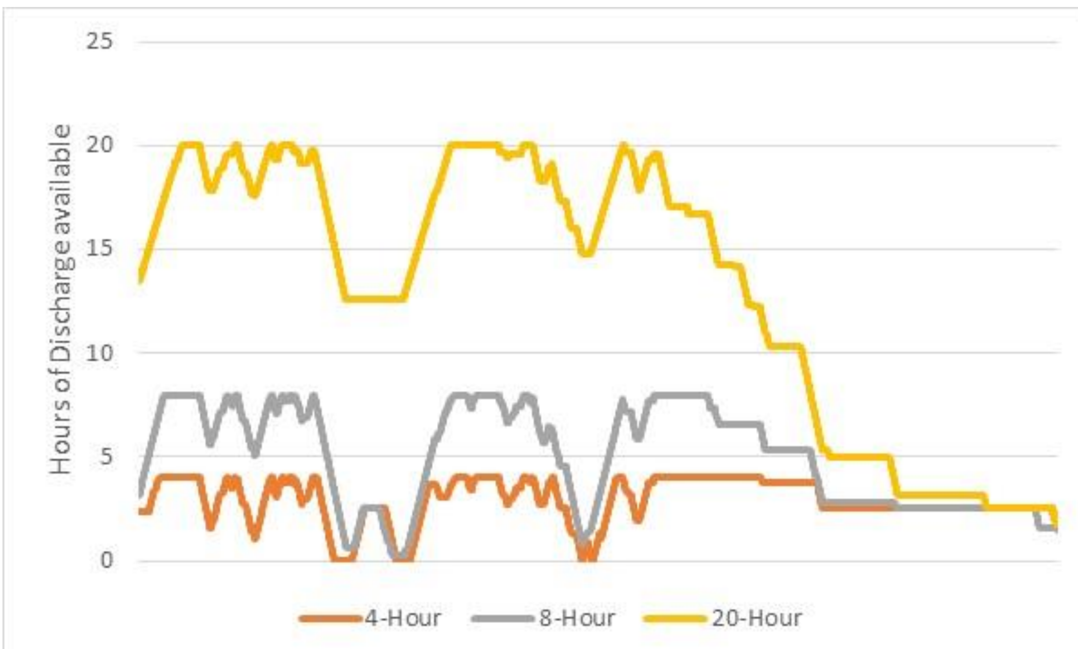


Exhibit 26: Battery state of charge projection for February 2021 sample period



Extreme weather event: July 2022

During this period of volatile prices, both natural gas-fueled resources and battery resources were projected to generate the majority of their revenue from the energy market. The spikes in revenue generated by these technologies can be clearly seen aligning with energy price spikes, as shown in Exhibit 27, relative to the price behavior documented earlier in Exhibit 23. When all costs were taken into account, the 20-Hour battery generated the most value, followed by natural gas resources, and then the rest of the battery technologies.

Battery storage technologies behaved in a more traditional manner during this period, charging and discharging in a regular pattern throughout the week, as shown in Exhibit 28.

