THE CONCENTRIC CASE FOR ENERGY STORAGE

Unlocking Resilience for Data Centers, Retail, Manufacturing and Distribution.

January 2023

Engineering Uptime.

THE **CONCENTRICCASE** *FOR ENERGY STORAGE*

Unlocking Resilience for Data Centers, Retail, Manufacturing and Distribution.

Introduction

Once relegated to the passenger seat, wind and solar are now dominant drivers in U.S. electricity generation.

If you are involved in operations, procurement, or facilities management in any capacity, this shift signals one thing: the growing importance of energy storage systems (ESS). Whether referred to as microgrids or distributed energy resources (DERs), ESS is essential to keep your operations running in the event of extreme weather — seasonal or unforeseen. Among other grid reliability concerns.

Without the power to sustain operations 24/7, businesses risk declines in both bottom line and consumer satisfaction.

Energy storage technology is not new. Batteries were invented in the early 1800s. Pumped-storage hydro-power has been operating in the United States since the 1920s.

However, the actual practice of ESS integration into public utilities didn't start until 1987. When a few rare, early demonstration projects proved battery storage could be used in conjunction with the grid.[1]

From 1987 to 2005, only a very small number of grid-scale battery systems were operational, but it drastically rose confidence in the technology's potential and the ESS industry's capabilities.

Today, procurements, planning, and announcements for utility-scale battery storage systems are increasingly widespread. But the ESS market itself, is ultimately in mid-stage maturation. Mirroring the trajectory of wind and solar power circa 2014.

While costs for lithium and batteries have plummeted, there's limited knowledge and data on many other emerging technologies, This includes batteries, renewable natural gas, long-duration energy storage, small modular reactors, and enhanced geothermal. Nor do reliable estimates exist of how long it might take for them to deploy at scale.[2]

ESS market growth is also shaped by geography, location and real estate. While accelerated by other external drivers like the aforementioned extreme weather events, grid reliability, rising retail electricity costs, and declining storage prices.

The commercial and industrial sectors anchor ESS adoption, led by data centers and the rapid proliferation of AI. Major retailers, as well as manufacturing and distribution facilities, are following suit. Each facing unique challenges that ESS technologies are designed to address. With nearly limitless combinations of energy storage solutions that can integrate with fossil fuel assets.

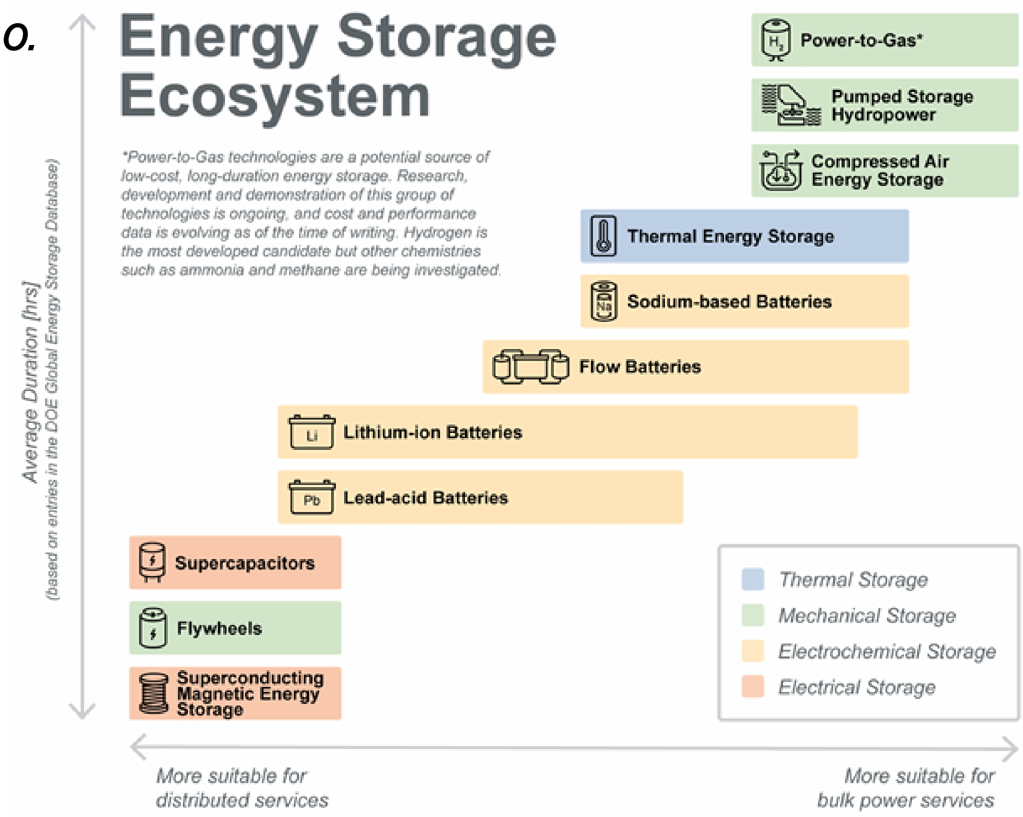
There is also no standard terminology in the U.S. for the flexible operation of ESS assets, including data centers, which poses a significant impediment to the rapid scale-up of flexibility programs, even when multiple parties are willing to cooperate.[3]

This paper examines the power challenges faced by these key data center, retail, manufacturing and distribution markets, while providing a high level overview of the most prevalent energy storage solutions in current use today as shown in Figure 1.0. Specifically:

- Electrochemical Battery Energy Storage Systems (BESS): led by lithium-ion, traditional lead-acid, flow batteries, and sodium-based batteries.
- Mechanical Storage: includes flywheels, hydrogen power-to-gas, pumped storage hydropower, and compressed air energy storage.
- Thermal Energy Storage (TES): includes chilled water systems.
- Electrical Storage: includes supercapacitors and superconducting magnetic energy storage.

With this foundation, we explore how ESS technologies are transforming the energy landscape and empowering businesses to meet their operational and sustainability goals.

Figure 1.0.


Energy Storage Ecosystem

*Power-to-Gas technologies are a potential source of low-cost, long-duration energy storage. Research, development and demonstration of this group of technologies is ongoing, and cost and performance data is evolving as of the time of writing. Hydrogen is the most developed candidate but other chemistries such as ammonia and methane are being investigated.

