

# ENERGY STORAGE TESTBEDS & TESTING PROTOCOLS

*ENERGY STORAGE ACADEMY  
9 NOVEMBER 2020*

# ENERGY STORAGE TESTBEDS & TESTING PROTOCOLS

## Agenda:

- *Landscape of Testing and Related Examples*
- *Overview of Testing Protocol Report*
- *Global Network of Energy Storage Testbeds*
- *Market perspective from DNV-GL*

## Experts:

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Carlo Mol – *Project Leader, Unit Energy Technology | VITO, Belgium*

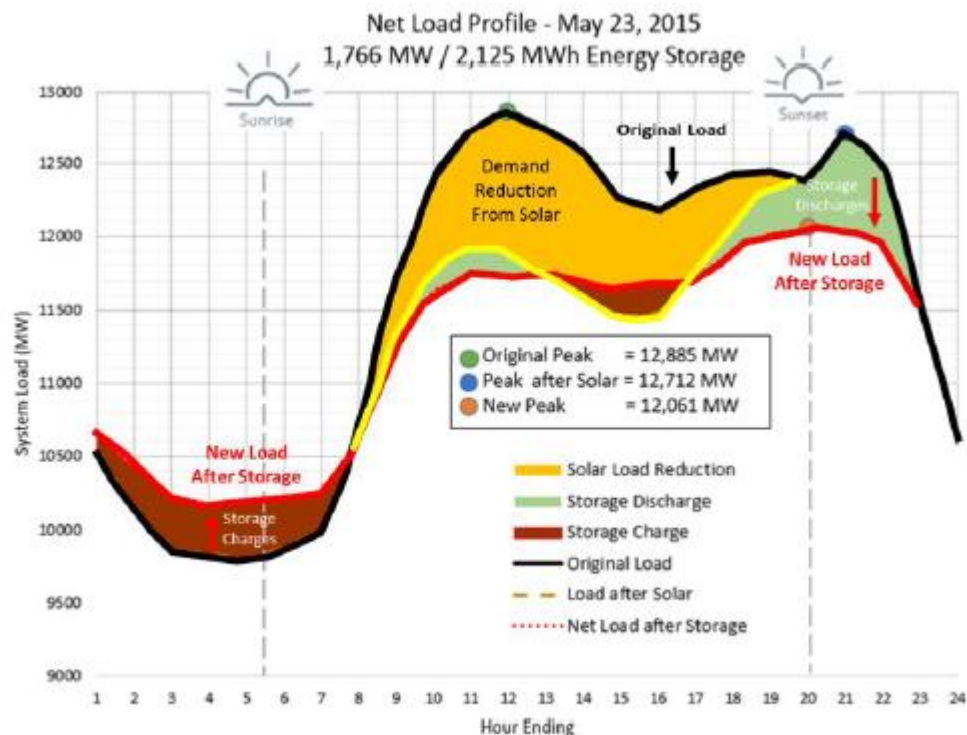
Phillip Hannam – *Energy Economist | World Bank*

Andrew Lebowitz – *Senior Consultant, Energy Storage Engineering | DNV GL, USA*

**Chair:** Sandra Chavez – *Energy Storage Partnership | World Bank*

# THE VALUE PROPOSITION OF ENERGY STORAGE

## Illustration of system flexibility with energy storage (sample day, Massachusetts)



Massachusetts Energy Storage Initiative (2016), p. 101. [\[Link\]](#)

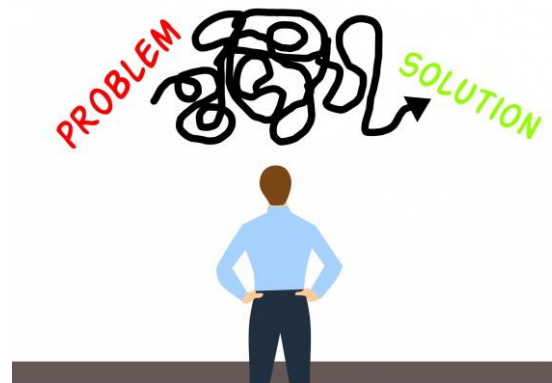
- Storage is a flexible resource, and can offer different services at different times (value stacking):
  - Modify the peak by charging during non-peak hours, and discharging during peak hours;
  - Time shifting and ramp rate control for integration of solar power without curtailment;
  - Avoid penalties for inaccurate forecast of demand and generation;
  - Increase the capacity utilization of existing generators, transmission and distribution;
  - Delay the need for replacing or upgrading T&D capacity;
  - Accuracy and speed of control over power quality (frequency regulation, voltage support, phase balancing)
  - Behind-the-meter
    - Backup Power / Resilience
    - Support to distribution grid
- Flexibility is critical for a highly resilient energy system.

