



WEBINAR





Long-Duration Energy Storage Applications & Opportunities

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About Lockheed Martin Energy

Lockheed Martin is a global security and aerospace company engaged in the development, manufacture and integration of advanced technology systems. It is home to Lockheed Martin Energy, which delivers energy solutions to advance resilient, clean and sustainable energy for utility, commercial, industrial and military applications.



ENERGY STORAGE

GridStar® Flow – a coordination chemistry flow battery for short and long duration energy storage



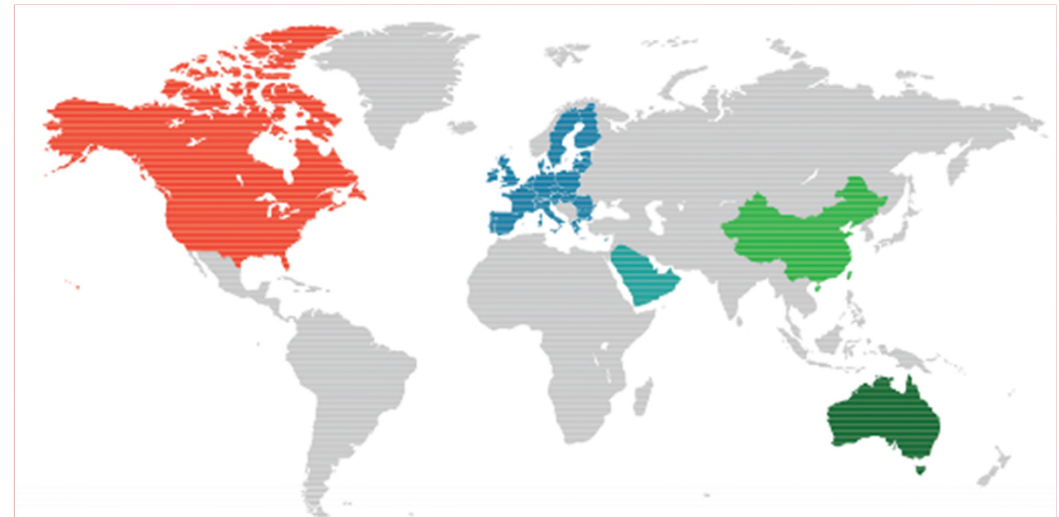
FEDERAL RESILIENCY

Energy storage to ensure mission readiness while reducing base operating costs



NUCLEAR INSTRUMENTATION & CONTROLS

Safety critical instrument and controls systems to support Navy nuclear fleet and commercial facilities

