

Economic and Regulatory Challenges of Utility Scale Battery Storage in Centralized and Decentralized U.S. Markets

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Abstract

The DeCordova Energy Storage Facility, situated in Granbury, Texas, is a pioneering project in the realm of utility-scale battery storage. This paper delves into a multifaceted analysis encompassing the economic feasibility, regulatory landscape, and technological challenges associated with the facility. Despite its innovative approach and strategic importance, the DeCordova project faces significant economic hurdles, evidenced by its high Levelized Cost of Storage (LCOS) of \$166.79 per MWh, which is substantially above the current market average for similar systems. The analysis begins with a detailed overview of the facility's capacity and technology, highlighting its use of lithium iron phosphate (LFP) batteries and its role in enhancing grid stability within the Electric Reliability Council of Texas (ERCOT) market. It then examines the regulatory frameworks that support and hinder the integration of battery storage in Texas, including ERCOT's policies and the impact of federal incentives like the Inflation Reduction Act of 2022. The paper also addresses the operational challenges posed by non-modular design and the early-stage nature of battery storage technology at the utility scale, which contribute to the high costs and limited efficiency. Comparative insights are drawn from the Moss Landing Battery Storage Facility in California's CAISO market, revealing that similar economic and operational challenges are prevalent across different market structures. This comparative analysis underscores the need for continued advancements in battery technology, cost reduction strategies, and supportive regulatory policies to enhance the economic viability of utility-scale battery storage systems. The paper concludes with actionable recommendations for improving the economic feasibility of battery storage projects. These include technological innovations to reduce costs and improve efficiency, the development of standardized and modular designs, and the implementation of balanced regulatory frameworks that encourage investment while ensuring grid reliability. Overall, this comprehensive analysis provides valuable insights into the current state and future potential of utility-scale battery storage systems, emphasizing the critical need for targeted research, supportive policies, and technological advancements to overcome existing barriers and promote widespread adoption in diverse energy market contexts.

Introduction

Utility-scale battery storage systems have emerged as a cornerstone of modern energy infrastructure, enabling greater integration of renewable energy sources, enhancing grid reliability, and supporting the transition to a cleaner energy future. These systems play a pivotal role in balancing supply and demand, storing excess energy during periods of low demand and releasing it during peak times, thereby reducing reliance on fossil fuel-based peaking plants. Since 2021, the U.S. has experienced remarkable growth in battery storage capacity, with projections indicating an 89% increase by the end of 2024. This growth reflects a broader global trend, driven by declining costs of lithium-ion batteries, advancements in storage technology, and increasing policy support for renewable energy integration.

Despite these promising developments, the rapid expansion of battery storage faces notable challenges. Key setbacks include high upfront costs, uncertainties in long-term performance and degradation rates, and supply chain constraints, particularly for critical materials such as lithium, cobalt, and nickel. Additionally, the lack of standardized regulatory frameworks across states and market structures has created barriers to the efficient deployment of storage systems. These regulatory gaps often lead to inconsistencies in how storage systems are valued and compensated for their contributions to the grid, limiting their economic potential.

As the demand for energy storage continues to grow, addressing these challenges will be critical to unlocking the full potential of utility-scale battery systems. Understanding the economic and regulatory factors shaping this evolving sector is essential for policymakers, industry stakeholders, and researchers striving to accelerate the adoption of this transformative technology. This report aims to explore these dynamics in depth through a focused analysis of two key case studies focused in centralized and decentralized energy markets, shedding light on the opportunities and barriers that define the current state of utility-scale battery storage.

Scope of The Investigation

Through a detailed case study of the DeCordova Energy Storage Facility in Texas, we aim to provide a high-level analysis of the factors influencing the deployment and operation of large-scale battery storage projects in regions with significant renewable energy penetration. This case study has the potential to highlight the distinct opportunities and barriers present in decentralized energy systems.