# FAST CHANGING TECHNO-ECONOMIC LANDSCAPE

	Lead Acid battery	Lithium-ion battery	Flow batteries (very diverse chemistries)	Zinc-air battery	Sodium Sulphur battery	Sodium-ion battery	Thermal storage
<b>Chemistries</b>	Flooded, VLR/AGM/Gel, carbon matt	LCO, LMO, NMC, NCA, LFP, Li-S, Li Metal, LTO, Li-Si	Vanadium redox, Iron-Chromium, Zinc-Bromine	Zinc-air	NaS		Molten salts, different types of rocks, concrete
<b>Discharge time</b>	Short to long (>20h)	Short (up to 4h)	Medium to very long (>4h; >10h possible)	Long (>6h)	Medium to long (4h-10h)	Very long (20 h)	Medium to long (4h-10+h)
<b>Lifetime (# of deep cycles)</b>	200 – 800	2,000 – 8,000	10,000 – 15,000	10,000+	7,500	3,000 – 4,500	10,000+
<b>Round Trip Efficiency</b>	60%-70%	85%-98%	60%-85%	50-70%	70 – 90%	80 – 90%	60%-85%
<b>Density</b>	Low	High	Medium	Medium	High	Low	Medium
<b>Cell Price (for batteries)</b>	<\$100/kWh	<250\$/kWh, and falling	\$200-\$600 per kWh	\$160-250/kWh	\$250/kW	\$300/kW	Varies per technology
<b>Safety</b>	Risk of gassing, flammability risk	Flammability risk	No flammability. Electrolyte spills possible.	No safety risk observed	Operates at high temperature so risks to operators	No safety risk observed	No safety risk observed
<b>Toxicity</b>	Very critical	Depends on chemistry. LFP has no toxic materials	Varies per chemistry: some very critical (Bromine), others no toxicity risks	None	Medium (Sulphur)	None	None
<b>Cooling and miscellaneous issues</b>	Hazardous manufacturing	Complex heat management critical in hot climates	Possible maintenance issues in harsh environments	No cooling required	Operates at high temperature	No cooling required	No cooling required

# THE PROBLEM

- Potential lack of quality across battery technologies.
- Complex use cases that need testing
- Grid storage usage different than vehicle usage for batteries
- Significant emerging technologies (gravity, liquid air, geothermal, etc.) without test or commissioning protocols
- Rapidly evolving markets and manufacturers with minimal track-record and clients new to storage who aren't clear on their own needs.
- Lifetime testing: Very difficult or impossible to test robustly at multi-MW scale.



# FEEDBACK FROM DEVELOPING COUNTRIES

- Which technology should be used?
- Which suppliers to use?
- Is the quality and lifetime as good as the manufacturer says?
- If we want some samples tested, where can we go?
- If we want to set up our own testing center, how do we go about doing that?



# RELATED HISTORY OF PV TESTING

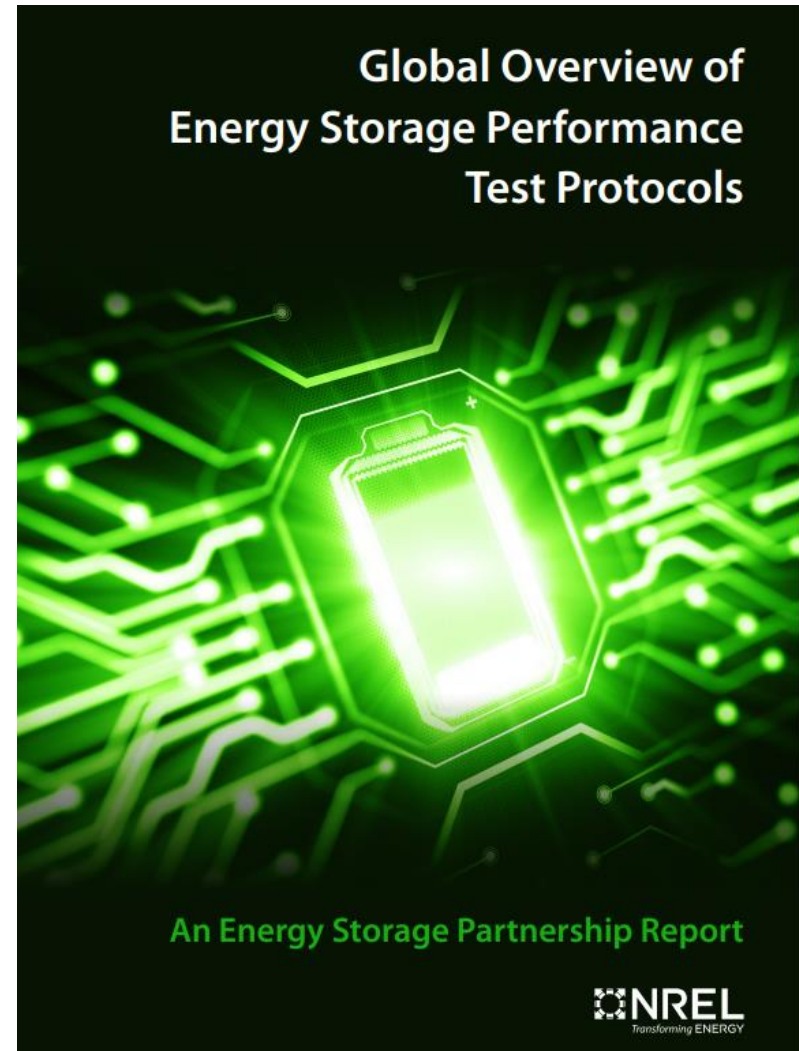
- Historically, PV output from manufacturers was inaccurate.
- Research labs globally developed test methods for performance, safety, durability, etc.
- Those protocols have now been rolled out to other government labs as well as private business test labs.
- New and unique PV designs (like bifacial panels) require ongoing development and refinement of testing protocols by research teams.
- Consistent characterization and databases of performance characteristics have made PV modules much easier to model and predict.