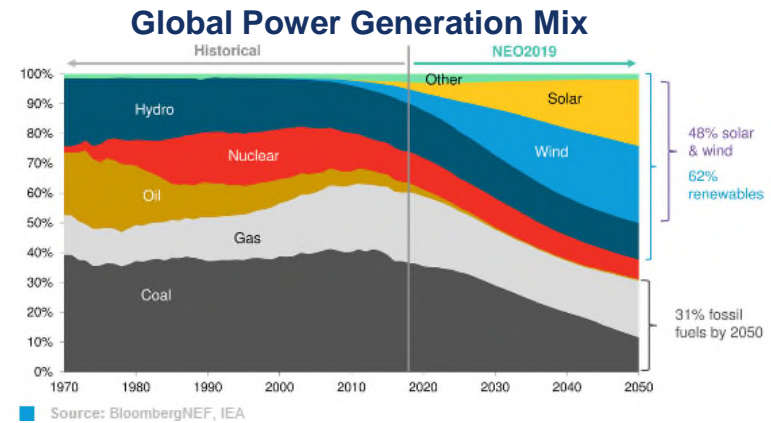


Lockheed Martin Energy is active in shaping policies driving energy innovation

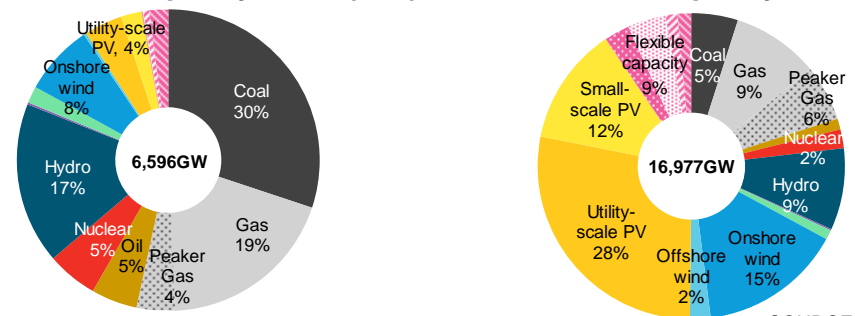
The worldwide energy market is rapidly transforming to a renewable-based, flexible and distributed grid

GLOBAL MARKET DRIVERS

- **Economics, and increasingly mandates, not incentives** drive renewable adoption
- Decentralized electric grid accelerates as **renewable adoption continues growth**
- **Storage need accelerates** as renewables increase and fossil and new nuclear generation declines
- Global energy storage market is **increasingly long duration**



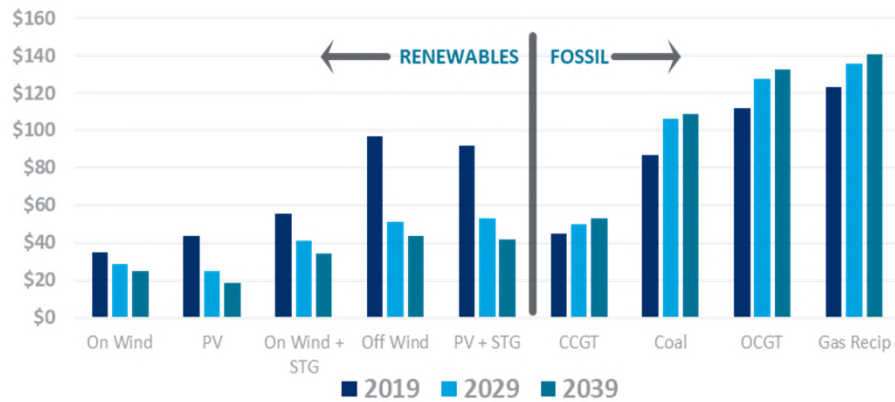
Total installed capacity, 2017 (GW) Total installed capacity, 2050 (GW)



SOURCE: BloombergNEF

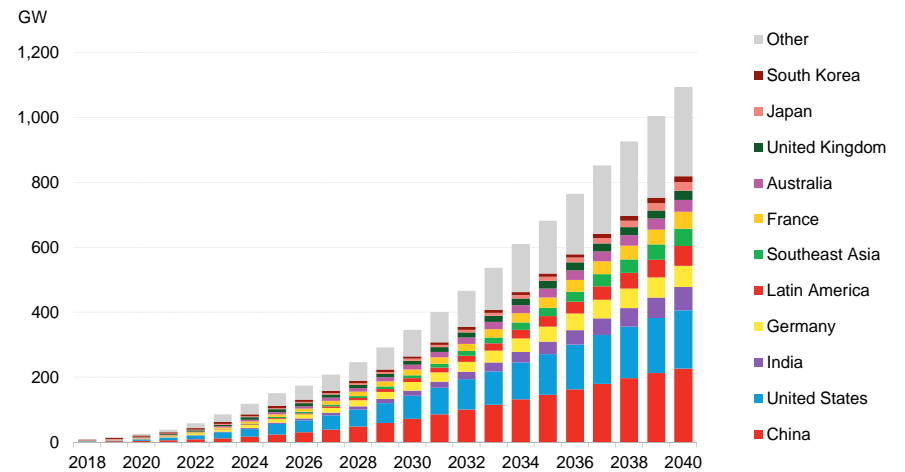
Key Mega-trends of the Global Electricity Market

LEVELIZED COST OF ENERGY (\$/MWh)