Data Centers: The Digital Backbone Driving ESS Innovation

These warehouse-scale sized computing buildings with thousands of servers, are the darlings of the ESS industry. They require constant, uninterrupted power to serve millions of users simultaneously, placing immense pressure on both their internal power systems and the larger grid.

At the same time, modern data centers are among the most innovative adopters of energy-efficient technologies. Despite misconceptions they're irresponsible energy consumers or power logs. While undeniably power-hungry and intensive, data centers are highly responsible in their energy usage. For example, Power Usage Effectiveness (PUE) — a key metric for measuring data center energy efficiency—has seen remarkable progress. The national average has dropped from 3.0 to an impressive 1.2, demonstrating the industry's commitment to sustainability while delivering scalable infrastructure for the digital economy.[4]

Yet, even with this progress, data centers face formidable challenges in scaling power capacity. Most of which are influenced by their geographic and regulatory contexts, as well as foundational real estate decisions.

> ***"Power Usage Effectiveness (PUE) — a key metric for measuring data center energy efficiency—has seen remarkable progress. The national average has dropped from 3.0 to an impressive 1.2."***

Key data center challenges include:

- *Grid Connection Stability*: absence of, or delays in stable grid connections in regions with constrained utility capacity. For example, Silicon Valley Power in Santa Clara, CA, halted new data center connections, and American Electric Power (AEP) in Central Ohio imposed similar restrictions. Impacting site selection and operational planning.
- *Space Constraints:* housing massive IT and operational equipment demands significant real estate, creating barries to expansion in urban or densely populated areas.
- *Permitting Challenges:* new greenfield sites or retrofitting brownfield facilities involves complex regulatory approvals, which vary across regions.
- *Regulations and Environmental Standards:* compliance with mandates for heat recovery, plant efficiency, and sustainability varies by location, influencing design and operations.
- *Geographic Resource Availability:* access to resources like water (critical for cooling) and renewable energy infrastructure varies, driving regional disparities in technology choices.
- *Carbon Footprint:* facilities in regions reliant on fossil fuels face higher energy costs and larger carbon footprints compared to more renewable-friendly areas.

Data center organizations aim to deploy and integrate as many ESS technologies as possible with one another and the grid. Refer to figure 2.0 on the next page for an example Gas Turbine Microgrid, an application commonly used in data centers.

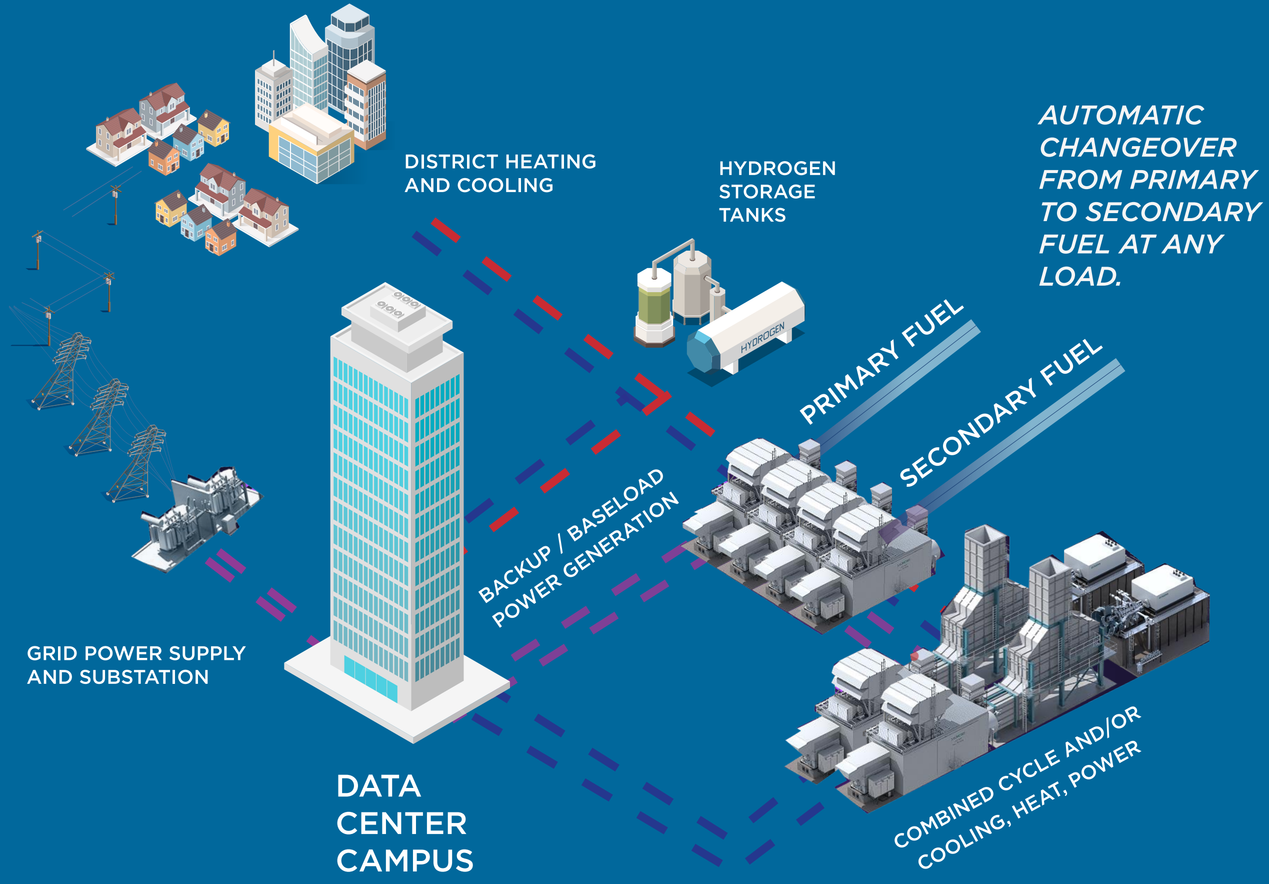
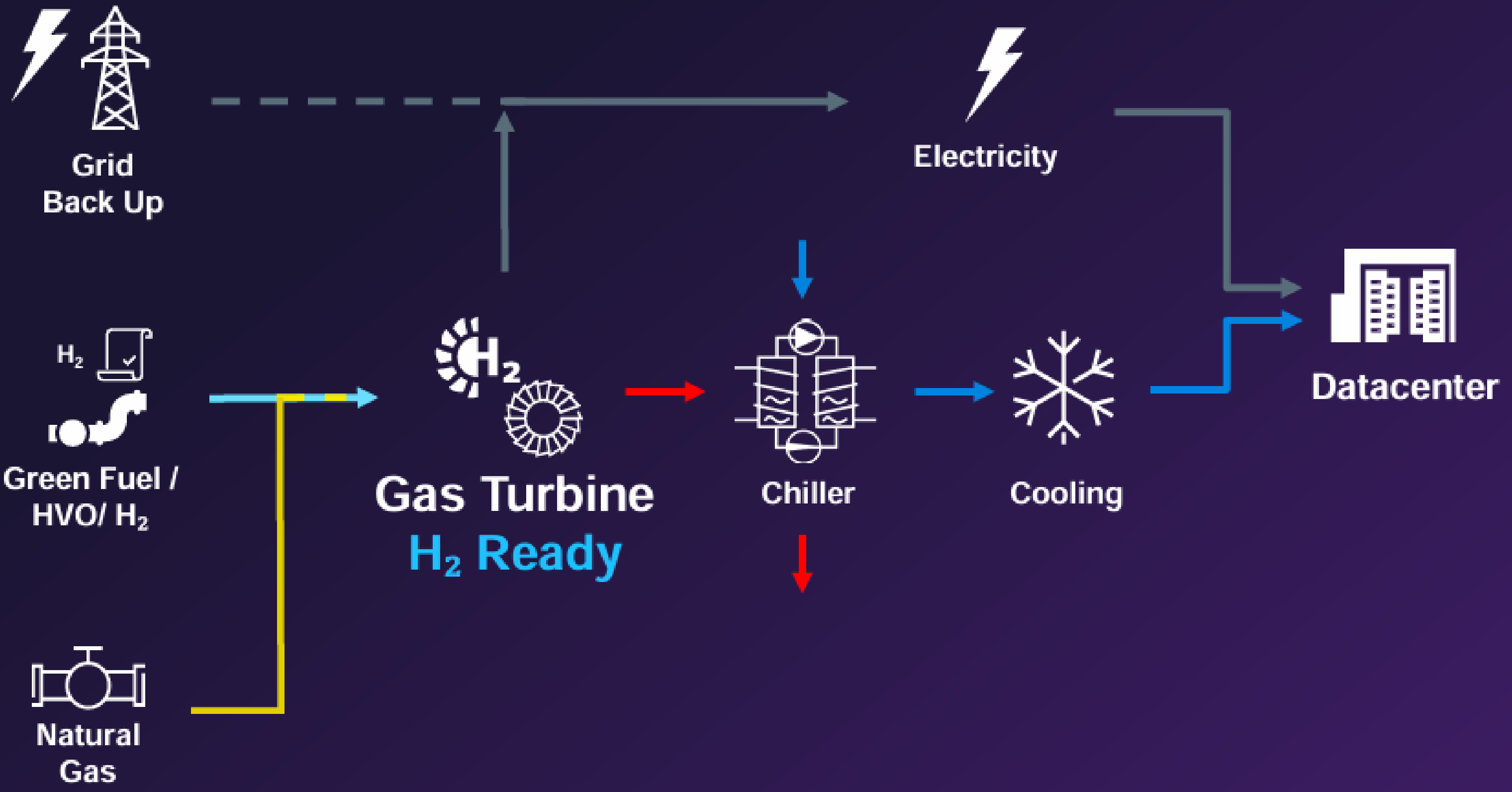