The analysis focuses on the Levelized Cost of Energy (LCOE) as a core metric to assess the economic feasibility and operational efficiency of battery storage systems. Through the LCOE framework, we evaluate the costs associated with construction, operation, and maintenance relative to energy output on an annual basis. Additionally, we review regulatory frameworks governing energy storage deployment, emphasizing gaps and inconsistencies that hinder the

widespread adoption of utility-scale battery storage. By synthesizing these two aspects, our report identifies critical economic and regulatory barriers while offering a comprehensive understanding of the potential for battery storage to facilitate grid reliability and renewable energy integration.

Texas was selected as the focal point due to the state's leadership in solar and wind energy generation, as well as the availability of extensive public data. The DeCordova Energy Storage Facility in Texas operates in a decentralized market, providing an opportunity to examine the implications of competitive market dynamics on battery storage economics and regulation.

Using publicly available financial, construction, and development data for this project, the report evaluates the interplay of market structure, economic metrics, and regulatory considerations. These findings will contribute to a deeper understanding of the challenges facing grid-scale battery storage and provide actionable insights into advancing the adoption of this critical technology in diverse energy market contexts.

Background on the DeCordova

Location

The DeCordova Energy Storage Facility is located in Granbury, Texas. This strategic location allows it to effectively serve the Electric Reliability Council of Texas (ERCOT) grid, which manages the flow of electric power to more than 26 million Texas customers (1).

Capacity and Technology Details

The DeCordova Energy Storage Facility boasts a capacity of 260 MW/260 MWh, making it the largest battery energy storage project in Texas. The facility utilizes lithium iron phosphate (LFP) technology, known for its safety and long cycle life. The project includes over 22,000 individual battery modules housed in 86 enclosures. These batteries capture excess electricity from the grid, primarily during low-demand periods, and release it during peak demand times (2).

Role in the Decentralized Market

The DeCordova facility plays a crucial role in the decentralized energy market by providing dispatchable, instant-start, and emission-free power. It enhances grid stability and resiliency by balancing the intermittency of renewable energy sources. The facility is co-located with the DeCordova natural gas-fueled power plant, allowing for a unique pairing that offers both quick-start capabilities and reliable generation. This setup ensures continuity of operation and supports the grid during peak demand periods, contributing to the overall reliability and efficiency of the ERCOT market (3).

Overview of Current Regulatory Frameworks

Texas: Policies Supporting Battery Storage

ERCOT established several policies and frameworks to integrate utility-scale battery energy storage systems into its decentralized grid. In 2019, ERCOT launched the Battery Energy Storage Task Force, tasked with identifying the requirements for integrating energy storage resources into grid operations (7). The task force developed Nodal Protocol Revision Requests (NPRRs) to refine existing policies and establish new standards. Through NPRRs, ERCOT established clear definitions for energy storage resources, distinguishing them from traditional generation or load resources, allowing batteries to function as both. It also enabled real-time control of a supply and demand balance by integrating batteries into the dispatch system. Finally, these policies encouraged the management of batteries' state of charge (SOC) when participating in ancillary services markets. NPRR 1186 required batteries to maintain a minimum SOC when providing grid support to ensure they could discharge energy when called upon during emergencies (6). This policy helped greatly enhance grid reliability for the state.

The Texas Legislature also enacted laws to promote energy storage deployment. For instance, legislation effective on September 1, 2019, affirmed, "...that electric [cooperatives] could install, own, and operate BESS"(4) thereby expanding the entities capable of contributing to grid reliability through energy storage solutions. On the Federal level, the Inflation Reduction Act of 2022 provided tax incentives that enhanced the financial viability of utility-scale BESS projects in Texas (5). These incentives contributed to a significant decrease in battery production cost and an increase in battery storage capacity within the state.