SOURCES: : Lazard

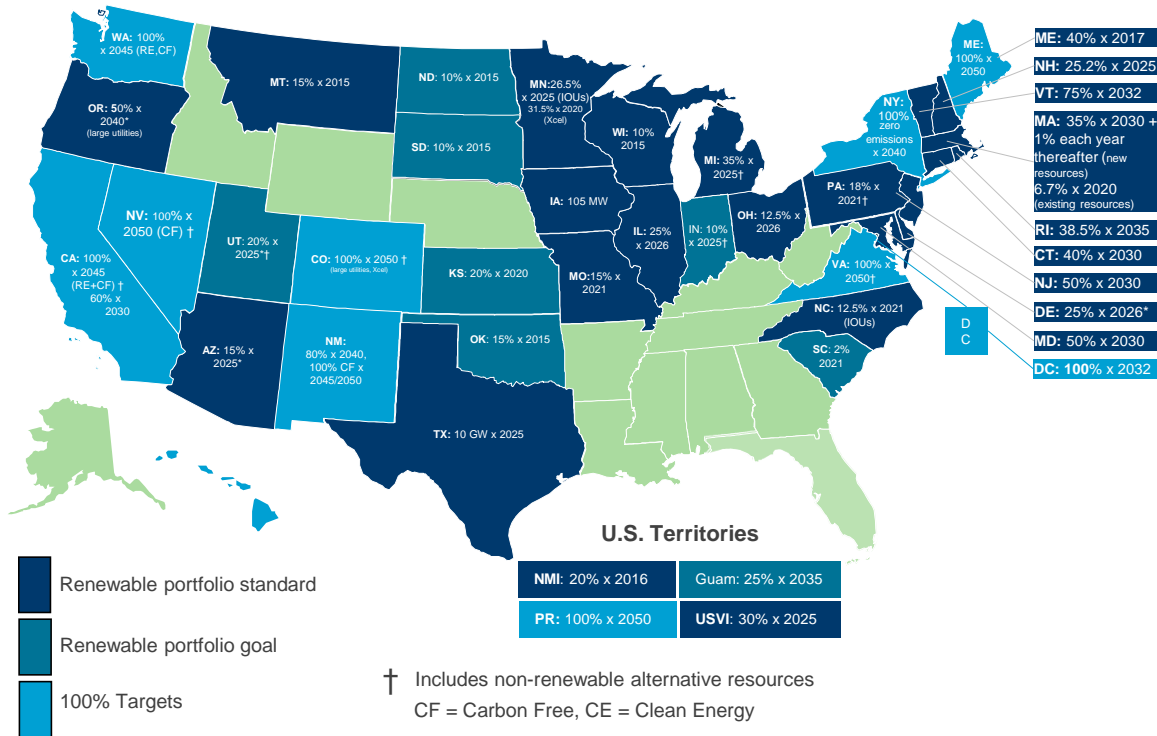
GLOBAL CUMULATIVE ENERGY STORAGE INSTALLATIONS



SOURCE: Bloomberg NEF 2019

Renewable Economics have crossed critical thresholds driving storage demand

Energy Storage Policy Driving Rapid Change



SOURCE: www.dsireusa.org and ncl.org. Dec 2019.

POLICY DRIVERS



- States, not Federal, drive current energy policy and investment decisions
- 75% of states have set clean power goals
- Many states have 100% green grid mandates by 2050 (CA, HI, WA, NV, NM, VA, ME, PR)
- State energy storage procurement mandates growing (CA, NY, MA, VA)
- US utilities integrated resource plans increasingly include energy storage



- Europe has targeted 100% net zero carbon emissions by 2050.
- EU announces Green Deal with €320B in potential funding through 2027 – could total €1T through 2050



- South Australia net 100%, Victoria 50%, renewable green grids by 2030.

On 11 Feb 2020, Virginia announced net zero carbon emissions by 2050; including 3.1 GW of storage by 2035

Long-duration storage requirements being built into long range plans



The U.S. National Renewable Energy Laboratory (NREL) identifies significant need for >4 hour storage to provide peaking capacity in U.S. markets.



US regional (NY-ISO and PJM) market studies forecast that in high-renewable penetration grids, >10 hour duration energy storage will be required to meet the majority of peak electricity demand.