Figure 2.0 Example Gas Turbine Microgrid

A gas turbine microgrid is a popular application in today's data center design. A localized system designed to generate and manage power independently, on an island, in coordination with the main electric grid. It uses gas turbines as its primary source of electricity generation — ranging from natural gas, diesel, biofuel, or hydrogen.



> *"Publix, Kroger, Target, Walmart — are all at the forefront of energy innovation. These retail giants primarily embrace rooftop solar applications."*

Major Retail:
Powering Seamless Consumer Experiences
Publix, Kroger, Target, Walmart — are all at the forefront of energy innovation. These retail giants primarily embrace rooftop solar applications and drive other best practices in retail energy-efficiency. From DC-capable LED lighting and smart motors for refrigeration and HVAC systems to IoT-powered water and energy management solutions, retailers are striving to balance sustainability, reliability, and cost efficiency.

ESS plays a pivotal role in ensuring uptime for critical infrastructure such as point-of-sale platforms and cash registers, which are essential for delivering uninterrupted consumer experiences. While retailers share some of the same energy challenges as data centers and manufacturing facilities, they also face unique hurdles that require tailored solutions.

Key Retail Challenges:

- *High Energy Consumption:* large, energy-intensive facilities that run 24/7, demand significant power. Lighting, HVAC systems, refrigeration, and other critical equipment consistently drive high energy usage, leaving little room for inefficiency.
- *Grid Reliability and Power Outages:* in regions prone to extreme weather, grid instability can bring operations to a standstill. Power outages not only stop sales but also disrupt supply chains, spoil perishable goods, and lead to significant revenue losses.
- *Rising Energy Costs:* retailers are heavily impacted by fluctuating costs of renewable energy and premiums associated with peak-demand periods. Operating in times of maximum grid stress drives expenses even higher, challenging operational budgets.
- *Sustainability and Regulatory Compliance:* increasing consumer and regulatory pressure to reduce carbon emissions forces retailers to adopt greener practices. But the upfront costs of renewable energy sources and energy-efficient technologies pose barriers to widespread implementation.
- *Integration of Renewable Energy:* while rooftop solar adoption is growing among major retailers, integrating these systems into existing grid infrastructure comes with challenges. Intermittent energy supply from solar power requires reliable backup systems to ensure consistent operations.
- *Energy Management Across Multiple Locations:* large retailers often operate hundreds or thousands of brick-and-mortar stores and warehouses across diverse geographic regions, each with varying energy needs and regulations. Coordinating energy management programs across these locations can be incredibly complex and resource-intensive.

Despite these challenges, energy storage systems—particularly thermal solutions (page 9) in commercial and retail applications—empower retailers to maintain seamless operations with confidence while advancing their sustainability goals.

