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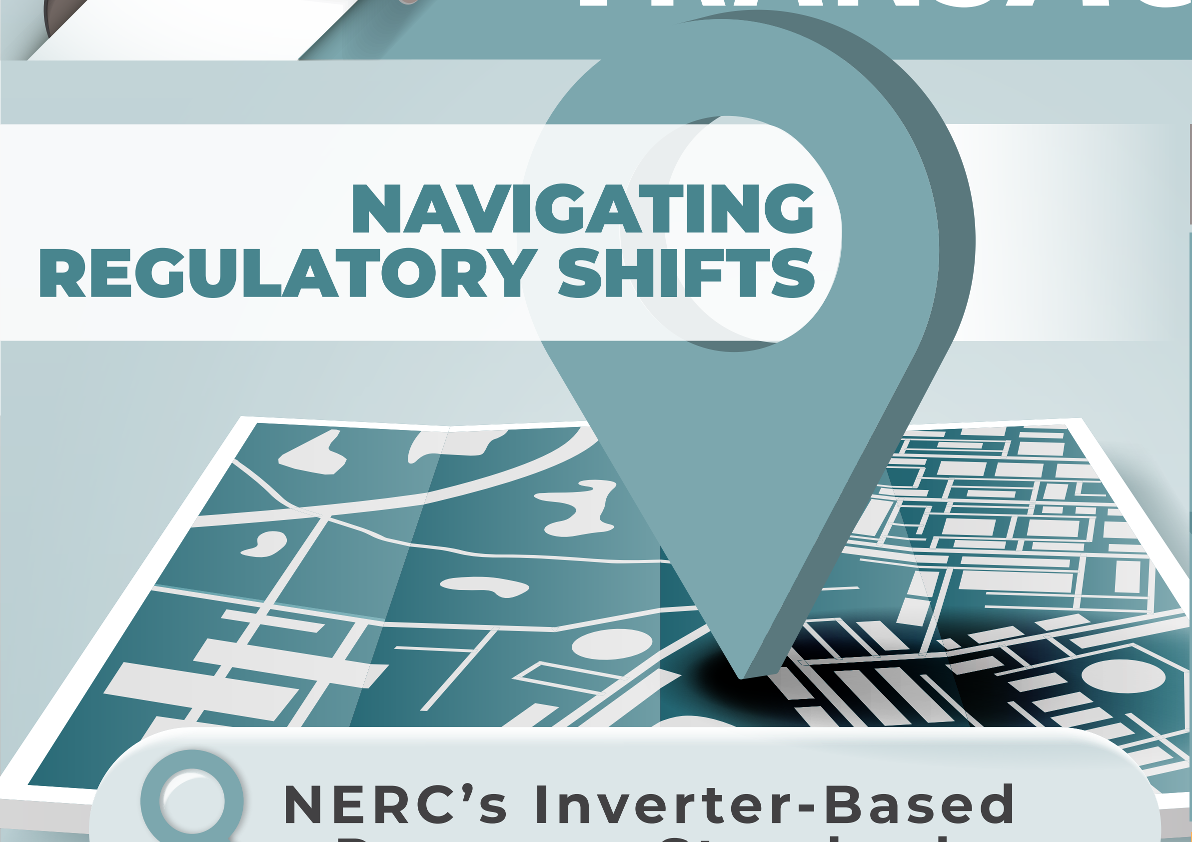

NAVIGATING REGULATORY SHIFTS

NERC's Inverter-Based Resource Standards

As the energy landscape undergoes a significant transformation with the growing integration of renewable energy sources, regulatory frameworks are evolving to address new challenges and opportunities. ***The North American Electric Reliability Corporation (NERC) has introduced updates to its standards concerning inverter-based resources (IBRs) such as solar photovoltaic (PV) systems, wind turbines, and battery storage.*** These changes reflect the increasing role of IBRs in the grid and aim to ensure continued reliability and stability. This article delves into NERC's regulatory changes regarding inverter-based resources, exploring their implications, challenges, and the path forward for stakeholders. ***The NERC Rules of Procedure and Standards changes will entangle IBR owners and operators that were not eligible for NERC registration previously, resulting in a significant impact on smaller IBR resources.***