Texas: Regulatory Barriers

While ERCOT's policies have advanced the integration of energy storage, their implementation has not been without challenges. When NPRR 1186 was initially proposed, the Public Utility Commission of Texas (PUCT) raised concerns that its requirements for Energy Storage Resources (ESRs) to maintain a specific state of charge (SOC) would reduce operational flexibility and deter investment due to profitability risks (9). Additionally, penalties for failing to meet SOC obligations prompted further pushback. In response, PUCT acted swiftly, demanding revisions to ensure the policy did not discourage investment. The revised NPRR 1186 now focuses on improving SOC awareness, accounting, and monitoring, without imposing penalties. This outcome highlights the iterative nature of policy development in a decentralized market, where revisions are often necessary to balance grid reliability and market participation.

Similarly, Senate Bill 1500, passed in 2023, addressed interconnection costs for generation and storage projects, which had previously been a barrier. The Texas Legislature established a transmission cost allowance, capping expenses at \$14 million for projects up to 138 kV and \$20

million for those above 138 kV (8). The amendment to Texas Administrative Code 25.195 provided much-needed financial relief, easing the burden for many generation and storage projects seeking grid access across the state.

While the decentralized market structure in Texas inherently creates complexities, such as balancing the interests of competing entities and addressing interconnection delays, the overall trajectory for utility-scale battery storage remains positive. Policies like NPRR 1186 and Senate Bill 1500 reflect the ongoing efforts to refine regulatory frameworks, ensuring they support both grid stability and investment in Battery Energy Storage Systems (BESS).

Economic Analysis

Capital Cost and Lifespan

The capital cost for the battery storage system is assumed to be approximately \$142.86 million. This assumption is based on Vistra Energy's investment of \$1 billion across seven projects within ERCOT, with the investment evenly distributed among these projects. The lifespan of the project is set at 15 years, as determined by Vistra Energy (5).

The DeCordova Energy Storage Facility, one of the projects under Vistra's investment, is a 260 MW/260 MWh standalone energy storage system. It is the largest energy storage project in Texas, providing dispatchable, instant-start, and emission-free power to the ERCOT grid. The facility can store enough energy to power approximately 130,000 average Texas residences (7).

Cost and Revenue

Operation and Maintenance (O&M) costs for battery storage projects are generally estimated to be about 1-2% of the overall capital cost. For this project, the O&M costs range between \$1.43 million and \$2.86 million annually (7). This analysis assumes no additional repair costs over the project's lifespan.

According to the National Renewable Energy Laboratory (NREL), fixed O&M costs include battery augmentation costs, which enable the system to operate at its rated capacity throughout its 15-year lifetime (8). This ensures that the battery system remains efficient and reliable over its operational period.

Although not included in the LCOE, the revenue for the battery storage system comes from the difference between the cost of charging the battery and the selling price of the discharged energy per day. This price differential, known as arbitrage revenue, is summed up over the entire year to provide a significant source of income for the system. By capitalizing on periods of low

electricity prices to charge the batteries and discharging during high-price periods, the DeCordova facility can generate substantial revenue, enhancing its overall economic viability.