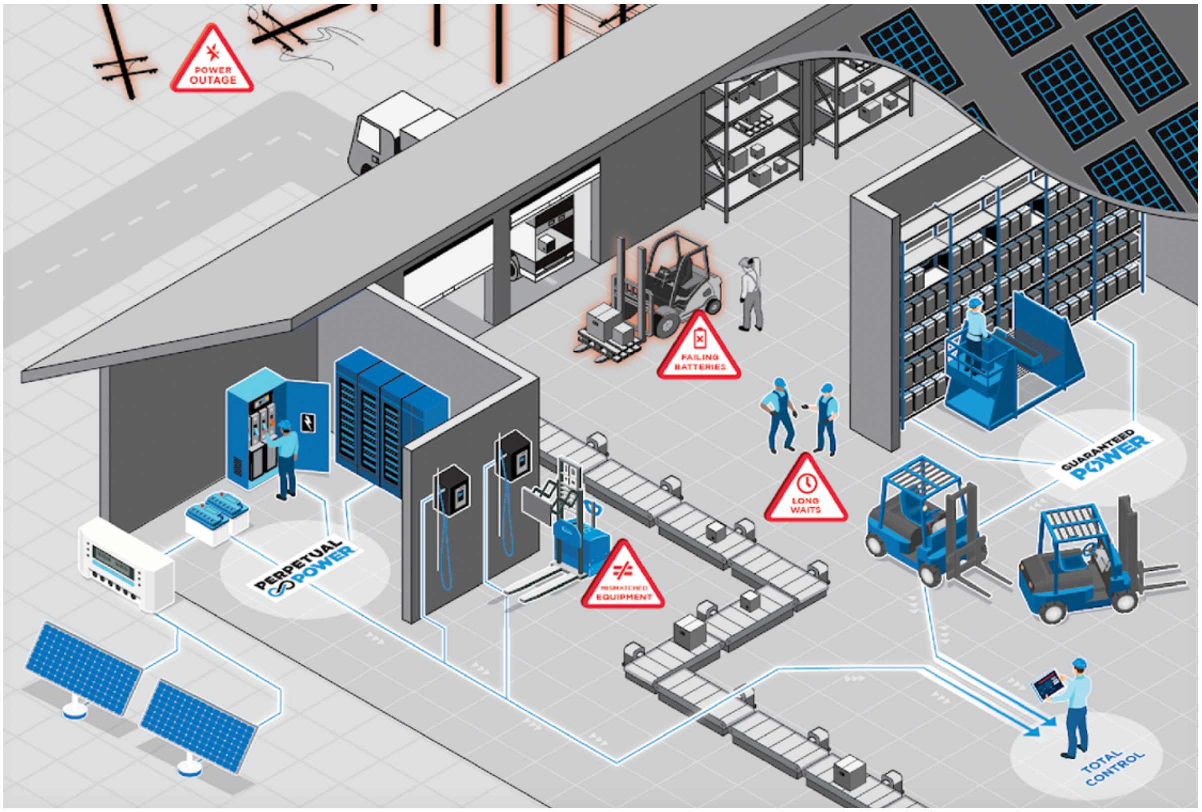


Figure 3.0 — manufacturers are plagued by failing forklift batteries, mismatched power equipment, unreliable UPS systems, among numerous other production and cost inefficiencies.

Manufacturing and Distribution: Powering Production and Supply Chains

Manufacturing and distribution is critical to the economy. Driving production and delivering products to brick-and mortar-stores and end consumers. However, these sectors face immense energy challenges, especially mid-sized and Fortune 500 organizations in energy-intensive segments. Markets like food and beverage, refrigerated warehousing, pharmaceuticals, and biotechnology.

Their high operational energy demands necessitate innovative energy storage solutions tailored to their unique requirements.

While some manufacturing facilities implement traditional BESS storage systems — just like retailers, most are turning to Thermal Energy Storage to address challenges. TES provides the resilience and efficiency needed to meet their fluctuating demand and sustainability goals.

However, the challenges of these organizations that produce and ship product are needless to say, dynamic, and ever-changing.

Manufacturing & Distribution challenges:

- *High and Variable Energy Demand:* these facilities rely on machinery like conveyors, robotics, and assembly lines. Demand fluctuates based on production schedules and seasonality. Peak demand during busy periods racks up utility costs.
- *Grid Reliability and Power Outages:* with unreliable UPS, production downtime causes delays and financial losses. Outages can damage equipment and create spoilage risk.
- *Rising Energy Costs:* particularly 24/7 food and beverage, or other key retail, suffer most from variable electricity prices. Dependence on fossil fuels also increases costs that are also vulnerable.
- *Sustainability and Regulatory Compliance:* pressure from stakeholders, regulators, and consumers, are in some cases, nonnegotiable, and a must. However meeting these goals is extremely logistically and financial challenging.
- *Integration of Renweable Energy:* intermittent energy supply makes it difficult to integrate renewables effectively.

As shown in figure 3.0 above, manufacturing and distribution facilities have an array of equipment to power, and countless of ESS solutions to achieve it. The most popular of which are covered in the section that follows. Expanding on the Energy Storage Ecosystem.

As stated, these markets push the centralized grid and utilities to its limits. Traditional power institutions can no longer meet demands emerging industries require. This transformation continues to democratize the ESS marketplace, creating opportunities for smaller energy players, individuals, and power brokers to enter. These market dynamics will define the future of the industry, influencing both technologies adopted and deployment methods.

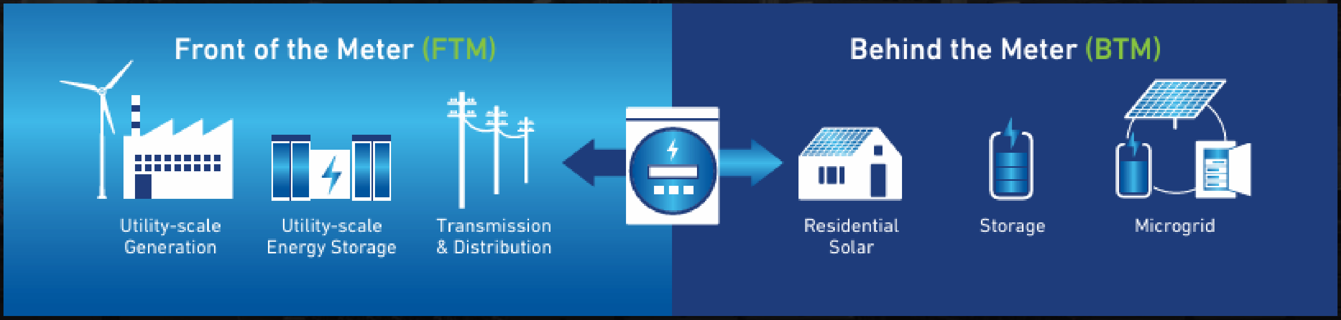
Expanding on the Energy Storage
ECOSYSTEM

ALL ABOUT **BESS**

Energy storage is ultimately any technology and application that enables power operators, utilities, developers, or consumers, to store energy for later use. And a battery energy storage system or BESS, is an electrochemical device that charges or collects grid energy or a distributed generation (DG) system, then discharges that energy later to provide electricity and other services when needed.