The Need for NERC's Inverter-Based Resource Changes

1. **Grid Stability Concerns:** Traditional generators provide inertia to the grid, which helps to stabilize frequency fluctuations. As the proportion of inverter-based resources increases, the grid's ability to maintain frequency and voltage stability is challenged. This is because inverters, while capable of precise control, do not provide physical inertia.
2. **Inverter Technology and Standards:** The capabilities of inverters are continually evolving. Older NERC standards may not fully capture the capabilities of modern inverters, which can offer advanced grid support functionalities. Updating these standards ensures that the new technologies can contribute effectively to grid stability.
3. **Integration of Renewable Resources:** The growing share of renewable resources necessitates updated standards to facilitate their seamless integration into the grid. This includes ensuring that these resources can respond to grid disturbances, contribute to voltage control, and participate in grid frequency regulation.

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Strategic Considerations for Businesses

For businesses in the energy sector, NERC's updated standards have significant strategic implications. Here's how companies can navigate these changes effectively:

1. **Invest in Advanced Technology:** *To comply with new standards, businesses must invest in advanced inverter technologies and control systems. This includes upgrading existing equipment and integrating new solutions that meet NERC's performance requirements.*
2. **Focus on Compliance and Risk Management:** *Ensuring compliance with updated standards is essential to avoid penalties and operational disruptions. Companies should prioritize risk management strategies that include regular audits, training programs, and technology assessments to stay aligned with NERC regulations.*
3. **Adapt Operational Strategies:** *Companies need to adapt their operational strategies to accommodate the unique characteristics of inverter-based resources. This may involve revising grid management practices, enhancing communication protocols, and adjusting maintenance schedules.*
4. **Monitor Regulatory Developments:** *Staying informed about ongoing regulatory changes and emerging best practices is crucial. Companies should engage with industry groups, attend relevant conferences, and participate in discussions to stay ahead of evolving standards.*

NERC's Updated Standards for Inverter-Based Resources

NERC has introduced several changes and updates to its standards to address the unique challenges posed by inverter-based resources. The primary standards affected include:

1. **NERC Rules of Procedure** were updated such that the Generator Owner (GO) and Generator Operator (GOP) registry criteria to include an expanded category of smaller resources, which NERC has labeled Category 2 GOs and Category 2 GOPs. Category 2 GOs/GOPs include non-bulk electric system inverter-based resources that: (i) have nameplate capacity of greater than or equal to 20 MVA and (ii) connected at a voltage greater than or equal to 60 kV.
2. **MOD / PRC Changes:** there are numerous MOD/PRC rule changes that are designed to address IBR dynamic model requirements, adequately supporting grid disturbances, reporting reactive power capability, and collecting the relevant data for analysis. Specifically, changes have been made to MOD-025, 031, and 032, and PRC-002, 019, and 024, along with a handful of other standards.

Case Studies and Real-World Applications

To illustrate the impact of NERC's inverter-based resource changes, several case studies provide valuable insights:

1. **Texas Grid Reliability Enhancements:** Following the 2021 winter storm, Texas has focused on improving grid reliability by incorporating advanced inverter-based technologies and updating regulatory standards. These efforts are aimed at enhancing the grid's resilience to extreme weather events and ensuring stable operation.
2. **New York ISO's Grid Modernization:** New York ISO has implemented several initiatives to integrate inverter-based resources while maintaining grid stability. These initiatives include updating grid codes, deploying advanced inverters, and enhancing grid monitoring and control systems.
3. **Tesla's Integration of Battery Storage:** Tesla has successfully integrated its battery storage systems into the grid by complying with NERC's standards. By leveraging advanced inverter technologies and participating in grid support programs, Tesla has demonstrated how businesses can adapt to regulatory changes while driving innovation.
4. **NextEra Energy's Renewable Projects:** NextEra Energy has been at the forefront of integrating renewable resources into the grid. By adhering to NERC's updated standards and investing in advanced technologies, NextEra has positioned itself as a leader in renewable energy and grid reliability.
5. **Pacific Gas and Electric's Grid Modernization Efforts:** Pacific Gas and Electric (PG&E) has undertaken significant efforts to modernize its grid in response to regulatory changes. By implementing advanced inverter-based technologies and enhancing grid management practices, PG&E has improved its operational efficiency and reliability.
6. **Duke Energy's Integration of Solar PV Systems:** Duke Energy has implemented advanced inverter technologies and revised its operational practices to comply with NERC's updated standards. By investing in new control systems and enhancing grid management capabilities, Duke Energy has improved its ability to integrate solar PV systems while maintaining grid stability.
7. **Grand Valley Power (GVP):** GVP, a cooperative utility, serves a rural area with significant renewable energy projects. They have incorporated wind and solar resources into their generation mix. GVP has adjusted inverter settings to improve reactive power support and voltage control, in alignment with NERC's

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updated reliability standards. The cooperative has seen improved grid reliability and efficiency, demonstrating the successful adaptation of small utilities to large-scale renewable integration.

8. **Tucson Electric Power (TEP):** TEP has incorporated large-scale solar farms into its energy mix, requiring changes in grid operations and reliability management. TEP has updated its inverter standards to align with NERC requirements, improving grid reliability and performance. The utility has effectively managed the challenges of high solar penetration, demonstrating how advanced technologies and compliance with NERC standards can enhance grid reliability.

Looking Ahead: Future Developments and Considerations

As the energy landscape continues to evolve, several future developments and considerations will shape the integration of inverter-based resources:

1. ***Advancements in Inverter Technology:*** Ongoing research and development in inverter technology will likely lead to even more advanced capabilities, such as enhanced grid support functions and improved communication protocols.
2. ***Evolving Regulatory Frameworks:*** NERC and other regulatory bodies are likely to continue updating standards to address new challenges and opportunities in the energy sector. Stakeholders should monitor regulatory developments and engage with policymakers to influence future standards and ensure they align with industry needs.
3. ***Decentralized Energy Systems:*** The rise of decentralized energy systems, including microgrids and distributed energy resources, will present new challenges and opportunities for grid management and reliability.

Conclusion

NERC's updates to standards for inverter-based resources represent a crucial shift in the energy sector. For businesses involved in energy production, distribution, and infrastructure, adapting to these changes is essential for maintaining compliance, ensuring operational efficiency, and capitalizing on new opportunities. ***By investing in advanced technologies, adapting operational strategies, and staying informed about regulatory developments, companies can navigate the evolving landscape and position themselves for long-term success.*** As the energy sector continues to evolve, ongoing adaptation and innovation will be key to thriving in a dynamic and increasingly renewable-driven market. ■

