



Battery Energy Storage System and Vanadium Flow Battery

RKP IBU Team

Note to IBU Team:

This deck contains more slides than most customers will require. Please ensure you carefully select only the slides that are relevant to your specific discussion and tailored to the customer's expectations.



Utility & Power Infrastructure (Front-of-the-Meter)

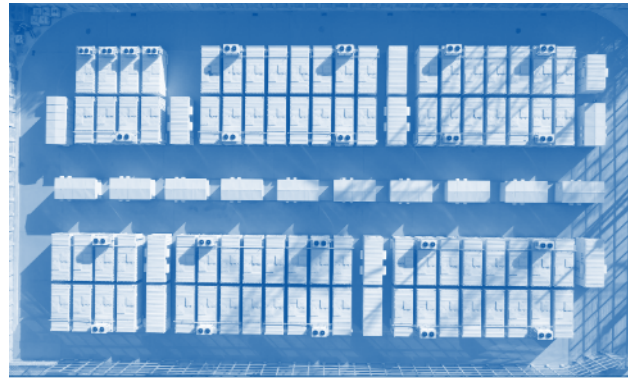


Large installations typically integrated into the power grid at substations or near renewable energy sites. They are essential for maintaining grid stability and enhancing the efficiency of the power system through high-capacity storage solutions.

Key Applications:

- Peak Shaving
- Frequency Modulation
- Energy Arbitrage
- Smoothing Output
- Blackout Recovery
- Offgrid Power Supply

Commercial & Industrial (Behind-the-Meter)



Installed on the premises of commercial and industrial facilities to manage energy costs effectively and improve operational resilience. They are tailored to specific business needs and contribute to energy efficiency and sustainability goals.

Key Applications:

- Peak Demand Shaving
- Backup Power
- Load Management
- Energy Cost Saving
- Advanced Decarbonization
- Micro Grid Forming

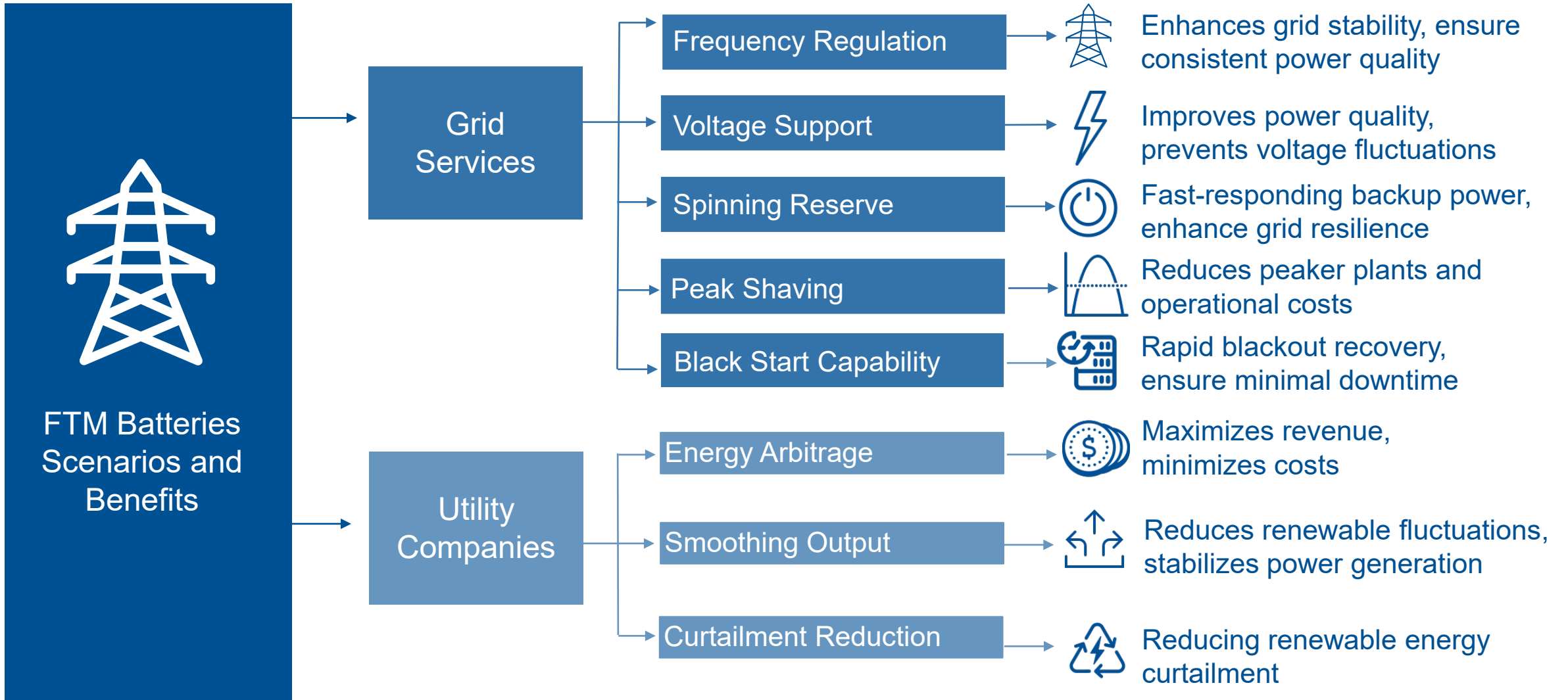
Residential (Behind-the-Meter)