Exhibit 27: Net Revenue by Technology for July 2022 Sample Period

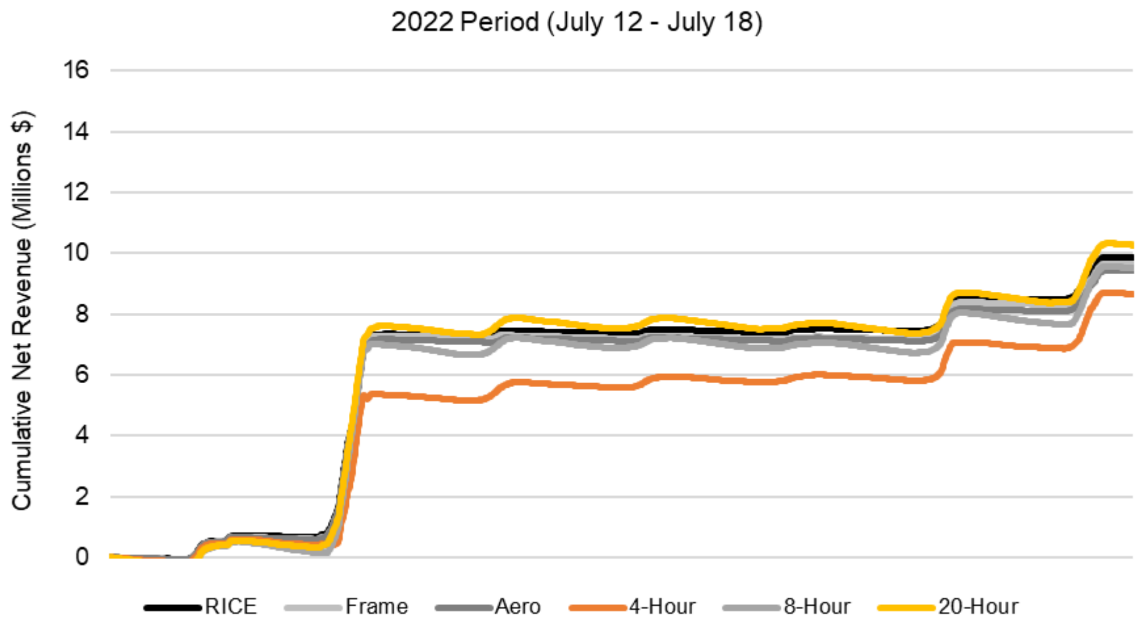
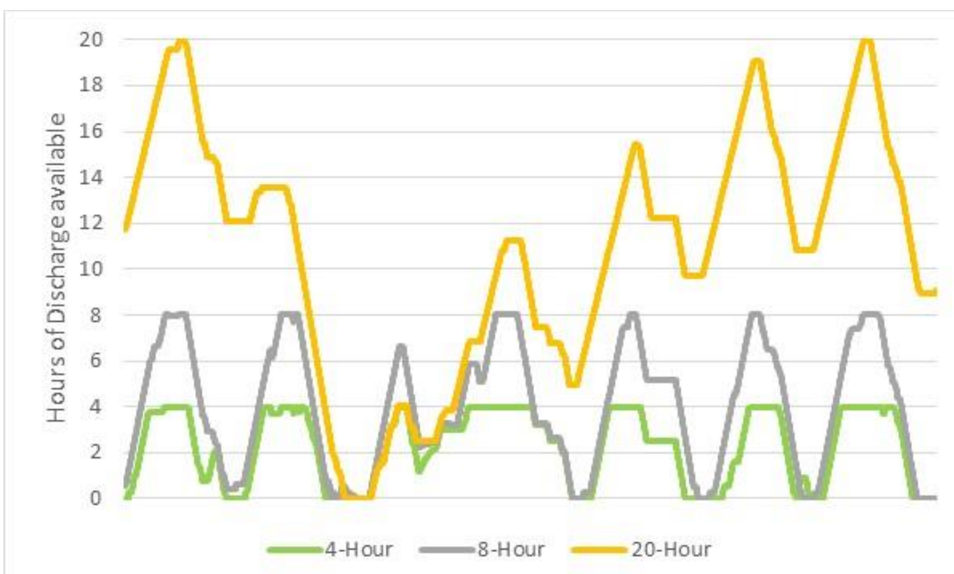


Exhibit 28: Battery state of charge projection for July 2022 sample period



Calm shoulder month period: Spring 2023

This interval, representing a calm period of market prices, demonstrated that there can be durations of net loss for all technologies when fixed costs are taken into account (See Exhibit 29). The price differences over the week and ancillary service prices were insufficient for battery technologies to return positive value, even while active during this period (See Exhibit 30). Natural gas units' lower FOM and capital costs reduce the financial downside of the technologies when energy margins are low. The negative trend of these technologies during this period are driven by capital and fixed costs.