Southern California Edison (SCE) forecasts that 85% of energy storage in California in 2045 will require durations of 6 hours or greater

"Longer storage duration is needed to replace the function of today's dispatchable generation."

- SCE, "Pathway 2045," November 2019



The Australian Energy Market Operator (AEMO) forecasts an increased role for 6 to 12 hour storage to integrate solar

"Large role for energy storage to smooth the production of variable renewable energy."

- AEMO, "Integrated System Plan," July 2018

Market analysis finds increasing demand for long-duration in high-renewable grids

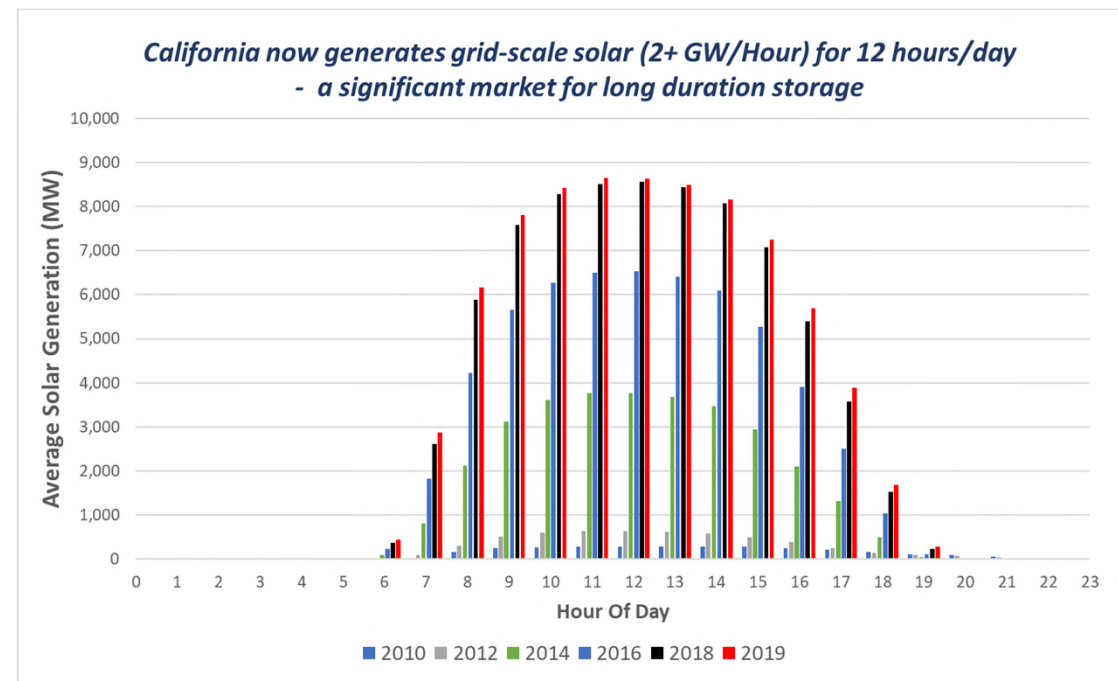
Managing grid and market volatility will be the key challenge in the US over the next 20 years

KEY TRENDS

- Increasing renewables penetration
- Transportation electrification
- Growth of distributed generation

IMPACT

- Increase in subhourly supply-demand imbalances
- Multiple hours that require flexible resources
- Need for supply diversity



SOURCE: Hitachi ABB Power Grids 2020. All rights reserved

GridStar Flow

FLEXIBLE. DURABLE. SAFE.

Pioneering utility-scale flow battery
utilizing proprietary metal ligand
coordination chemistry.