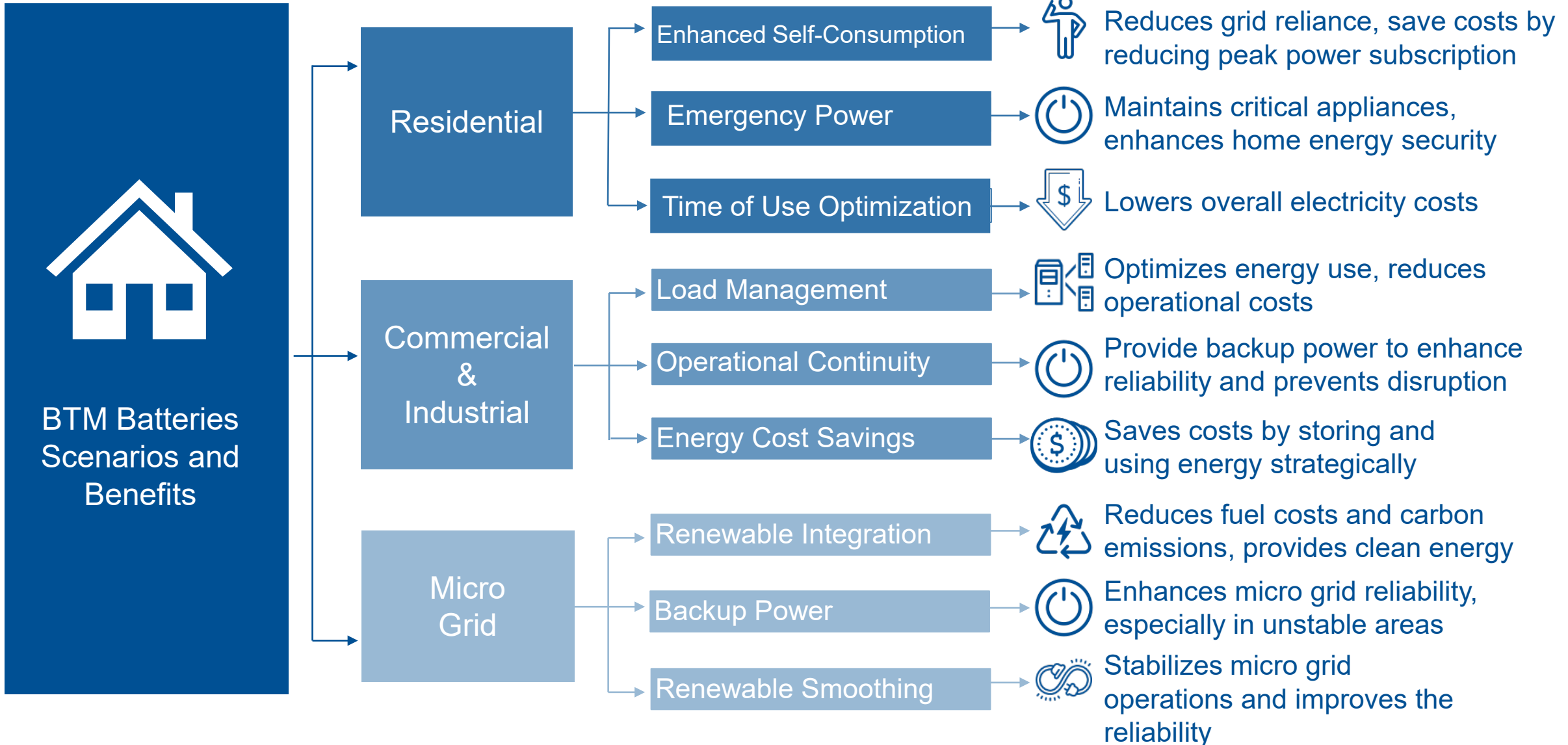


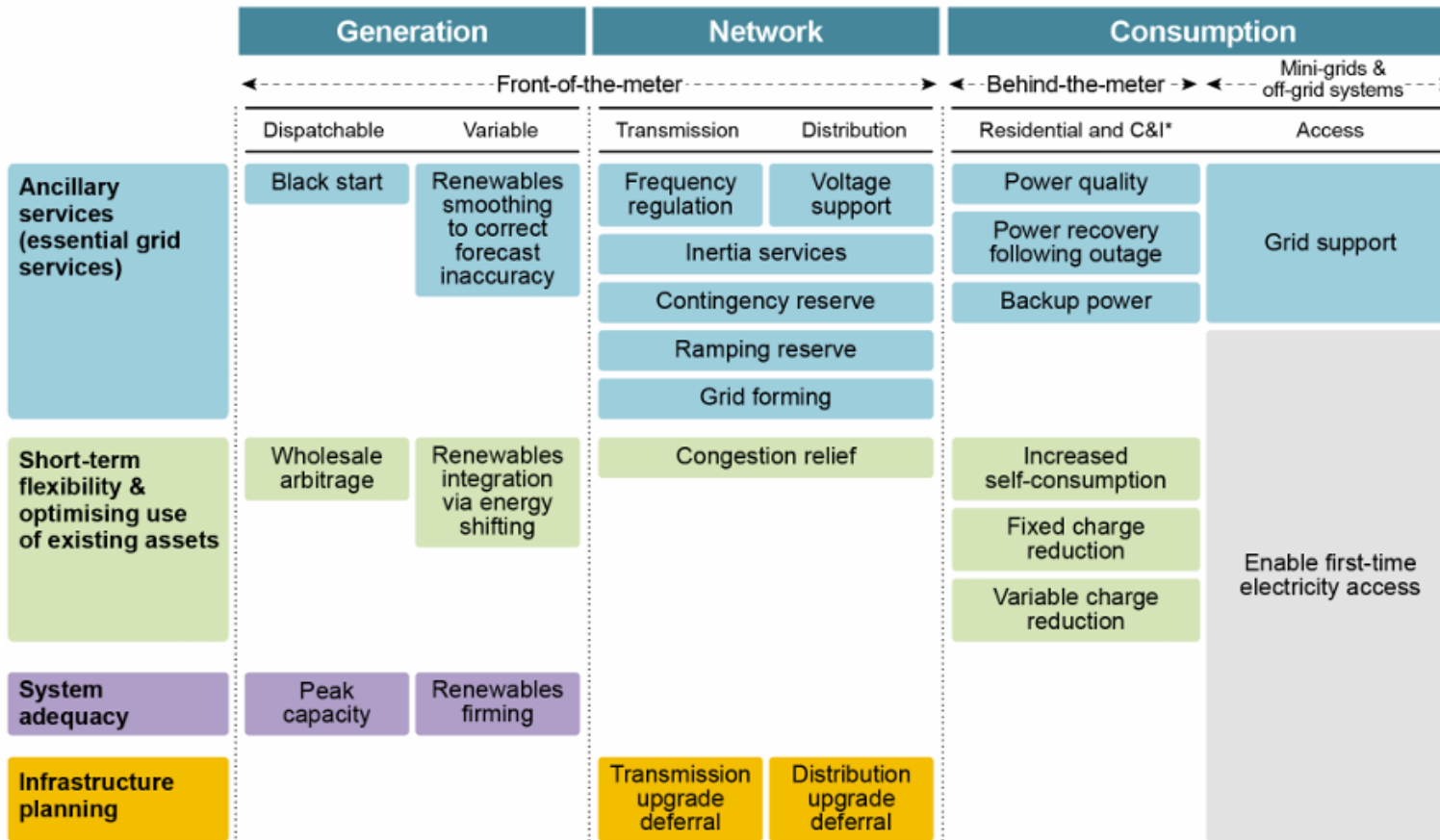
Typically paired with home solar installations, enabling homeowners to utilize solar power efficiently. These systems store excess energy produced during the day for use during non-production hours or when grid power is unavailable.