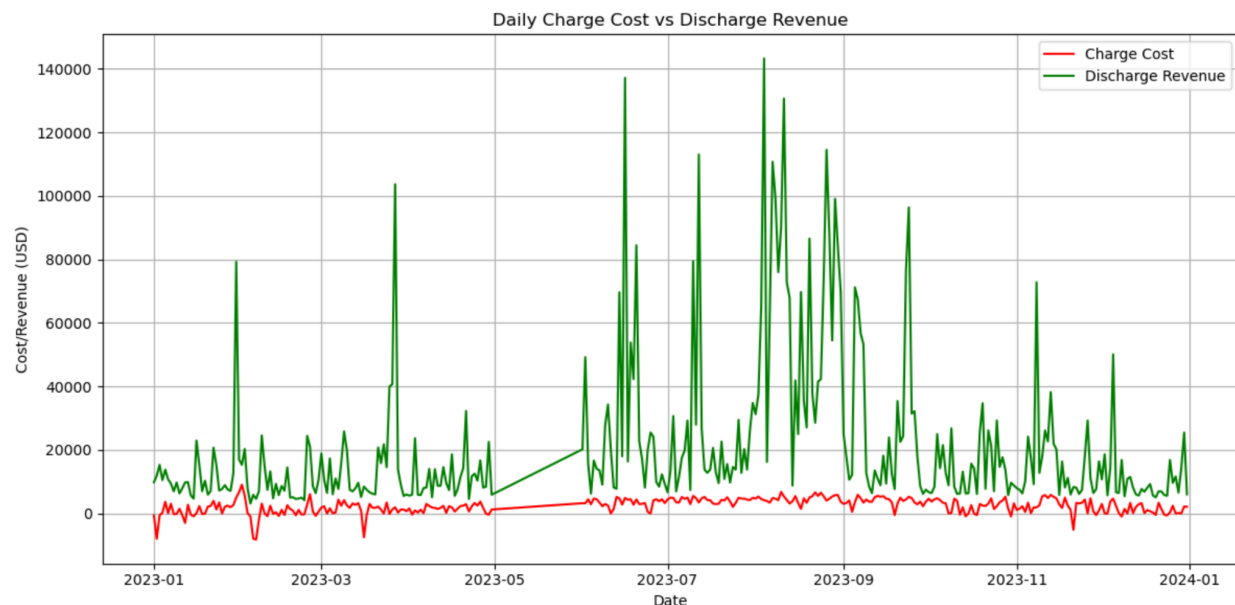


Figure 2: Made from python LCOE analysis derived from the RTM in ERCOT for the year 2023

Capacity Factor

The capacity factor for the battery storage system is estimated at 20%. This estimate considers the battery's use for energy arbitrage, which involves frequent charging and discharging, leading to faster efficiency degradation compared to uses like peak shaving or frequency regulation³. Additionally, the battery is set to discharge over only 4 hours each day, limiting its energy provision capacity (11).

NREL's data indicates that the capacity factor for utility-scale battery storage systems can vary significantly based on their use case and operational strategy. For energy arbitrage, the constant cycling of the battery impacts its overall efficiency and lifespan (11).

Battery Degradation

Battery degradation is assumed to be 2% per year. This higher end of the typical 1-2% range is chosen due to the intensive use case of energy arbitrage (9). Over the 15-year lifespan, this degradation rate will significantly impact the battery's performance and capacity.

Discount Rate

A discount rate of 7% is used for this analysis. This rate falls within the typical range of 6-8% for such projects, reflecting the investment's risk profile (13). The backing of a major company like Vistra Energy and the strategic importance of large-scale battery storage systems in Texas help keep the discount rate towards the lower end of the range (12).

The discount rate is crucial in financial analysis as it accounts for the time value of money, risk, and opportunity cost. A lower discount rate indicates a lower perceived risk and higher confidence in the project's financial returns (14).

Annual Energy Output

The analysis assumes that the battery can discharge its full capacity of 260 MWh every day throughout the year (14). This assumption ignores battery degradation, maintaining that the battery operates at its maximum efficiency over its lifespan.

The DeCordova Energy Storage Facility's design allows it to charge from the grid during low-demand times, primarily overnight, and release power during periods of high demand. This operational strategy maximizes the facility's efficiency and contribution to grid stability (15).

Levelized Cost of Energy (LCOE)

The LCOE calculation is essential for comparing the cost-effectiveness of different energy generation and storage technologies. It provides a standardized metric to evaluate the long-term economic viability of the battery storage system (16).

For calculating the LCOE, the analysis assumes that the battery charges during the four lowest price intervals (15 minutes each) and discharges during the sixteen highest price intervals (4 hour period) throughout the day (14). This approach assumes perfect real-time information for the battery system operator, allowing for optimal charging and discharging times. The charge capacity is evenly distributed across the intervals, with 65 MWh demand placed on each of the four charging intervals and 16.25 MWh discharged during each of the sixteen discharge intervals. The resulting LCOE is \$166.79 per MWh.