Next — there are Front-of-the-Meter (FTM) and Behind-the-Meter (BTM) BESS systems.

As depicted in figure XXX below, FTM energy storage refers to all components of the electrical grid between the meter and the public utility scale genertion site. While BTM BESS involves anything on the consumer side of the meter, including breaker panels and other electrical. Additionally solar, inverters, energy storage, and micro grids. Furthermore, it's essential to note that behind the meter applies to ALL residential, commercial, and industrial consumers. These markets are adopting both FTM and BTM storage systems.



ALL ABOUT **BESS BATTERY TYPES**

Different types of batteries can be used in Battery Energy Storage, each offering unique advantages and limitations depending on the application. As the demand for energy storage grows, the market has seen various battery technologies tailored to specific needs like scalability, cost-efficiency, and longevity.

In this overview, we'll explore the most dominant batteries in the BESS market today at a very high level, focusing on lithium-ion, lead-acid, sodium-based, and the most recent entrant, flow batteries. Each of these technologies plays a critical role in advancing energy storage solutions for diverse applications ranging from residential systems to utility-scale projects.

Li·ion

Lithium-Ion Battery

Lithium-ion Batteries

Lithium dominates the energy storage market. Its density allows for small and lightweight storage that can hold a significant amount of electricity. Lithium powers everything from electric vehicles to grid-scale applications. A long life cycle and rapid discharge capabilities make them ideal for industries requiring high performance and relability. However, major sustainability concerns exist, as it relates to sourcing scarce raw materials like cobalt, coupled with high upfront costs and safety hazards like thermal runaway. Posing challenges for widespread adoption. Despite this, lithium-ion remains the technology of choice for most BESS.

Expanding on the Energy Storage ECOSYSTEM

Lead-Acid Battery

Lead-Acid Batteries

As one of the oldest and most reliable energy storage technologies, lead-acid batteries continue to provide a cost-effective solution for short-duration energy needs. Their mature infrastructure, recyclability, and low initial costs make them a go-to option for applications such as backup power and stationary storage. However, their heavy and bulky design, coupled with low energy density and shorter lifespans, limits their suitability for modern, high-demand energy systems. While lead-acid batteries are often overshadowed by newer technologies, they remain a valuable choice for projects where affordability and simplicity take precedence over advanced performance metrics.

Salt Water Battery

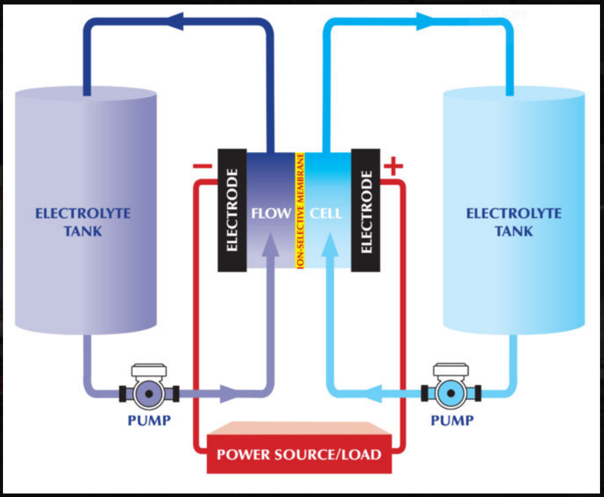
Sodium-based Batteries

Sodium-based batteries, including sodium-sulfur (NaS) and sodium-ion variants, are emerging as a promising alternative to lithium-ion, leveraging the abundance and affordability of sodium. Particularly suited for high-temperature operations, NaS batteries are well-equipped for industrial applications, while sodium-ion batteries hold potential for broader adoption as their technology matures. However, their relatively low energy density and, in the case of NaS, the need for high operating temperatures, limit their current use. Despite these hurdles, sodium-based batteries are gaining traction as a cost-effective, environmentally friendly solution, especially in applications where sustainability and resource availability are critical.

Flow Batteries

A flow battery is a type of rechargeable battery that stores energy in liquid electrolytes circulated within the system. The battery consists of two chemical components dissolved in separate liquid electrolytes, which are stored in external tanks and pumped through the battery's stack. These electrolytes are separated by a membrane within the stack, and the ion exchange across the membrane generates an electric current. Each liquid flows independently within its own compartment, enabling efficient energy storage and discharge. Flow batteries can discharge rapidly by replacing the liquid electrolyte while simultaneously recovering spent material for re-energinization.

Able to tolerate more discharge-recharge cycling, they require fewer safety and security precautions than many other battery technologies. High-tech membranes, pumps and seals, variable frequency drives, and advanced software and control systems have brought greater efficiencies at lower expenses, making flow batteries a feasible alternative to lithium-ion.



Source: International Flow Battery Forum

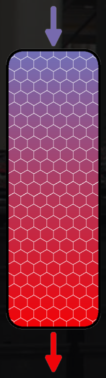
Expanding on the Energy Storage ECOSYSTEM

Thermal Energy Storage (TES)

Thermal Energy Storage (TES)

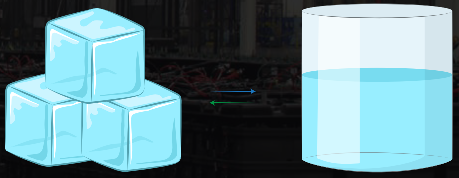
Thermal energy storage uses the concept of heat differential. TES options include: sensible, latent, and thermochemical technologies. Sensible storage relies on a temperature difference within the storage medium to enable useful work to be performed, such as using hot molten salt to heat water and generate steam to spin a turbine for electricity production. Latent heat storage involves storing heat in a phase-change material that utilizes the large latent heat of phase change, for example, during isothermal melting of a solid to a liquid, which requires heat, and subsequent freezing of the liquid to a solid, which releases heat, isothermally. Thermochemical energy storage (TCES) reversibly converts heat into chemical bonds using a reactive storage medium. When the energy is needed, a reverse reaction combines the reactants, releasing energy.