Key Applications:

- Enhanced Self-Consumption
- Emergency Power Supply
- Time of Use Optimization







*C&I = Commercial and industrial users

IEA. CC BY 4.0.

1. Utility-Scale Benefits:

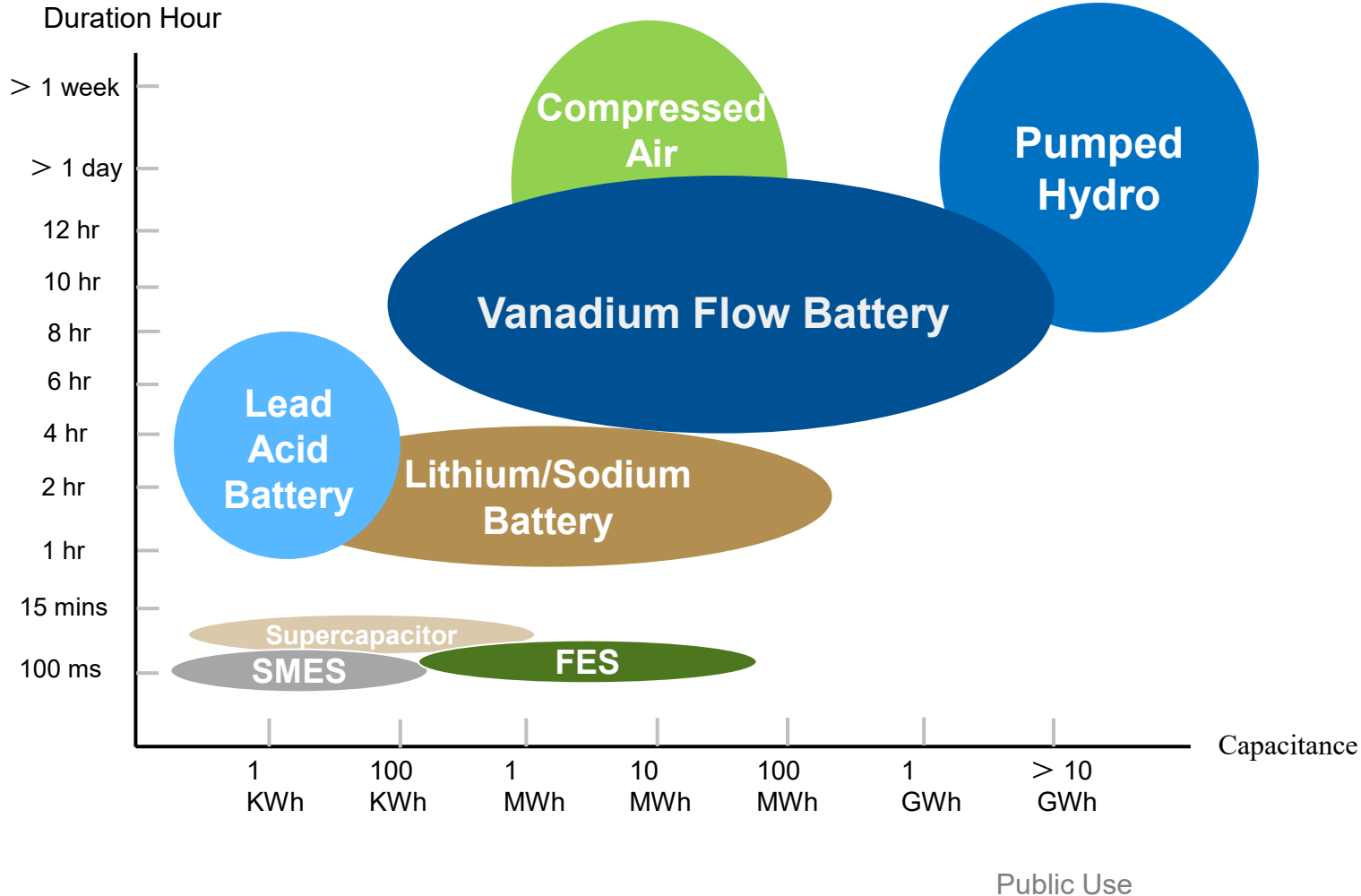
Helps maintain grid stability and security by offering energy shifting, ancillary services (inertia, voltage control, frequency regulation), fast-starting reserves, and managing congestion.