Thus, the LCOE for the DeCordova project, at \$166.79 per MWh, is significantly higher than the current market average for lithium-ion battery energy storage systems, which ranges from approximately \$30 to \$40 per MWh (12). This indicates that the DeCordova project's LCOS is not competitive in today's energy storage market. The high LCOS underscores the need for continued advancements in cost reduction and efficiency improvements in utility-scale battery storage systems to enhance their economic viability and competitiveness (14).

Key Assumptions and Limitations

A few key assumptions were made in the creation of this economic analysis. The analysis assumed no revenue from ancillary services. This decision was made in anticipation of future market saturation on the ancillary services to be offered by the battery storage system. Once more systems are online and labeled as ancillary services, battery storage systems are no longer able to exploit the non competitive daily revenue provided through arbitrage, instead, there will be less capacity distributed to more battery storage units. This will ultimately lead to a negligible amount of revenue coming from ancillary services in these markets (16).

Additionally, the analysis assumes that the \$1 billion investment from Vistra Energy is spread evenly among the seven projects currently being built by the company in Texas. This serves as a major limitation for the Levelized Cost of Energy (LCOE) analysis because cost is one of the leading factors in the calculation. If the DeCordova battery storage project takes a larger share of the \$1 billion investment, the LCOE will be higher than in the analysis. Conversely, if the share is smaller, the LCOE will decrease and become increasingly competitive.

Battery storage is still in the early stages of widespread utility-scale integration. This means that the cost to build and the efficiency of these systems still have significant room for improvement (6). Moreover, the integration of utility-scale battery storage is not modular at the moment, meaning each design build is somewhat unique. This leaves substantial room for cost efficiency improvements as more of these projects are put online and benefit from a large shared pool of knowledge in the construction of these systems.

Thus, the assumptions put forth in this analysis aim to provide the most accurate LCOE of the DeCordova project with the best public data available at this time. Therefore, this analysis is subject to the flaws in the information available. With perfect information, this analysis would tend toward a perfect model. Nonetheless, this LCOE indicates that there is still a major need for improvement in utility-scale battery storage moving forward so these storage methods can be widely adopted throughout the U.S.

Discussion & Future Steps

To improve the economic feasibility of utility-scale battery energy storage systems (BESS), decentralized markets like ERCOT (DeCordova) require targeted solutions. Enhanced market compensation mechanisms are critical to ensure BESS projects are fairly rewarded for the full range of services they provide, such as frequency regulation, peak load management, and grid stabilization. Additionally, cost recovery mechanisms must address the financial burden of interconnection and transmission upgrades, which remain significant barriers in both markets. Incentives for co-locating battery systems with renewable energy generation, such as tax credits

or rebates, can further improve efficiency by minimizing energy losses and maximizing grid integration.

Policy changes are also essential to overcome shared challenges. For instance, streamlined interconnection processes are necessary to accelerate grid connection timelines, especially in CAISO where delays often hinder project development. In ERCOT, recent revisions to NPPR 1186 highlight the importance of balancing state-of-charge (SOC) requirements with operational flexibility, a lesson that could benefit CAISO as it develops future regulations. Expanding federal incentives like the Investment Tax Credit (ITC) to prioritize standalone battery projects and providing financial relief for interconnection costs, similar to Texas Senate Bill 1500, can further stimulate private investment. Additionally, both markets must adopt clear valuation standards to ensure BESS contributions, such as load shifting and grid reliability, are fully recognized and compensated.