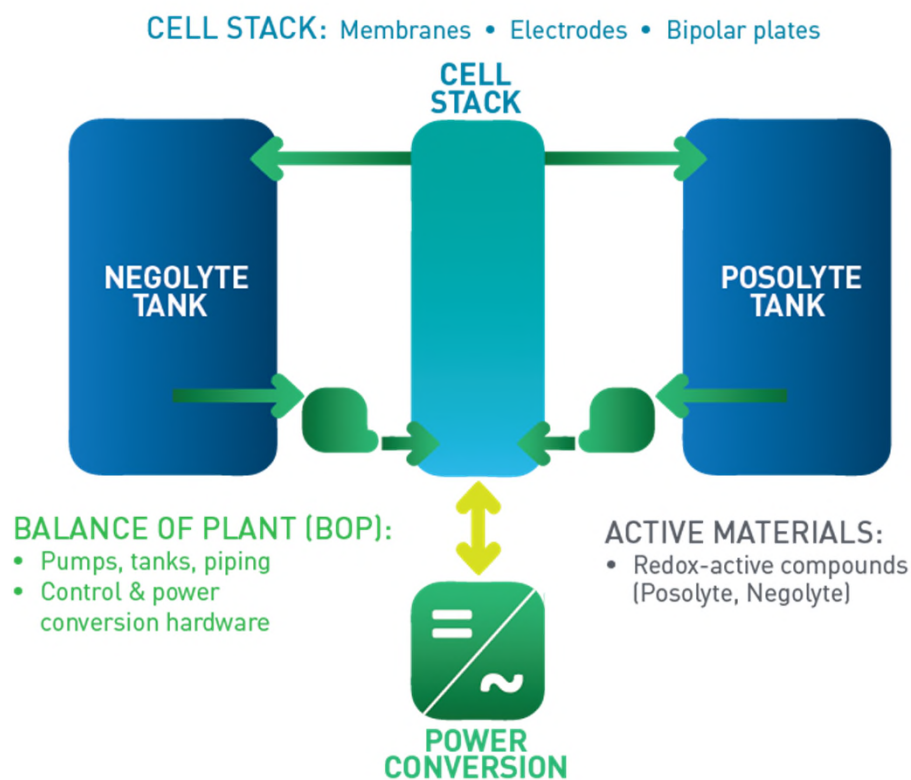
Traditional technologies are unable to meet expanding long duration requirements



- Degradation and shortened lifespan caused by frequent cycling, holding at high state-of-charge and calendar aging
- Degradation requires oversizing or augmentation leading to increased TCO
- Sealed batteries are not project-configurable, resulting in costly oversizing of power capacity for longer duration needs
- Thermal runaway presents potential safety hazard
- Durability and duration limitations increasingly impact Li-ion project economics at longer durations – best suited for applications of four hours or less

Li-ion value proposition breaks down for long-duration, high-cycling projects

Flow Battery Architecture and Opportunity



ARCHITECTURAL ADVANTAGES

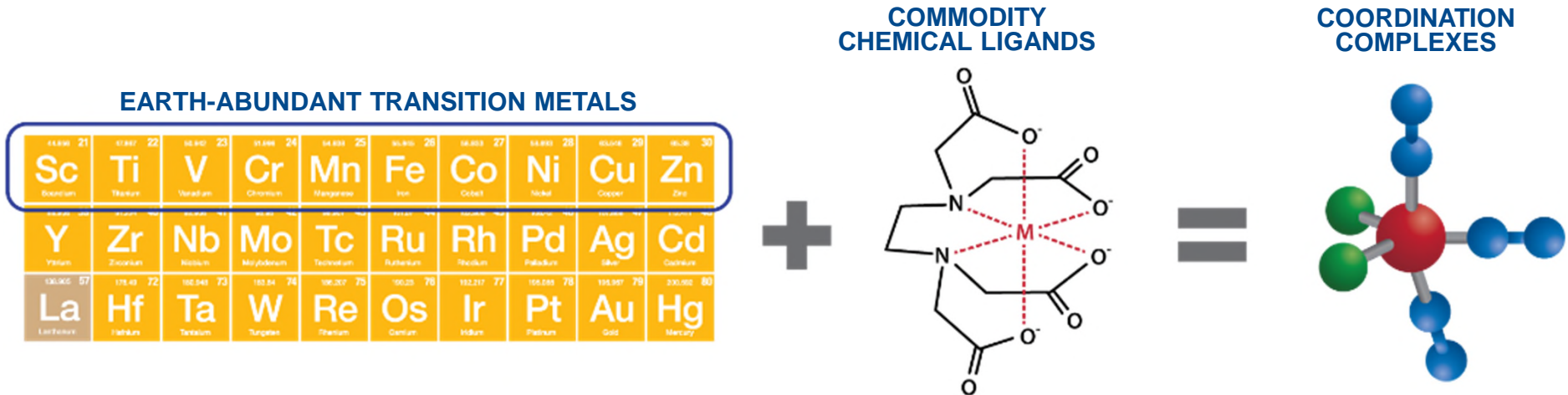
- Decoupling of power and energy enables low cost long-duration storage
- Energy capacity insensitivity to duty-cycle affords operational flexibility (e.g., deep or frequent cycling, storage at high states-of-charge)
- Straightforward augmentation
- Safety (e.g., aqueous electrolytes)