2. Behind-the-Meter Advantages:

Provide backup power and reduce electricity bills by optimizing self-consumption and variable tariffs. Aggregated into virtual power plants (VPPs), they can deliver similar benefits as utility-scale systems.

Both utility-scale and BTM battery storage systems offer a wide range of services to electricity systems, enhancing their versatility.

Vanadium flow batteries (VFBs) lead the way in energy storage, offering unmatched scalability and sustainability

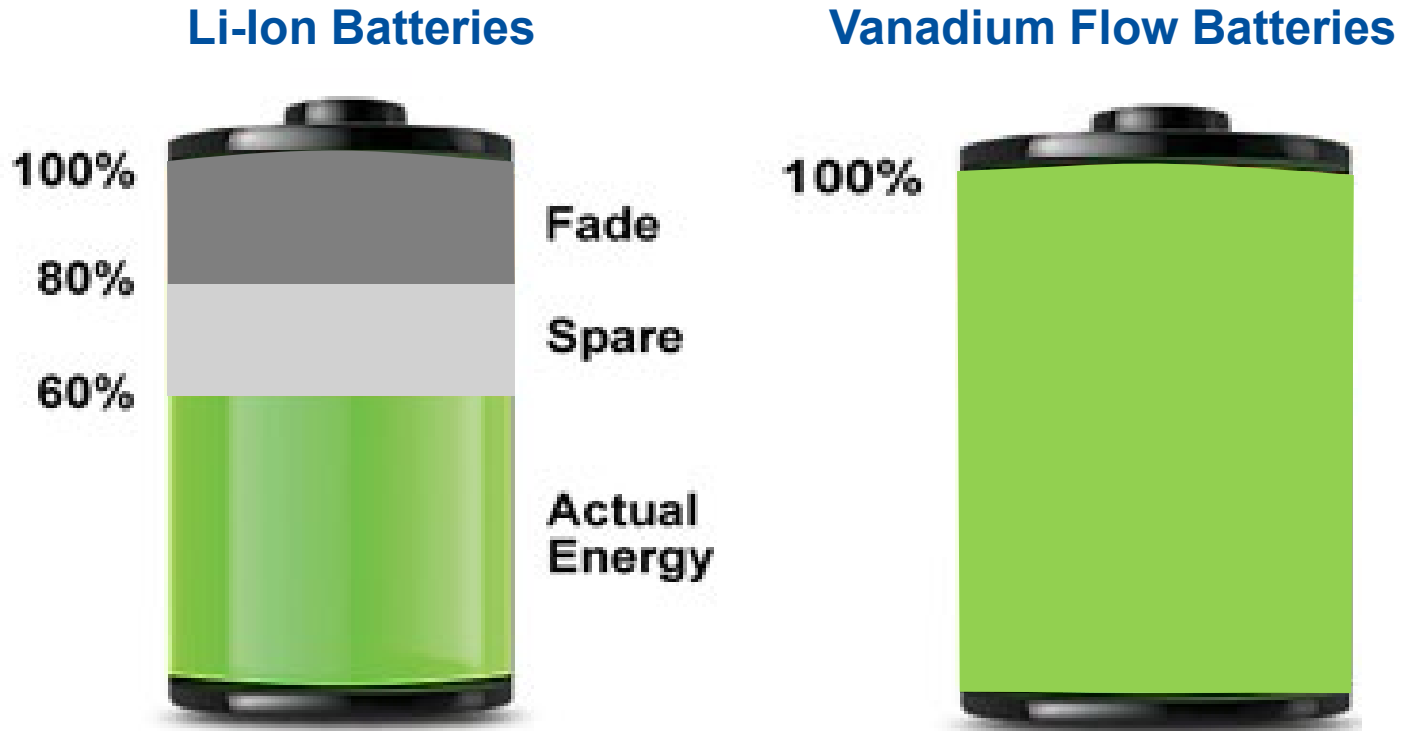


- Scalability and Capacity**
 VFBs offer high scalability, accommodating energy storage needs from MWh to multiple GWh, making them suitable for large-scale energy management.

- Long Duration and Reliability**
 With the capability to provide energy storage for durations exceeding 4 hours, VFBs ensure consistent and reliable power supply for long-term applications.

- Sustainable and Recyclable**
 VFBs are fully recyclable and use abundant vanadium resources, positioning them as an environmentally friendly and sustainable energy storage solution.

	Vanadium Flow Battery	Pumped Hydro	Lithium Battery
Energy Efficiency (AC)	70~75%	75%	80~85%
BMS	Simple and 0 risk of thermal runaway	—	Complicated with risk of thermal runaway
Safety	Inherently Safe	Inherently Safe	Potential Risks
Calendar Life	> 25 years	> 40 years	5-7 years
Cycle Life	>20,000 cycles	—	5000-8000 cycles
Capacity Degradation	100% capacity through lifetime	—	80% capacity after 2 years
Flexibility	Flexible	Site Limitations	Flexible
Sustainability	Reusable electrolyte and 100% recyclable battery material	Environmental damages	Limited resource with high recycling cost and hazardous waste



- **VFB:** Permanently retains 100% capacity, ensuring consistent performance throughout its lifecycle.
- **Li-Ion:** Loses significant capacity over time, requiring overbuild and increased costs for replacement and upgrades.