Future research will play a crucial role in refining the economic and regulatory landscape for battery storage. A lifecycle cost analysis of BESS, including long-term operational expenses and degradation rates, is essential to provide a clearer economic outlook for investors and policymakers. Further studies on grid integration impacts, such as congestion and transmission limitations, can identify infrastructure improvements needed to maximize storage benefits. Comparative regulatory analyses of other markets like PJM or NYISO can also offer insights into best practices for storage compensation, permitting, and grid reliability. A region of specific interest is CAISO, in a centralized market. The Moss Landing Battery Storage Facility in CAISO provides a useful comparison. Despite its larger scale and advanced technology, Moss Landing also grapples with high costs and the need for efficiency improvements (16). This suggests that the economic challenges observed in the DeCordova project are not unique and are prevalent across different market structures. Addressing these issues through technological advancements and supportive policies is essential for the broader adoption of battery storage systems. Lastly, research into the economic and regulatory impacts of fire safety standards, particularly in regions with heightened fire risk like California, will help streamline project development while ensuring safety.

Conclusion

The DeCordova Energy Storage Facility represents a significant advancement in utility-scale battery storage, yet its high Levelized Cost of Storage (LCOS) of \$166.79 per MWh highlights the economic challenges that still need to be addressed.

To enhance the economic viability of battery storage projects like DeCordova, several strategies can be employed. Continued advancements in battery technology and manufacturing processes can help reduce costs. Economies of scale, driven by increased production and deployment, will also contribute to lower costs. Enhancing the efficiency of battery systems through technological

innovations can reduce the LCOE. This includes improving energy density, cycle life, and charge/discharge efficiencies. Maximizing revenue through energy arbitrage, frequency regulation, and other ancillary services can improve the financial performance of battery storage systems. Although not included in the LCOE, the revenue from the difference between charging costs and selling prices can significantly impact overall profitability and the shape of the resulting LCOE.

Policy support is crucial for the widespread adoption of battery storage systems. Government incentives and subsidies for battery storage projects can lower initial capital costs and make these projects more attractive to investors. Establishing clear regulatory frameworks for ancillary services and energy storage can provide certainty and encourage investment. This includes ensuring fair compensation for grid-stabilizing services provided by battery storage systems. Increased funding for R&D in battery technology can accelerate advancements and cost reductions, making storage solutions more competitive.

Further research is needed to address the challenges and optimize the performance of battery storage systems. Continued research into new battery chemistries and technologies, such as solid-state batteries, can lead to significant improvements in performance and cost. Investigating the integration of battery storage with other renewable energy sources and grid infrastructure can enhance overall system efficiency and reliability. Analyzing the economic and operational performance of battery storage in different market structures, including centralized markets like CAISO, can provide valuable insights. Comparing these projects can help identify common issues and potential solutions.

The Moss Landing Battery Storage Facility in the California Independent System Operator (CAISO) market provides a useful comparison. Despite its larger scale and advanced technology, Moss Landing also grapples with high costs and the need for efficiency improvements. This suggests that the economic challenges observed in the DeCordova project are not unique and are prevalent across different market structures. Addressing these issues through technological advancements and supportive policies is essential for the broader adoption of battery storage systems.

Thus, while utility-scale battery storage systems like the DeCordova project offer significant benefits, their widespread adoption in U.S. markets is hindered by the economic, regulatory, technological, and market challenges that have been presented in this paper. Addressing these barriers through targeted research, supportive policies, and technological advancements is essential for realizing the full potential of this critical technology in diverse energy market contexts.