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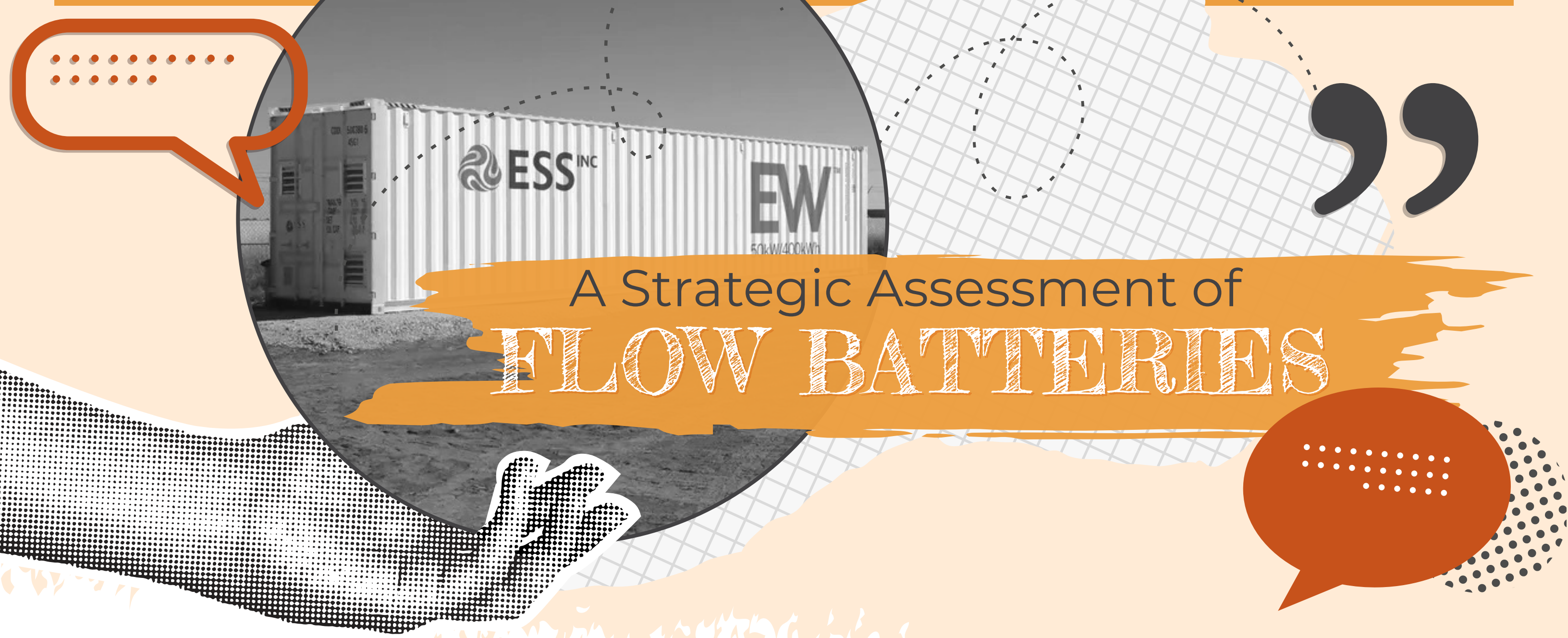

A Strategic Assessment of FLOW BATTERIES

As renewable energy resources continue to gain market share, Battery Energy Storage Systems (BESS) are increasingly being used to support use-cases such as renewables firming, peak management, ancillary services, energy and carbon arbitrage, storage as a transmission asset, and capacity for resource adequacy. Among monetary based use cases, the economics of new solar and wind installations can generally be improved when paired with energy storage.

Flow Batteries (FB) are now being evaluated in utility resource planning scenarios, and depending on the use case may be a viable alternative to lithium-ion batteries (LIB). ***FBs are proving to be a viable technology that will begin to displace LIB deployments due to their potential to provide low-cost Long Duration Energy Storage (LDES) (e.g. 10+ hour duration) and maintain performance over lengthy contract terms (20+ years).***

Use-Cases & Energy Storage Solutions

For a FB asset to remain relevant in the market for its 20-to-30 year expected life span, FB developers / owners are looking for clear use cases that can result in a reasonable return on investment. Matching the duration of an energy storage technology to the use-case demands (**FIGURE 1**) is critical to consider when selecting a storage technology. FBs capability spans over most use-cases including:

- ***Asset Deferral*** is the process of using energy storage to extend the life of existing electric system infrastructure, including natural gas power plants and transmission lines, by deferring or eliminating future investment in these capital-intensive assets
- ***Capacity Markets*** in many RTO regions are experiencing policy and regulatory changes and have had higher capacity auction prices. The capacity market is a potentially lucrative use-case for storage.
- ***Energy Arbitrage*** is the ability to store energy during low energy price periods and discharge during high energy price periods. Wholesale power markets have demonstrated rapid pricing swings, particularly during volatile pricing seasons. In addition to energy arbitrage, there is an emerging concept of carbon arbitrage as a potential area to demonstrate the value of LDES systems and FBs.
- ***Renewables Integration*** with BESS is emerging as an attractive option to enhance the economics by extending the availability of renewable resources across more hours of the day.
- ***Demand Response***, particularly within the Commercial and Industrial (C&I) space, energy storage is being deployed as a "behind-the-meter" resource in manufacturing facilities, hospitals, campuses and even residential locations as a means to shave power demand when premium rates are charged.
- ***Ancillary Services*** include spinning and non-spinning reserves, and VAR support are potential value streams for energy storage resources depending on the region.
- ***Black Start Capacity*** is valuable during a widespread outage when backfeed power is not available for generation resources to provide power thus preventing generator startup.