No Capacity Fading: A Key Benefit of VFBs

Vanadium Flow Batteries (VFBs) offer unique advantages for energy storage solutions

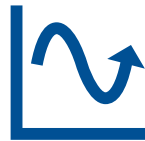
Inherently Safe

Water-based electrolyte, no thermal runaway



Long cycle life

Over 20,000 charge/discharge cycles with minimal degradation



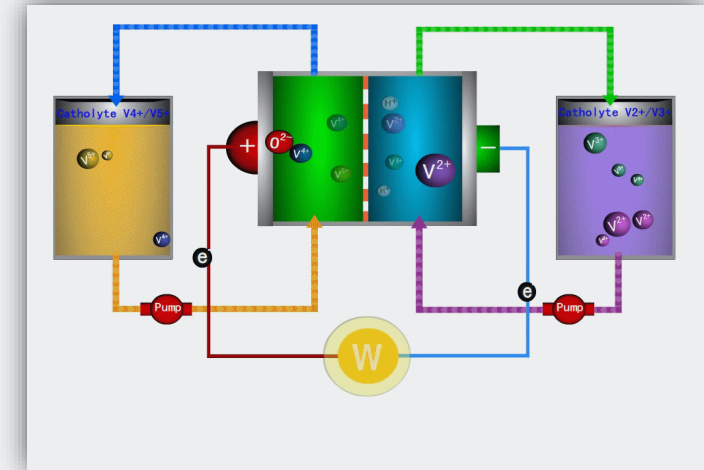
Allowing 100%DOD

Without structural damage



Flexibility

Independent power and energy scaling with KW to MW applications



Highlights of VFB Technology

- VFBs differ fundamentally from sodium and lithium-ion batteries due to the dual-tank system.
- Vanadium electrolytes are pumped through electrode cells for smooth charging and discharging.
- This tank separation enhances safety and durability by addressing high state-of-charge challenges.



Why Safe

- 1. Water-Based Electrolyte:**
Operates safely at room temperature and atmospheric pressure, reducing thermal risks.
- 2. Low Risk of Battery Failure:**
Straight forward BMS design with only 70-80 measurement points per MW minimizes potential battery failures.
- 3. Controlled Electrolyte Temperature:**
Even in the event of anode/cathode electrolyte mixing at 100% SOC, the maximum electrolyte temperature reaches only 70° C, demonstrating robust thermal management.



Why Long-life

- 1. Inherent Stability:**
VFB electrodes serve as the reaction interface, not as part of the reaction itself, ensuring consistent performance during charge and discharge cycles.
- 2. No Phase Transformation:**
The absence of phase changes during charge and discharge processes enhances system stability and longevity.
- 3. Performance Consistency:**
Battery performance remains unaffected by the depth of charge or discharge, with no degradation from deep cycling.



Why Zero Degradation

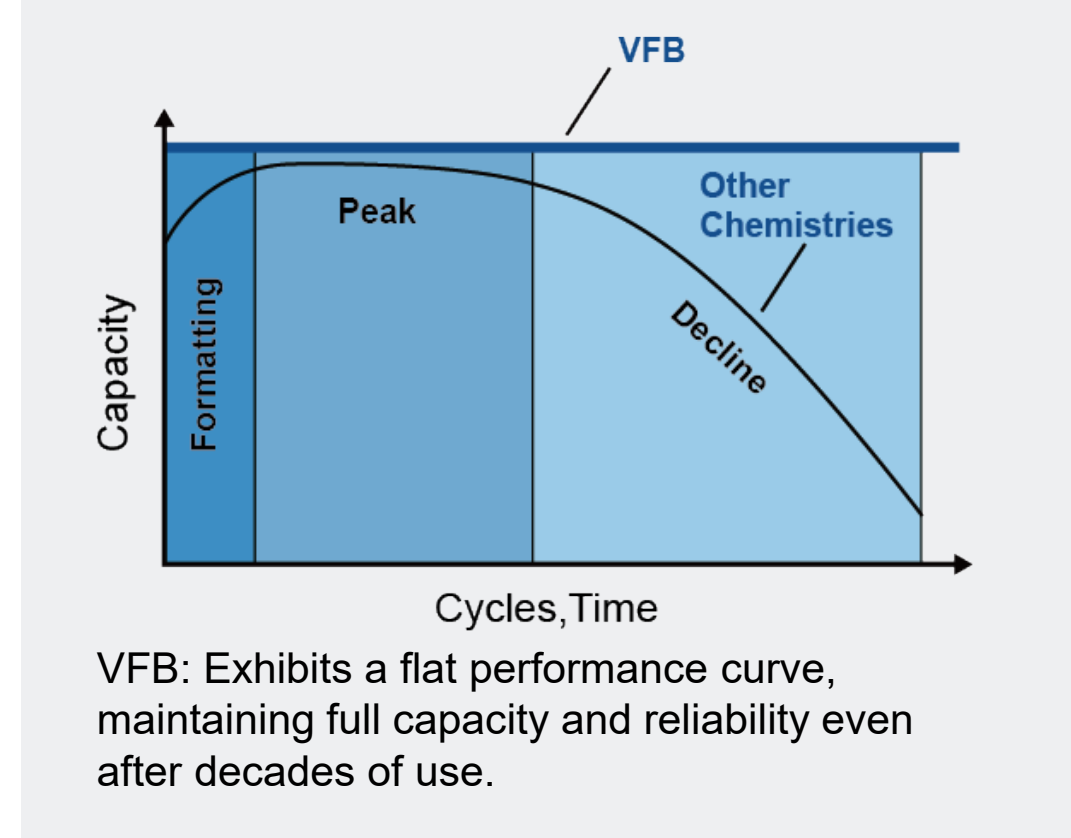
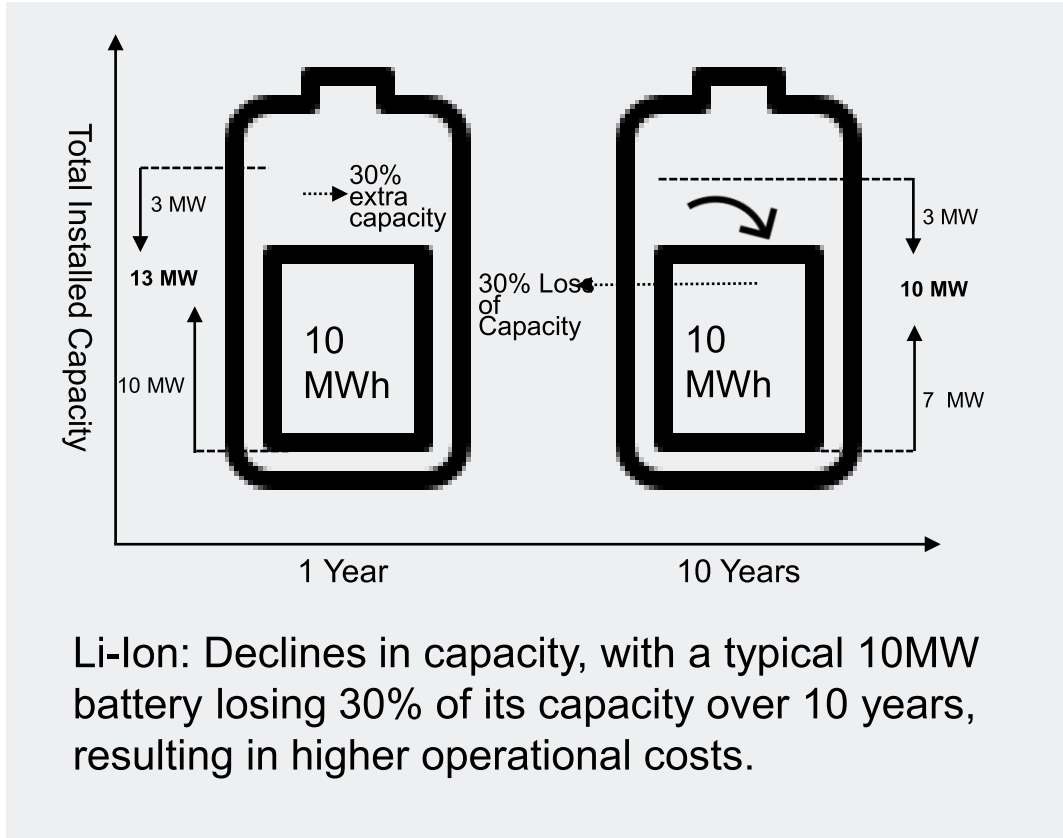
- 1. VFB Degradation Cause:**
Imbalance from minor side reactions.
- 2. Easy Restoration:**
Capacitance can be fully restored during operation period, using cost-effective chemical methods.
- 3. Lifetime Capacity Retention:**
VFB maintains 100% capacity retention throughout its entire lifespan.
- 4. Zero Efficiency Degradation:**
No efficiency loss occurs over the battery's lifetime, ensuring consistent performance.