References

1. U.S. Energy Information Administration. (2023, October 10). California sees unprecedented growth in energy storage as a key component of the state's clean energy future. Retrieved from <https://www.eia.gov/todayinenergy/detail.php?id=61202>
2. California Public Utilities Commission. (n.d.). Energy storage. Retrieved from <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/energy-storage>
3. California Energy Commission. (2023, October 10). California sees unprecedented growth in energy storage as a key component of the state's clean energy future. Retrieved from <https://www.energy.ca.gov/news/2023-10/california-sees-unprecedented-growth-energy-storage-key-component-states-clean>
4. National Rural Electric Cooperative Association. (2019, September 1). Texas OKs co-op battery storage ownership. Retrieved from <https://www.cooperative.com/news/Pages/texas-oks-co-op-battery-storage-ownership.aspx>
5. Texas Comptroller of Public Accounts. (2024). Battery storage: A key to Texas' energy future. Retrieved from <https://comptroller.texas.gov/economy/fiscal-notes/infrastructure/2024/battery-storage/>
6. Utility Dive. (2023, October 10). ERCOT battery capacity rule NPRR 1186: State of charge (SOC). Retrieved from <https://www.utilitydive.com/news/ercot-battery-capacity-rule-NPRR-1186-state-of-charge-SOC/697653/>
7. Electric Reliability Council of Texas. (n.d.). NPRR 1186: Background. Retrieved from <https://www.ercot.com/mktrules/issues/NPRR1186#background>
8. Haynes and Boone, LLP. (2023, October 10). Regulatory landscape: All eyes on energy storage. Retrieved from <https://www.haynesboone.com/news/alerts/regulatory-landscape-all-eyes-on-energy-storage>
9. Utility Dive. (2023, October 10). Texas regulators reject ERCOT battery rule NPRR 1186. Retrieved from <https://www.utilitydive.com/news/texas-regulators-reject-ERCOT-battery-rule-NPRR-1186/706294/>
10. Mortenson. (n.d.). DeCordova energy storage. Retrieved from <https://www.mortenson.com/projects/decordova-energy-storage>
11. National Renewable Energy Laboratory. (2023). 2023 Annual Technology Baseline (ATB): Utility-scale battery storage. Retrieved from <https://www.nrel.gov/docs/fy23osti/85332.pdf>

12. National Renewable Energy Laboratory. (2024). 2024 Annual Technology Baseline (ATB): Utility-scale battery storage. Retrieved from https://atb.nrel.gov/electricity/2024/utility-scale_battery_storage
13. Volstora. (n.d.). Financial analysis of energy storage. Retrieved from <https://volstora.com/resources/business-case-knowledge-hub/financial-analysis-of-energy-storage/>
14. Modo Energy. (2024). ERCOT battery energy storage ancillary services: ECRS, non-spinning reserve, regulation saturation 2024. Retrieved from <https://modoenergy.com/research/ercot-battery-energy-storage-ancillary-services-ecrs-non-spinning-reserve-regulation-saturation-2024>
15. InfoLink Consulting. (2023). Key cost reduction and LCOE fundamentals for energy storage. Retrieved from <https://www.infolink-group.com/energy-article/energy-storage-topic-key-cost-reduction-ess-life-cycle-lcoe-fundamentals>
16. NS Energy. (n.d.). Moss Landing battery storage project. Retrieved from <https://www.nsenergybusiness.com/projects/moss-landing/>

Appendix

A. Levelized Cost of Energy (LCOE) Calculation

This section provides the detailed calculations used to determine the Levelized Cost of Energy (LCOE) for the DeCordova Energy Storage Facility.

```
import pandas as pd

# Load the north_hub_prices.csv file
north_hub_prices = pd.read_csv('ERCOT Energy Data/north_hub_prices.csv')

# Convert the 'Settlement Point Price' column to numeric, forcing errors to NaN
north_hub_prices['Settlement Point Price'] = pd.
↳to_numeric(north_hub_prices['Settlement Point Price'], errors='coerce')

# Initialize a DataFrame to store daily profits
daily_profits = pd.DataFrame(columns=['Date', 'Profit'])

# Initialize a DataFrame to store daily profits, charge costs, and discharge_
↳revenues
daily_data_summary = pd.DataFrame(columns=['Date', 'Charge Cost', 'Discharge_
↳Revenue'])

# Iterate through each unique date in the DataFrame
for date in north_hub_prices['Delivery Date'].unique():
    # Filter data for the current date
    daily_data = north_hub_prices[north_hub_prices['Delivery Date'] == date]

    # Find the 4 intervals with the lowest prices for charging
    charge_intervals = daily_data.nsmallest(4, 'Settlement Point Price')
    charge_cost = (charge_intervals['Settlement Point Price']*65).sum()

    # Find the 4 intervals with the highest prices for discharging
    discharge_intervals = daily_data.nlargest(16, 'Settlement Point Price')
    discharge_revenue = (discharge_intervals['Settlement Point Price']*16.25).
↳sum()

    # Append the daily charge cost and discharge revenue to the DataFrame
    daily_data_summary = pd.concat([daily_data_summary, pd.DataFrame({'Date':
↳[date], 'Charge Cost': [charge_cost], 'Discharge Revenue':
↳[discharge_revenue]})], ignore_index=True)
```

```

daily_data_summary['Date'] = pd.to_datetime(daily_data_summary['Date'])

# Calculate daily profit
daily_profit = discharge_revenue - charge_cost

# Append the daily profit to the DataFrame
daily_profits = pd.concat([daily_profits, pd.DataFrame({'Date': [date],
↳ 'Profit': [daily_profit]})], ignore_index=True)

# Extract month and year from the 'Date' column
daily_profits['Month'] = pd.to_datetime(daily_profits['Date']).dt.to_period('M')

# Calculate monthly profits
monthly_profits = daily_profits.groupby('Month').sum()['Profit']
annual_profit = sum(monthly_profits)
# Print monthly profits
print(monthly_profits)
print(annual_profit)