INCUMBENT TECHNOLOGIES HAVE FAILED

- High cost, corrosivity, and/or toxicity of electrolytes
- Low current density (e.g., zinc plating systems)
- Active material cross-over

Coordination Chemistry Advantages

- Enhanced performance due to larger molecule size & negative charge of complex
- Enhanced safety due to non flammable and modest pH electrolytes
- Enhanced efficiency by using molecular design to tune potential
- Established supply chain allowing procurement of raw materials from reliable partners



We have developed our proprietary GridStar Flow technology to optimize energy storage performance, flexibility, and safety for long-duration applications.

Advantages of GridStar Flow

Long-Duration

- 6 to >12 hours duration

Durable

- Able to do multiple daily deep-discharge cycles
- Long useful life

Flexible

- Freedom to operate in future differently than originally planned
- Energy and power can be sized independently
- Can add additional energy in future, as required
- Switch between products over any time period to maximize revenue
- Able to address shorter duration applications

Cost Competitive

- Competitive total cost of ownership

Safe

- Designed for system-level safety and site-ability
- Non-flammable battery chemistry

Lockheed Martin Reputation

- History of pioneering innovation and technology commercialization
- Fortune 500 company

GridStar Flow System Prototypes



ALPHA Unit:

Power: 250 kW_{AC}

Energy: 500 kWh (2 hr)



BETA Unit:

Power: 250 kW_{AC}

Energy: 1500 kWh (6 hr)



GridStar Flow S/N 01:

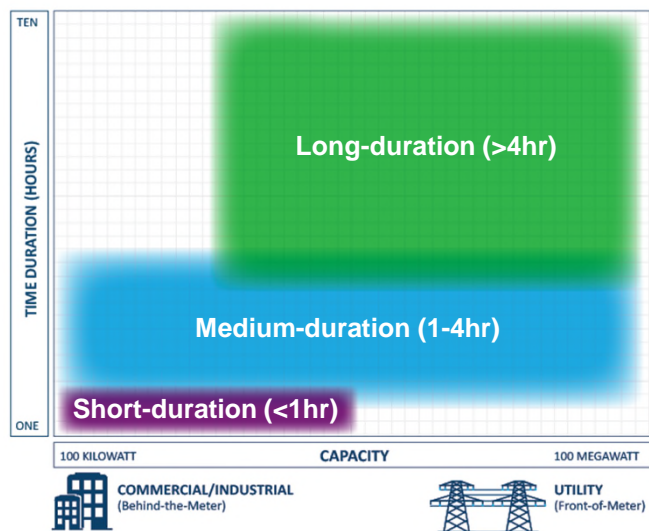
Power: 250 - 500 kW_{AC}

Energy: 2.5 MWh_{AC} (5 -10 hr)

Energy Storage Applications

APPLICATION REQUIREMENTS

Applications with various size, duration, cycling and flexibility requirements...



ENERGY STORAGE APPLICATIONS

...are required for the 20+ services energy storage can provide.