Exhibit 29: Net revenue by technology for May 2023 sample period

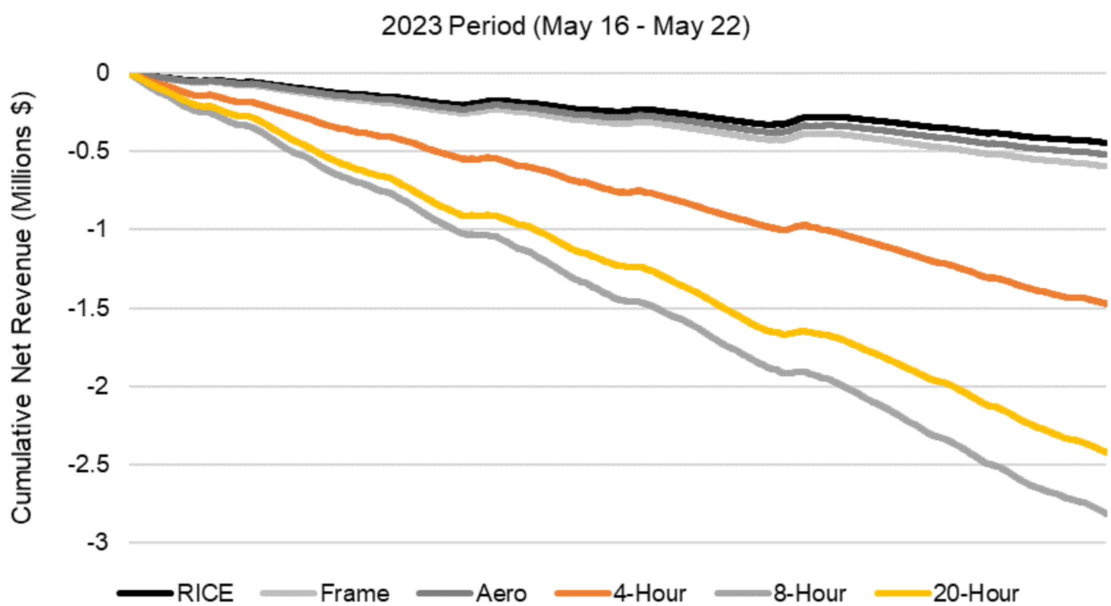
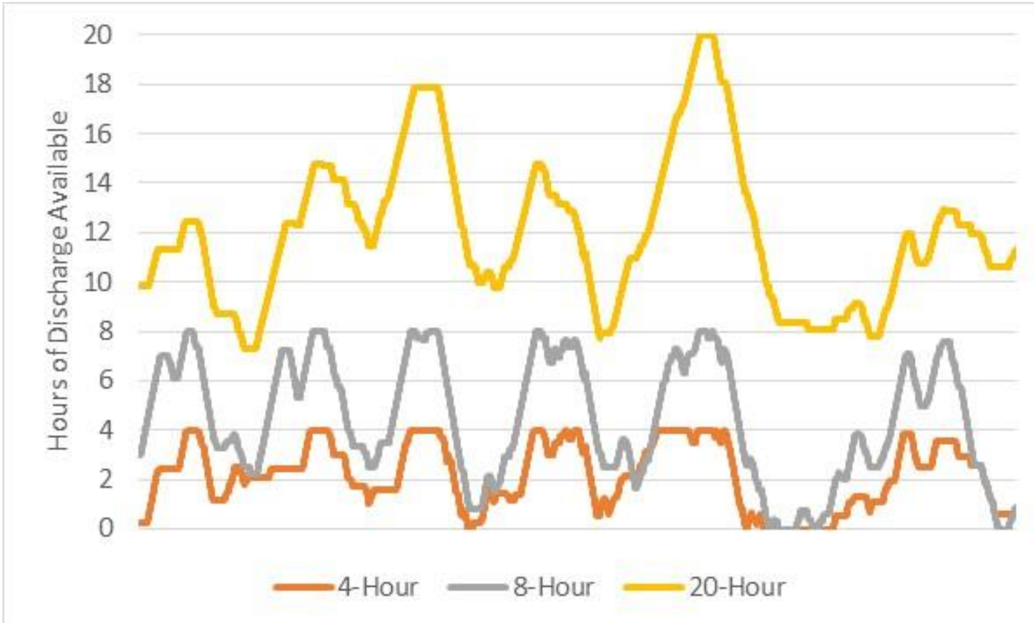


Exhibit 30: Battery state of charge projection for May 2023 sample period



Additional considerations

Besides CRA's quantitative analysis on the performance of these technologies, additional qualitative factors should be considered when evaluating various flexible natural gas-fueled and battery storage technologies:

Resource block size

Block size for natural gas technologies are quite important. To reach a size of ~275 MW, CRA modeled a facility consisting of eleven RICE units, a facility of six aero units, and a facility of only one frame unit. The smaller capacity size of RICE and aero units allowed them to achieve their maximum heat rate efficiency at lower capacity levels than the less expensive frame unit. Effectively, the RICE and aero facility would have a heat rate curve that achieves its most efficient level at a much lower energy capacity utilization.