TES is popular in many commercial and industrial applications. Especially cold storage and refrigeration, so key industries like food and beverage, and pharmaceuticals heavily rely on TES.



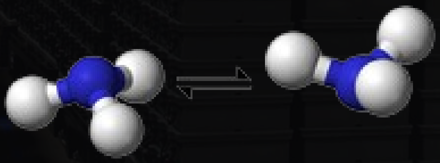
Sensible (single-phase) Storage

- Uses temperature difference to store heat
- Molten salts (nitrates <600 °C; carbonates, chlorides 700 – 900 °C)
- Solids storage (graphite, concrete, ceramic particles), >1000 °C



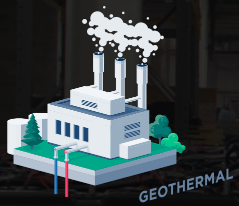
Phase-change Materials

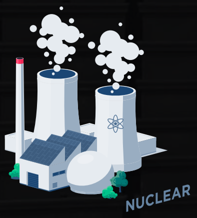
- Uses latent heat to store energy (e.g., molten salts, metallic alloys)



Thermochemical Storage

- Converts thermal energy into chemical bonds (e.g., decomposition/synthesis, redox reactions)





This, is in addition to the sector that's increasing the most — nuclear. At times of low or negative electricity prices, heat (or electricity) generated by the nuclear reactor is sent to thermal storage. At times of high electricity prices, the heat from the reactor and thermal storage is used to produce maximum electricity output.

New Generation IV nuclear reactors deliver higher temperatures to the power cycle relative to water-cooled reactors, which is beneficial for thermal storage because at higher temperatures, less storage material is required to deliver a desired amount of thermal power. Higher temperatures also enable more efficient thermal-to-electric power conversion. Adding thermal energy storage to geothermal power plants to increase flexibility and dispatchability is also widely practiced.

Expanding on the Energy Storage
ECOSYSTEM

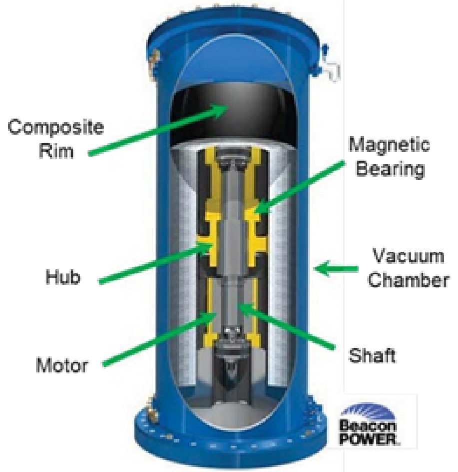
Flywheel Energy Storage (FES)

Flywheels

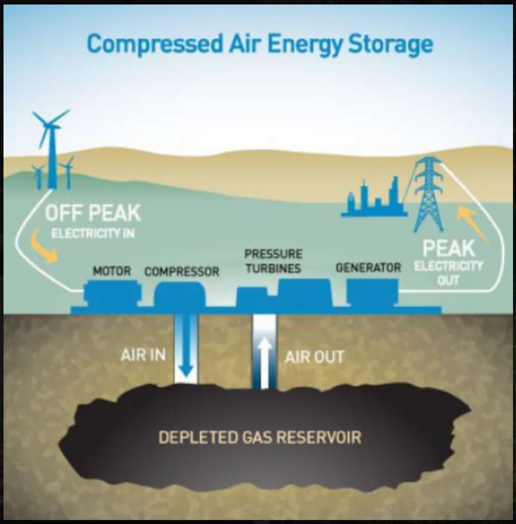
Flywheels are an ancient energy technology still in use for a broad range of power-intensive applications today. They essentially store kinetic energy in a spinning mass, called a rotor.

Flywhels charge by receiving energy electrically, converting electricity into kinetic energy using a motor that accelerates the rotor. A flywheel discharges by operating its motor as a generator. Decelerating the rotor and returning electrical power to the application.

Flywheel energy storage systems are found in data and telecommunication centers, healthcare, and other industry from manufacturing to aerospace and defense.



Source: Donald Bender, Sandia National Laboratories. ESHB_Ch07_Flywheels



Source: Richard Bowersox, Geological Society of America,

Compressed Air Energy Storage (CAES)

Compressed Air Energy Storage (CAES)

Compressed air energy storage (CAES) is one of the many energy storage options that can store electric energy in the form of potential energy (compressed air) and can be deployed near central power plants or distribution centers.

In response to demand, the stored energy can be discharged by expanding the stored air with a turboexpander generator. An attractive feature of this technology is the relative simplicity of the process—a compressor is powered by available electricity to compress air (charging), which is then stored in a chamber until the energy is needed. During discharge, the compressed air is run through a turboexpander to generate electricity back to the grid.

CAES systems are used in grid energy storage, data centers, and other large commercial buildings.

Expanding on the Energy Storage ECOSYSTEM

Power-to-Gas

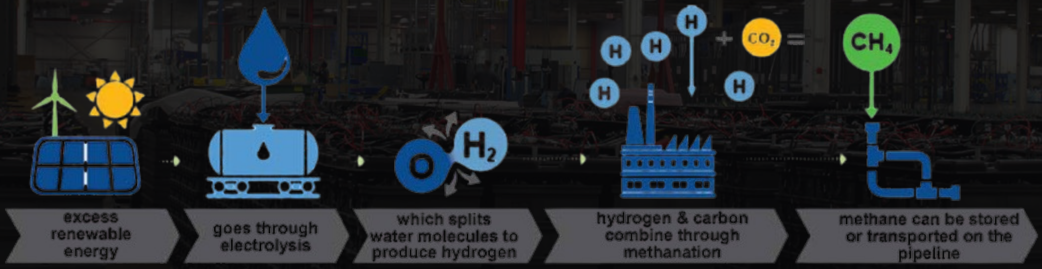
Power-to-gas (P2G) is the process of converting excess renewable electricity to a gaseous fuel (hydrogen or methane). The technology relies on the principle of electrolysis: using electricity to separate water into its component parts of hydrogen and oxygen.