```

```

# Function to find LCOE of Battery Storage Facility

# Given data
capital_cost = 142.86e6 # $142.86 million
lifespan = 15 # years
discount_rate = 0.07 # 7%
o_and_m_cost_percentage = 0.015 # 1.5% of capital cost per year
annual_energy_output = 260 * 365 # MWh/year
o_and_m_cost = capital_cost * o_and_m_cost_percentage # O&M is 1.5% of the
↳ total cap cost

annuity_factor = ((discount_rate)*(1+discount_rate)**lifespan)/
↳ ((1+discount_rate)**lifespan - 1)
annual_capital_cost = capital_cost * annuity_factor

# Calculate yearly O&M cost
yearly_o_and_m_cost = o_and_m_cost / lifespan

# Calculate total annual cost

```

```

total_annual_cost = annual_capital_cost + yearly_o_and_m_cost

# Calculate LCOE for the year 2023
lcoe_2023 = total_annual_cost / annual_energy_output

# Print Necessary Findings
print(f"total cost", annual_capital_cost)
print(f"total yearly production", annual_energy_output)
print(f"The Levelized Cost of Energy (LCOE) for the DeCordova battery storage_
↵system for the year 2023 is ${lcoe_2023:.2f} per MWh.")

```

B. Cost vs. Revenue Graph Code

This section includes the code used to generate the cost vs. revenue graph (Figure 1) presented in the article. The graph illustrates the relationship between the costs incurred and the revenue generated by the DeCordova Energy Storage Facility over the year 2023. The area between the cost and revenue curves represents the unrealized profits for the battery storage system.

```

import matplotlib.pyplot as plt

# Plot the daily charge cost vs discharge revenue
plt.figure(figsize=(12, 6))
plt.plot(daily_data_summary['Date'], daily_data_summary['Charge Cost'],_
↵label='Charge Cost', color='red')
plt.plot(daily_data_summary['Date'], daily_data_summary['Discharge Revenue'],_
↵label='Discharge Revenue', color='green')
plt.title('Daily Charge Cost vs Discharge Revenue')

plt.xlabel('Date')
plt.ylabel('Cost/Revenue (USD)')
plt.legend()
plt.grid(True)
plt.tight_layout()

# Show the plot
plt.show()

```

Conclusion

This appendix provides a comprehensive overview of the calculations and methodologies used to determine the LCOE for the DeCordova Energy Storage Facility, as well as the code for generating the cost vs. revenue graph. These detailed insights can prove to be helpful for understanding the economic feasibility and financial performance of the project. By transparently presenting these calculations and visualizations, we aim to offer a clear and thorough analysis that supports the findings and recommendations discussed in the main body of the paper.