Additionally, the use of multiple smaller units mitigates forced outage risk. The loss of a RICE unit would diminish the effective capacity of a 275 MW RICE facility by only 9%. For an aero facility of a similar size, the loss of a unit would reduce effective capacity by ~17%. If a frame unit went offline, the full capacity would be unavailable for operations. Likewise, the distributed nature of smaller resources allows a facility to stage its maintenance cycles in a way that permits for significant portions of the facility to remain online and capable of operations.

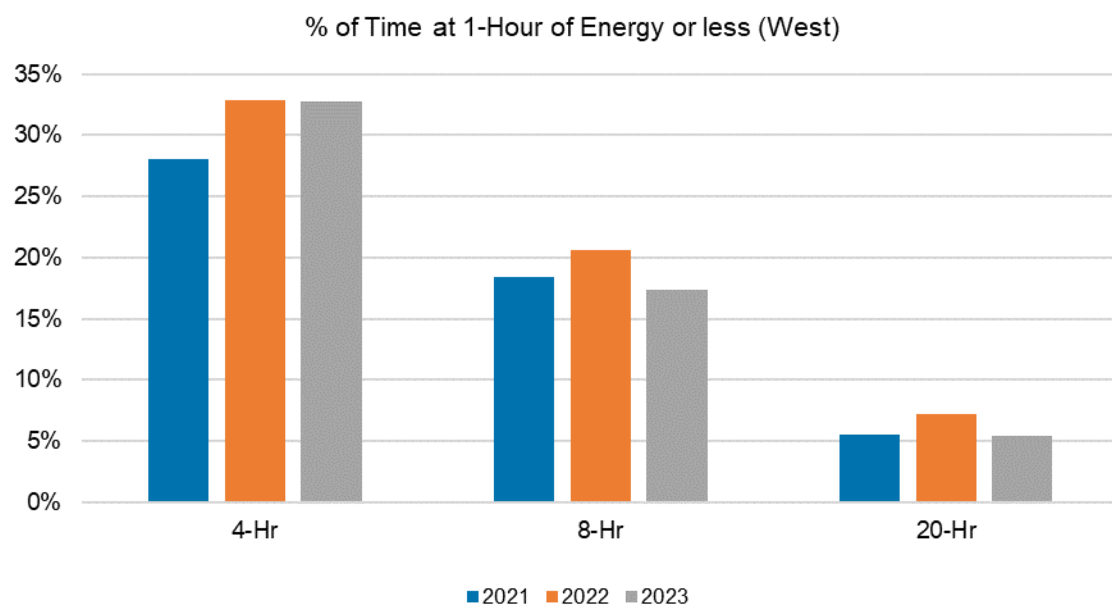
Finally, within the ERCOT system, bidding block size is set to 25 MW. Smaller resources allow a facility finer control over how it presents its resources to the market. Instead of committing the full capacity of a facility into the energy or ancillary services market, a RICE or an aero facility could commit some units to the energy market and others to the ancillary service market. The ESOP model assumes perfect knowledge of price formation, so the ability of operators without perfect foresight to hedge their facility's commitments provides an advantage over large nameplate resources like a frame unit.

Long-duration dispatchability during extreme events

Winter Storm Uri demonstrated the need for reliable and resilient resources to maintain grid operations. Natural gas resources generally have the capacity to store and burn alternative fuels at their facilities, allowing for continued operations even in the event of natural gas supply disruptions. Storage technologies are net energy consumers, losing some energy in the charging/discharging process. During a period of tight energy supplies it may not be feasible to charge battery facilities. CRA's analysis demonstrated that storage facilities are likely to be primarily serving the ancillary service market during a period of sustained prices at the market cap, with limited energy discharge into the system.