Why Sustainable

- 1. Sustainable Vanadium Sourcing:**
Vanadium for VFBs can be extracted from industrial waste, such as steel slag and oil ash. Additionally, vanadium is not resource limited.
- 2. Reusable Electrolyte:**
The electrolyte in VFBs is fully reusable, contributing to a circular economy.
- 3. Fully Recyclable:**
VFBs are made from 100% recyclable materials, with no hazardous substances used, ensuring an environmentally friendly solution.

Typical 10MW Li-ion Battery in 10 years



Long-Term Performance: VFB vs. Li-Ion Batteries

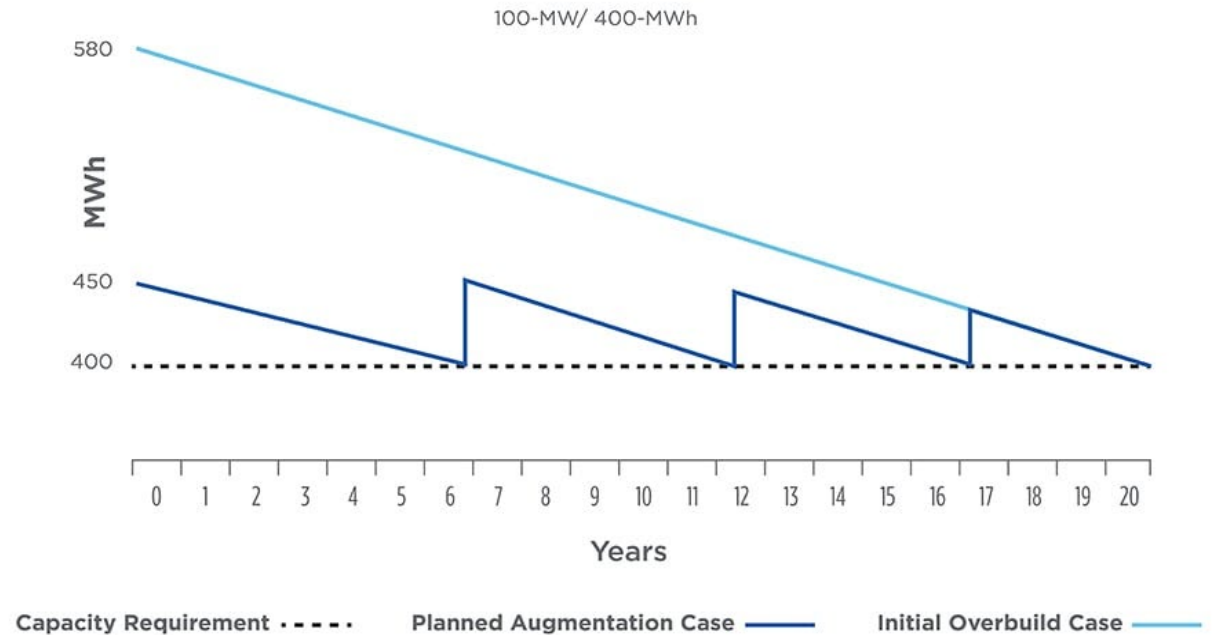
Li-Ion Batteries:

- **Capacity Fade:** As shown in the diagram, Li-ion systems experience significant capacity loss over time, dropping from 580 MWh to below 400 MWh after 20 years.
- **Frequent Augmentation:** To compensate for capacity fade, Li-ion requires regular capacity augmentation, shown by the stepped line (Planned Augmentation Case), increasing maintenance and costs over the system's life.
- **Initial Overbuild:** Another strategy is building extra capacity upfront (Initial Overbuild Case), resulting in higher upfront CAPEX but still suffering from eventual decline.