As shown in the P2G figure image below, several purposes can be considered for the hydrogen produced by water electrolysis:

1. Converted in Synthetic Natural Gas (SNG) through methanation process
2. Directly injected into the natural gas network
3. Used as fuel in the transport sector
4. Converted back into electricity and heat by fuel cells
5. Directly used as raw material for industrial processes

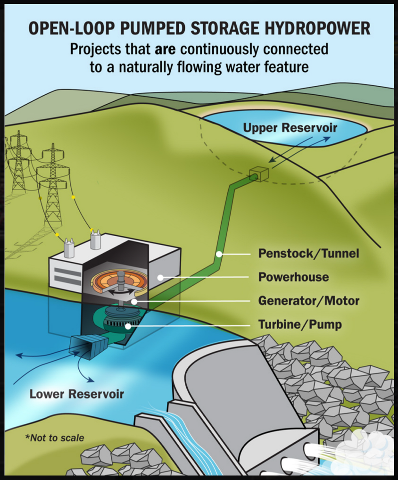
Power-to-Gas (P2G)

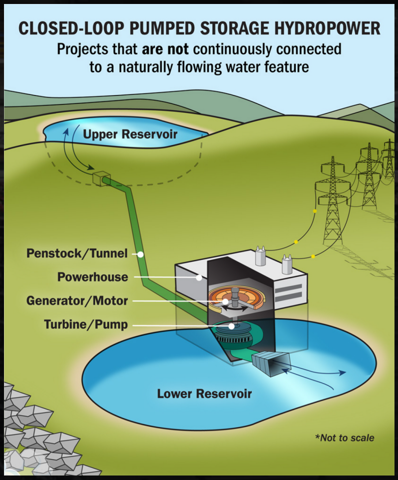
Power-to-Gas (P2G) is not only well-suited for large-scale grid storage and balancing but also plays a crucial role in advancing the transportation sector through hydrogen fuel for vehicles and synthetic alternatives. Additionally, it serves as a transformative solution for manufacturing industries such as steel and chemicals, where hydrogen acts as a key raw material for production processes, supporting both efficiency and decarbonization.



Pumped Storage Hydropower (PSH)

Pumped storage hydropower is a type of hydroelectric energy storage where there's a configuration of two water reservoirs at different elevations that can generate power as water moves from one to another. (Also known as discharge), passing through a turbine. PSH additionally requires power as it pumps water back up into the upper reservoir. (Also known as recharge). Acting as a giant battery, pumped hydropower systems can store and release power when needed.





Source: Department of Energy

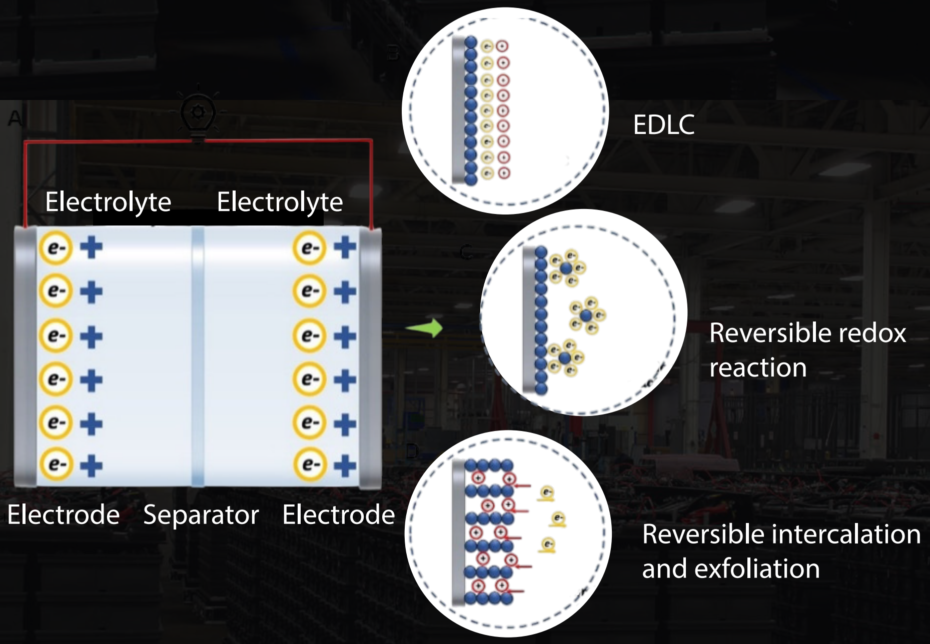
Open-loop pumped storage hydropower (PSH) systems involve a connection between a reservoir and a natural water body, utilizing a tunnel equipped with turbine-pump and generator-motor mechanisms to transfer water and generate electricity.

In contrast, closed-loop PSH systems link two reservoirs that are independent of natural water flows. These systems also rely on a tunnel and similar turbine-pump and generator-motor configurations to facilitate water movement and electricity production.

Expanding on the Energy Storage

ECOSYSTEM

Supercapacitors
Considered a comparatively new generation of electrochemical energy storage, supercapacitors, ultracapacitors, or nanocapacitators, are a family ESS devices with drastically high specific power when compared two other electrochemical storage devices. The three aforementioned names refer to a hybrid energy storage process, shown in the image below, that incorporates features from both a traditional electrostatic capacitor and electrochemical voltaic battery.



Supercapacitors are far superior to the traditional capacitor in terms of energy storage. However a capacitor can be charged and discharged much more rapidly than a battery. As a hybrid technology, the features and benefits of supercapacitors are somewhere in between those of a battery and traditional capacitor. Making them useful to support a wide range of applications. From motor startups in large engines (e.g. trucks, locomotives, submarines) to consumer electronics (e.g. cell phones and laptops), and electric cars.

The major drawbacks of supercapacitors are low energy density and a high self-discharge rate. For example, a supercapacitor passively discharges from 100% to 50% in a month compared with only 5% for a lithium-ion batterry. High capital cost and low energy density of supercapacitors make the unit cost of energy stored (kWh) more expensive than alternatives such as batteries. Their attributes make them attractive for uses in which frequent small charges/discharges are required (e.g., ensuring power quality or providing frequency regulation). Their attributes and cost make them less attractive for long-duration energy storage, which favors technologies with low self-discharge that cost less per unit of energy stored.