As shown in Exhibit 31, over the course of the analysis, battery technologies frequently operated in a manner that left storage capacity at or below one hour of full discharge. 4-hour batteries were at or below one hour of full discharge in roughly 1 in 3 hours of the year. For the 8-hour battery this value was roughly 1 in 5 hours, and for the 20-hour battery 1 in 20 hours. For producing a sustained energy supply during periods of tight energy supplies, LDES or traditional generators are needed. Shorter duration storage resources will lack the storage reserves needed to weather the tight energy conditions. Even LDES, such as 20-hour battery storage facilities, will not be capable of contributing significant energy into the system for more than a day.

Exhibit 31: Percentage of time battery storage units retained one hour of full discharge



Future market considerations

ISOs are considering or in the process of changing the capacity accreditation for generation technologies in their jurisdiction. The trend in these reassessments has been declining capacity accreditation for renewable technologies and shorter duration (4-hour and less) battery systems, especially as these technologies grow in their share of capacity. Traditional generators like gas turbines and engines maintain a high and steady capacity value under the new rules. Additionally, the presence on site fuel storage enhances these technologies' capacity value as they would be capable of providing reliable energy supplies during periods of fuel supply interruptions.

Many states and utilities have aggressive carbon emission targets. These targets are challenged by the rapid growth of data center demand in many localities and their near constant energy needs. To meet both new data center load and environmental targets, larger levels of renewable or carbon free energy is needed. Batteries' ability to shift energy from surplus hours to higher demand hours (albeit at a loss) will assist in this transition, but only as facilitators of renewable generators. Absent surplus renewable generation, storage technologies may struggle to secure consistent, low-cost renewable energy from their system. New gas turbines and engines that are capable of burning carbon free fuels (such as ammonia) or hydrogen offer an alternative energy source to meet carbon free energy targets and growing data center demand with on demand generation capabilities.

Conclusions

CRA's analysis demonstrated that the ERCOT market provides different value opportunities for different resource types. Overall, natural gas technologies offer lower fixed cost resources that can generate energy for extended periods of time, especially when paired with on-site alternative fuel storage. Meanwhile, storage technologies offer more flexibility for ancillary service market participation and can absorb energy during low price periods for use during higher priced periods. The analysis showed that, excluding February of 2021, roughly 33% of the storage technologies' revenue was projected to come from the ancillary service market compared to ~10% for gas technologies.

For a system that values a technology that can provide firm, reliable energy during prolonged periods of grid stress as well a flexible and fast responding energy resource, RICE and other flexible gas resources provide the best value. Coupled with future clean fuel flexibility and durable capacity accreditation, these technology options offer a wide variety of long-term benefits to a system even in a carbon limited future.

For a system that values operational flexibility and has a high level of intermittent generation that is misaligned with system demand, a battery option may provide higher value. Batteries allow operators to be more active in ancillary service markets and take more advantage of volatile price periods. However, ancillary service markets are at risk of over supply as more batteries are brought online, risking a repeat of the Australian experience where high levels of storage resources significantly diminished ancillary service product prices.

Taking all revenue and cost streams into account the gas fired generators had a higher value compared to storage technologies over the analyzed period (2021-2023), with the RICE unit providing the highest value among the tested technologies.

Exhibit 32: Technology revenues and costs

Millions $ - Net Revenue	West 4-Hour	West 8-Hour	West 20-Hour	West RICE Spot	West Frame Spot	West Aero Spot
2021	-37.83	-102.82	-79.73	-19.28	-25.46	-27.60
2022	-18.24	-83.08	-55.92	13.93	2.69	-0.74
2023	14.26	-49.12	-24.46	44.09	39.45	37.13
Total	**-41.91**	**-234.92**	**-160.00**	**38.75**	**16.69**	**8.79**

About CRA's Energy Practice

Charles River Associates is a leading global consulting firm that offers strategic, economic, and financial expertise to major corporations and other businesses around the world. CRA's Energy Practice provides services to a wide range of industry clients, including utilities, ISOs, RTOs, large customers, and investors. The Energy Practice has offices in Boston, New York City, Washington DC, Toronto, London, Houston, Los Angeles, Salt Lake City, Dusseldorf, and Munich. Learn more at **www.crai.com/energy**.

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