Vanadium Flow Batteries Advantage:

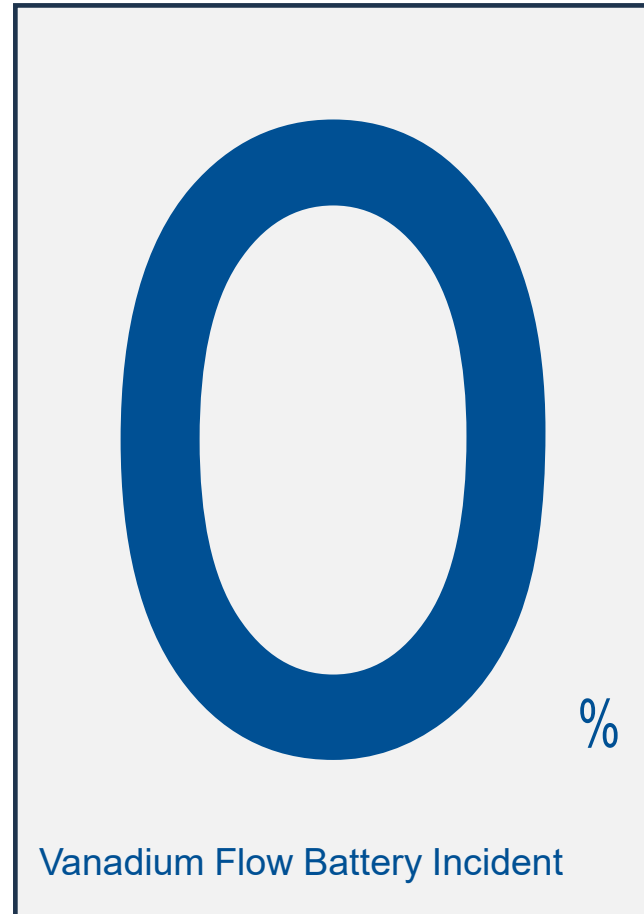
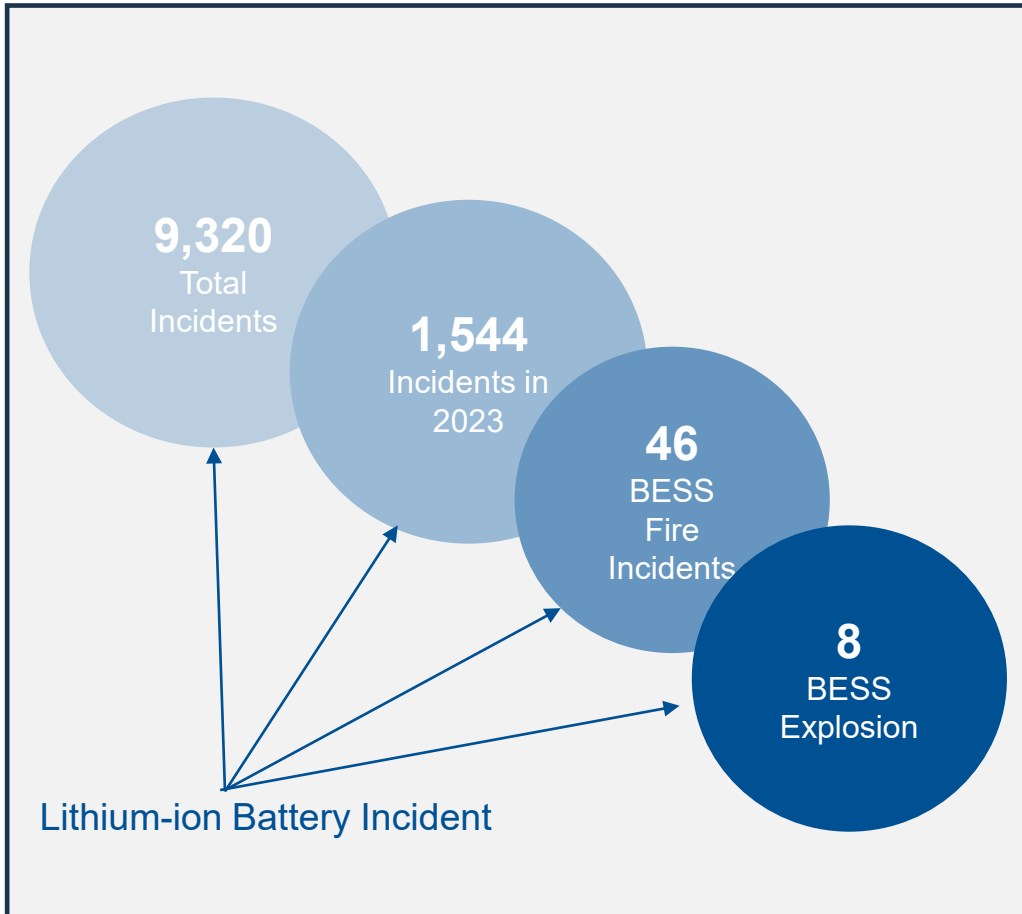
- **No Augmentation Needed:** Unlike Li-ion, VFBs retain 100% capacity for decades, eliminating the need for overbuild or augmentation.
- **Cost Efficiency:** VFB's ability to maintain stable performance without degradation results in lower long-term costs compared to the continuous investment needed for Li-ion augmentation.