Supercapacitors can be used stand-alone or as part of a hybrid energy storage system composed of two or more technologies. The most common commercial applications include medical. Supercapacitors are used in devices like defilibrators, medical implants (e.g., pacemakers), and patient monitoring equipment. They're also commonly used in many industrial applications.

Expanding on the Energy Storage
ECOSYSTEM

Super Conducting Magnetic Energy Storage (SMES)
Superconducting Magnetic Energy Storage (SMES) is an energy storage system and concept that uses the dual nature of electromagnetism. An electrical current in a coil creates a magnetic field and the changes of this magnetic field create an electrical field, a voltage drop.

The magnetic flux is a reservoir of energy. Superconducting wires do not deliver energy when conducting a current, so a coil made with that materials maintain the current and the magnetic flux can be stored. The magnetic flux is a reservoir of electrical energy. As shown in figure 4.0 the energy is stored/delivered when a controller changes the current, increasing or reducing it, a voltage appears in the terminal which is regulated by the rate of change of the current, and can be adjusted by the regulator delivering or catching energy to or from the external circuits as shown in figure 5.0 below. A cubic meter of magnetic flux with a density of 10 T has an energy of 40 MJ (11 kWh), the same than 40 m3 of water at 100 m high.

SMES coils should be made with superconducting wires and they require to be cold, very much cold. Typically, under 60 K even down to the liquid helium temperature (4 K) depending on the materials employed: High-Temperature Superconductors (HTS) or Low Temperature Superconductors. The new scope for SMES is just using HTS at temperatures in the range of 30-40 K.

SMES systems have a long lifetime — 30 years. They're ideal for industrial polygons, hospitals, liquid nitrogen carriers, etc since it can take advantage of external resources as cooling.

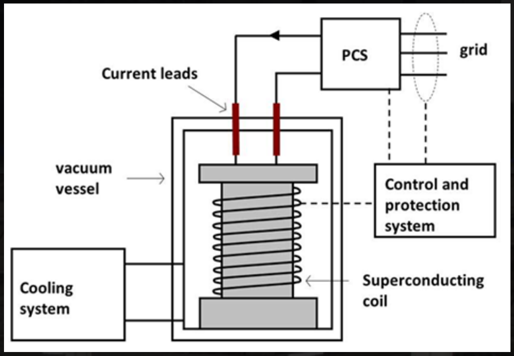
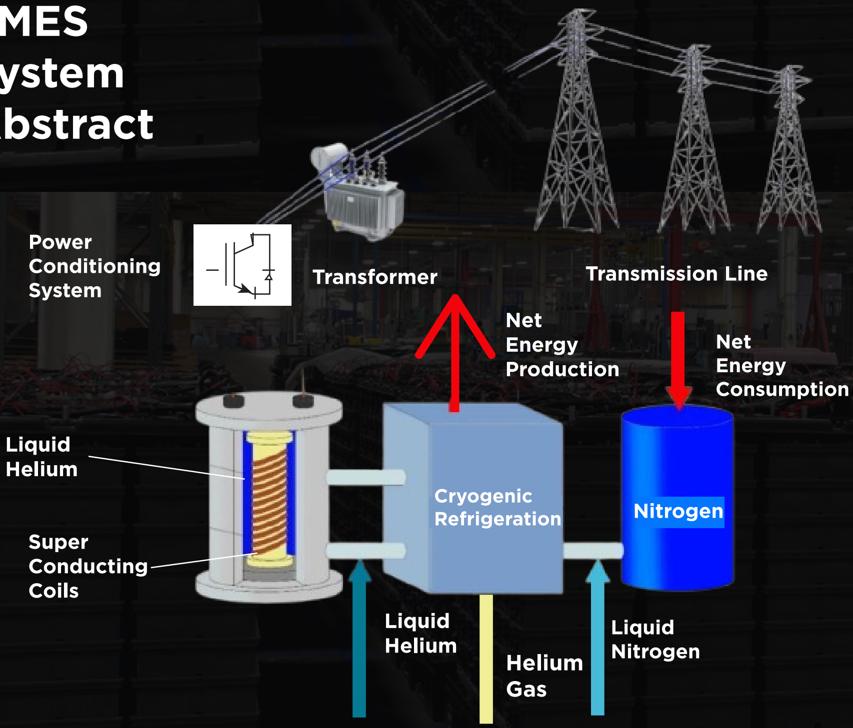


Figure 4.0 — Schematic representation of a SMES system, including the Power Conditioning System (PCS), cryogenics and control and protection system, besides the superconducting coil.

References:

1. *Michael Jacobs Union of Concerned Scientist, 2017. 2017_EESAT_Proceeding_Jacobs.*
2. *U.S. Department of Energy: Powering AI and Data Center Infrastructure Recommendations July 2024*
3. *U.S. Department of Energy: Powering AI and Data Center Infrastructure Recommendations July 2024*
4. *KC Mares – Data Center Designer Achieves PUE.*

SMES System Abstract



CONTACT US TO UNLEASH YOUR FACILITY'S POWER TODAY.

Don't let power limit your operations.

With 25 years of experience in industrial power, Concentric solves power problems for clients so they can focus on their core business.

We're the only provider of forklift power, critical power, and energy storage solutions with service teams nationwide. Our power expertise covers a range of equipment brands that allow us to add to or maintain your existing equipment based on your business needs.

Talk to a power expert today to stay running 24/7.

CONTACT: **TJ Shelters**
Vice President Sales
336.450.2356
tjshelters@concentricusa.com

ENERGY STORAGE, CRITICAL POWER & MAINTENANCE SERVICES

- **Battery Energy Storage Systems (BESS)**
- **Virtual Power Plant (VPP) Enablement**
- AC – DC, AC – AC, DC – AC Power
- EPA Certified Recycling Program
- **Distributed Energy Resources (DER)**
- **Microgrid Planning & Design**
- Lithium Thermal Scanning
- Grounding Upgrades

FORKLIFT & AGV POWER MAINTENANCE SERVICES

- Cable Repair & Replacement
- Battery Washing
- Watering System Repair
- Acid Adjustments
- Battery Recycling
- Capacity Testing
- Battery Reconditioning
- Safety Evaluations
- Remote Monitoring
- Planned Maintenance