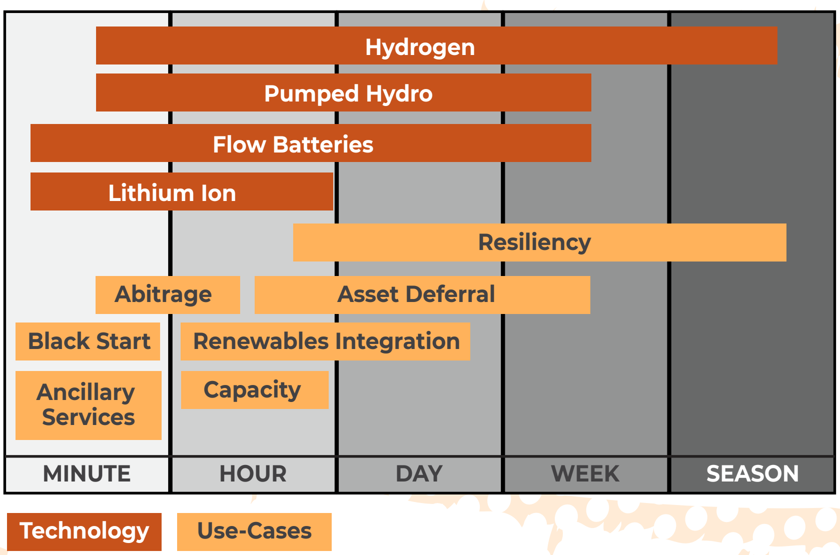

FIGURE 1. COMMON USE-CASES & ENERGY STORAGE DURATION CHARACTERISTICS

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- ***Resiliency*** *has become a high-profile use-case in recent years related to weather related events which has inhibited normal operation of gas assets, transmission and distribution system, and other power generation/delivery resources.*

Principle of Operation

A FB is a rechargeable fuel cell in which an electrolyte containing dissolved electroactive elements flows through an electrochemical cell stack that reversibly converts chemical energy directly to electricity (**FIGURE 2**). In short, FBs work by pumping negative and positive electrolytes through electrodes stacks, allowing energy to be stored and released as needed through electrochemical energy storage. Flow batteries allow power and energy to be scaled separately to certain degrees depending on technology. For example, the energy (MWh) component is driven by the volume of electrolyte fluid in the tanks, while the power is driven by the surface area of the electrode stacks, depending on the design. Due to manufacturing and design constraints, this flexibility is limited, but flow batteries are typically well suited for LDES applications.

> Flow batteries are a maturing technology, with many OEMs developing products/platforms suitable for utility scale projects.

Flow Battery Supply Chain

Flow batteries are a maturing technology, with many original equipment manufacturers (OEMs) developing products / platforms suitable for utility scale projects. Though there are a multitude of FB types, only about 3-4 specific chemistries appear ready for utility applications. Vanadium Redox flow batteries (VRFBs), Iron flow batteries (IRFBs), and Zinc-Bromine flow batteries (ZBFBs) all operate on the same basic principle and are discussed in greater detail below.

Vanadium Redox Flow Batteries. A VRFB cell consists of two electrodes or "stacks" (made from carbon felt, plastics, and metal alloys) and two circulating electrolyte solutions (a positive/cathode-side electrolyte or catholyte, and a negative/anode-side electrolyte or anolyte) that are separated by an ion exchange membrane. The conversion from electrical energy to chemical potential energy (charge) and vice versa (discharge) occurs instantly within the electrodes as the liquid electrolytes flow through the cell. Vanadium flow batteries use only a single element in both half-cells which eliminates the problem of cross-contamination across the membrane.