Li-ion Battery System Capacity



While Li-ion requires frequent augmentation or overbuild to maintain capacity, VFB provides a long-lasting, stable solution without capacity degradation—making it the more cost-effective and reliable choice over decades.

Dozens of battery-related fire incidents have highlighted the importance of battery safety. Vanadium Flow Batteries (VFBs) offer a safer alternative.



VFBs are known for the inherent safety advantages, including:

- Non-flammable electrolyte
- Separation of energy storage and power generation.
- VFB absorbs heat during charge (Li-ion gets hotter)

- 1 **No risk of thermal runaway, reduce risk of fire and explosion**
- 2 **Perfect fit for solar integration in areas of hot daytime temperatures**

Energy Storage Fire and Explosion



Tesla Megapack on fire at Victorian Big Battery, Australia



Korea energy storage system explosion



Fire at a Jefferson County, New York solar farm



Data center fire in France



Terra-Gen battery storage facility caught fire



An energy storage system at a Hyundai Steel facility in Incheon is on fire



Taiwan energy storage explosion

Water Desalination Plants



Reliable and Cost-Efficient Operation:

VFBs offer a stable energy storage solution that supports continuous desalination processes. Their ability to operate at 100% Depth of Discharge (DoD) without degradation ensures long-term cost efficiency, especially in regions where energy supply can be intermittent.

Why VFBs:

Unlike lithium-ion batteries, VFBs don't suffer from significant degradation with deep cycling, making them more suitable for the constant, high-demand energy needs of desalination plants.

Data Centers



Consistent and Efficient Energy Storage:

Data centers rely on uninterrupted power to prevent data loss and downtime. VFBs offer long-term reliability with no capacity degradation over time, ensuring continuous operation without the frequent maintenance that lithium-ion batteries might require.

Why VFBs:

The potential for reduced performance and capacity fade in lithium-ion batteries makes VFBs a more dependable option for data centers where reliability is paramount.

Renewable Generation (Solar/Wind)



Maximizing Renewable Energy Use:

VFBs are ideal for storing excess energy generated by solar or wind farms and discharging it during periods of low generation. Their ability to handle high cycling with minimal degradation ensures long-term efficiency and sustainability.

Why VFBs:

The cycle life limitations of lithium-ion batteries can make them less suitable for the continuous cycling demands of renewable energy farms, where VFBs excel.

Telecommunications Infrastructure



Reliable Backup for Critical Networks:

Telecommunications infrastructure depends on a reliable backup power source to maintain service during outages. VFBs provide consistent energy storage with minimal maintenance needs, ensuring long-term reliability in remote or difficult-to-access areas.

Why VFBs:

Unlike lithium-ion batteries, which may degrade over time and require more frequent replacement, VFBs offer a stable, long-term solution for critical communication networks.

Oil and Gas



Safe and Reliable Energy Storage:

Offshore platforms need a dependable energy storage solution that can withstand harsh conditions. VFBs, with their safe, water-based electrolyte, offer a secure energy supply with no risk of thermal runaway.

Why VFBs:

The safety and operational challenges associated with lithium-ion batteries in harsh environments make VFBs a more robust and secure option for offshore applications.

Utility-Scale Energy Storage for Grid Stabilization



Enhancing Grid Stability:

VFBs excel in large-scale energy storage, which is crucial for stabilizing the grid as more renewable energy sources like solar and wind are integrated. They can store vast amounts of energy and release it when needed to balance supply and demand, thus ensuring consistent power delivery and minimizing fluctuations.

Why VFBs:

VFBs offer a scalable and reliable solution for utility-scale projects, unlike lithium-ion batteries which may degrade over time with frequent cycling. VFBs excel in extensive cycling, making them perfect for maintaining grid stability in high-demand scenarios.

Hospitals



Uninterruptible and Safe Power Supply:

Hospitals require a consistent power supply for life-critical systems. VFBs provide a reliable backup power source with a high safety profile, thanks to their water-based electrolyte, which eliminates the risk of thermal runaway.

Why VFBs:

The long lifespan and minimal degradation of VFBs ensure that hospitals can depend on them for decades, unlike lithium-ion batteries, which may require frequent replacements due to capacity fade.

Airports



Scalable Energy Management:

VFBs allow airports to manage peak energy loads effectively by storing energy during low-demand periods and discharging it when demand is high. Their scalability makes them adaptable to the growing energy needs of large infrastructure.

Why VFBs:

Lithium-ion batteries might require complex and costly scaling solutions, while VFBs can easily expand energy storage capacity by increasing electrolyte volume, making them a more flexible option.

Mining Operations



Durable Energy Supply in Remote Locations:

Mining operations often take place in remote areas with harsh environmental conditions. VFBs provide a reliable and safe energy supply, with no risk of thermal runaway, ensuring continuous operation even in challenging climates.

Why VFBs:

Unlike lithium-ion batteries, which can be sensitive to extreme temperatures and may require additional cooling systems, VFBs perform well across a wide temperature range, reducing the need for complex thermal management.

Cold Storage Facilities



Stable Power for Temperature-Sensitive Operations:

Cold storage facilities require a consistent energy supply to maintain precise temperature control. VFBs provide reliable energy storage that performs well in varying temperatures, ensuring product integrity.

Why VFBs:

Lithium-ion batteries may need extensive thermal management to operate efficiently, whereas VFBs can maintain performance without additional cooling, making them more cost-effective and reliable for cold storage.



Thank you.