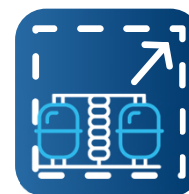
Wholesale Energy Markets	End User / Customer
Price Arbitrage	Demand Response
Portfolio Optimization	Demand Charge Management
Grid Systems	Transmission Rate Management
T&D Upgrade Deferral	Capacity Rate Management
T&D Congestion Relief	Energy Rate Management
Substation On-site Power	Electric Service Reliability
Microgrids	Electric Power Quality
Islanded Microgrids	Ancillary Services
Grid-Connected Smart Microgrids	Frequency Regulation
Renewables	Load Following
Solar Energy Time-shifting	Reserve Products – Spinning / Primary
Wind Energy Time-shifting	Voltage / VAR Support
Solar Smoothing / Firming	
Wind Smoothing / Firming	

■ Short-duration
 ■ Medium-duration
 ■ Long-duration

OPTIONALITY

GridStar Flow provides optionality to flex among multiple applications, maximizing value and reducing risk as a T&D and/or wholesale market asset.

OPERATIONAL



On a day-to-day basis, GridStar Flow can flex among applications across durations.

- Energy arbitrage
- Frequency regulation
- Contingency reserves

STRATEGIC



The role of GridStar Flow can change with evolving market and grid needs

- Flexible design
- 20 year design life
- High durability

Long-Duration Energy Storage projected to be a \$20B market by 2027 Navigant Research

Strategic & Tactical Optionality

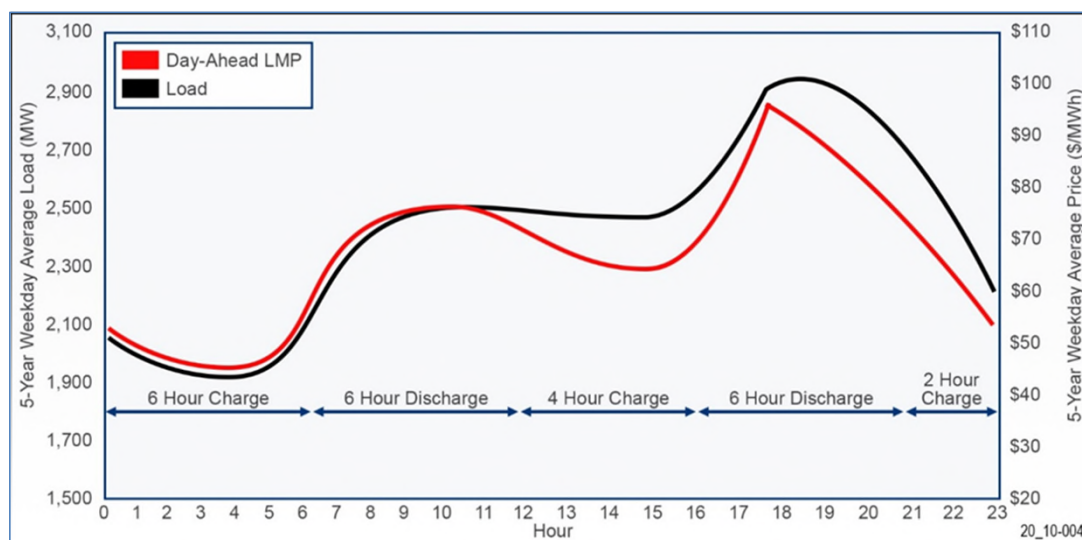
TACTICAL: MAXIMIZE ASSET VALUE

- Switch between market products – Reg, Reserves, Energy - on the fly in real-time
 - Fast response time, high ramp rate, high cycling ability, highly durable
- Leverage customized duration
- Multiday optimization possible

STRATEGIC: EVOLVE USE

- Customize energy & power separately
- Switch application focus with market
- Dual-use cases maximize revenue

Simple Energy Arbitrage: Long Island



Simulated January operation for illustrative purposes only. Lockheed Martin proprietary research

GridStar Flow is a bespoke solution with applications and design tailored to maximize value for each customer

Final Takeaways

- The energy market disruption is accelerating led by renewables and decarbonization.
- The grid needs extremely flexible resources. The longer the duration, the greater the optionality and the higher the revenue potential.
- Long duration energy storage will play a critical role in the grid of the future.



GridStar Flow

10 MW_{AC} / 100 MWh Configuration

THANK YOU!

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