Hybrid Flow Battery

In a hybrid flow battery, electroactive material is deposited on the surface of the electrode during the charge cycle and then dissolved back into the electrolyte solution during discharge. For hybrid technologies, the storage duration is a function of both the electrolyte volume and the electrode surface area. While most hybrid technologies can achieve durations of 6-12 hours, power and energy are not fully decoupled.

Iron Redox Flow Batteries. The IRFB stores and releases energy through the electrochemical reaction of iron salt. The configuration of IRFBs is similar to other redox-flow battery types. IRFBs consists of two tanks, which in the uncharged state store electrolytes of dissolved iron ions. The electrolyte is pumped into the battery cell which consists of two separated half-cells. The electrochemical reaction takes place at the carbon-based porous electrodes within each half-cell. IRFB OEM landscape is not well developed but ESS Inc. is currently constructing several systems throughout the U.S.

Zinc-Bromine Flow Battery. A zinc-bromine battery is a rechargeable battery system that uses the reaction between zinc metal and bromine to produce electric current, with an electrolyte composed of an aqueous solution of zinc bromide. The ZBFB is a hybrid flow battery which utilizes a solution of zinc bromide (electrolytes) stored in two tanks. When the battery is charged or discharged, the electrolytes are pumped through a reactor stack from one tank to the other. The ZBFB OEM landscape is not well developed but Redflow has >50 MWH deployed and is currently constructing dozens of systems throughout the U.S. and world.

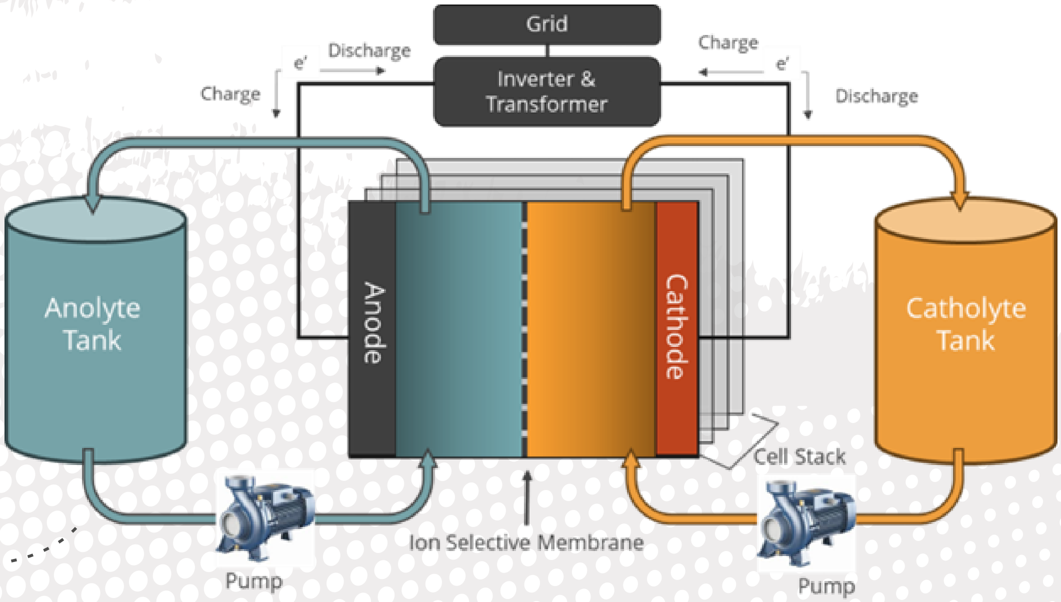

FIGURE 2. ILLUSTRATION OF A FLOW BATTERY SYSTEM

Performance Summary of Commercially Available Technologies

The elimination of repeated ion insertion and de-insertion in RFB electrodes as occurs in other batteries, preserves the structural and mechanical integrity of the cells/stacks, enabling a long-cycle life of the battery. In a true VRFB that utilizes liquid electrolytes on both positive and negative sides, its cycle life is independent of the battery's State of Charge (SOC) and depth of discharge (DOD). This is not the case with traditional batteries that store energy in their solid electrodes that causes energy capacity degradation over the life of the product. Unlike LIBs, FB systems have less limitations on cycling characteristics that cause performance degradation or impacts to warranties. However, they have lower energy densities and lower efficiencies than LIB, which lead to larger footprints for similarly sized power systems.

TECHNICAL VIABILITY

Cost models for utility-scale BESS are based on a bottom-up cost model using the data and methodology for utility-scale BESS. There are two common references used for BESS costs analysis: (1) National Renewable Energy Laboratory (NREL) Annual Technology Baseline Report[1] and (2) the Pacific Northwest National Laboratory (PNNL) Cost and Performance Database[2]. The bottom-up BESS model accounts for major components, including the battery pack, inverter, and the balance of system (BOS) needed for the installation, Fixed Operation and Maintenance. Using PNNL's detailed cost models for BESS installation allows for an illustrative capital cost comparison for a 10 MW / 100 MWh BESS facility (**FIGURE 3**).

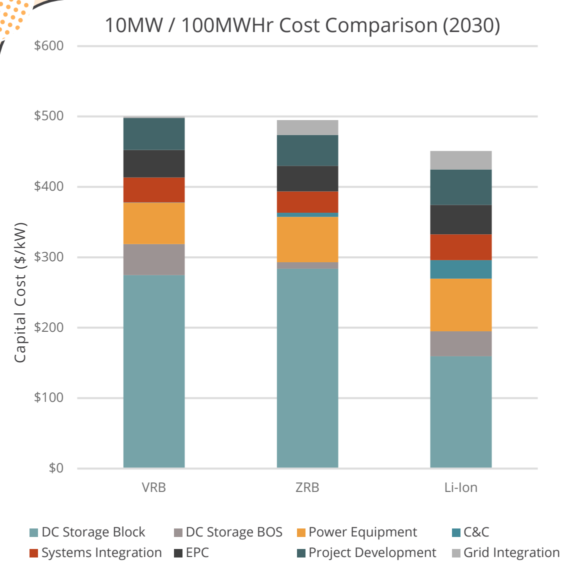

FIGURE 3. INSTALLED COST COMPARISON OF LDES BATTERIES (VRB, ZRB, AND LI-ION)

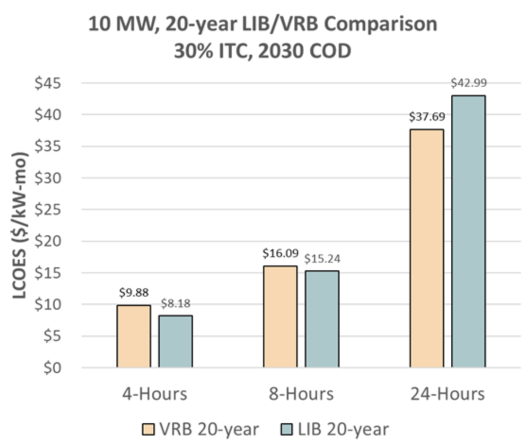

FIGURE 4. LCOES COMPARISON OF VRB VERSUS LIB FOR A 10MW UNIT WITH VARIOUS DURATIONS

Conclusion

FIGURE 4 shows the results of a life cycle cost analysis comparing 10 MW LIB and VRB systems at various durations. The model includes capital, O&M and performance losses for a 20-year project life based on cost public references. ■

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References / Credits

[1] https://www.pnnl.gov/lithium-ion-battery-lfp-and-nmc

[2] https://atb.nrel.gov/electricity/2023/data

Page 4 image, 3 MWH Iron Flow Battery (OEM: ESS, Inc.) Deployment for Sacramento Municipal Utility District

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