# RECENT REPORT ON TESTING PROTOCOLS

## “Global Overview of Energy Storage Performance Test Protocols”

- Authors:
  - Nate Blair, Andrew Schiek, Tony Burrell, Matthew Keyser – NREL
  - Andrew Deadman, Ian Ellerington – Faraday Institution
  - Leen Govaerts, Grietus Mulder, Patrick Hendrick, Thomas Polfliet – BERA
  - Phil Hannam, Chong Suk Song – World Bank, ESMAP
- Available at:  
<https://www.nrel.gov/docs/fy21osti/77621.pdf>





# RECENT REPORT ON TESTING PROTOCOLS - CONTENTS

- Short collection of documents on best practices related to storage testing and modeling.
- Initial list of models available to model energy storage
- Overview of grid services and relevant metrics provided by energy storage
- Global coverage of performance testing protocols for battery energy storage
- Listing of key organizations involved with testing by region
- Description of opportunity for contributions of publicly available test data on [energydata.info](https://energydata.info)

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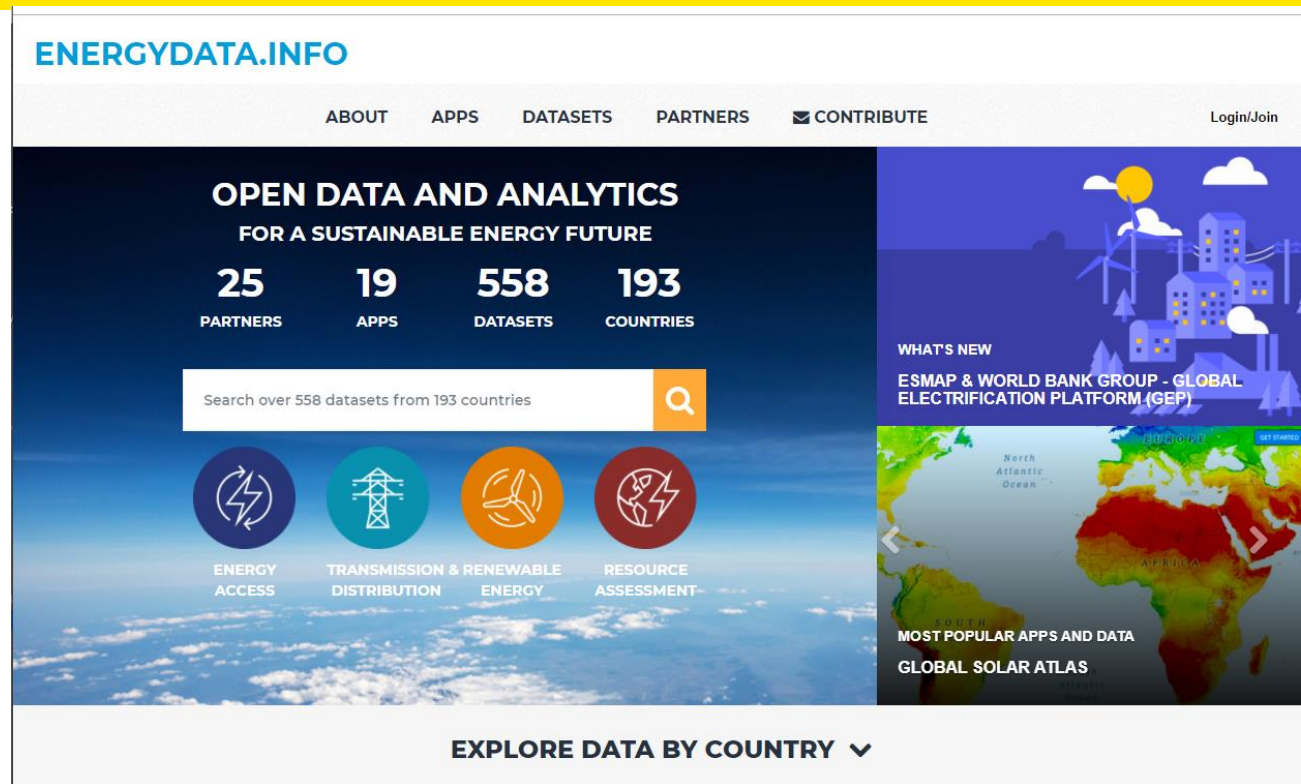
# A REVIEW OF BEST PRACTICES

- “Electric energy storage – future storage demand” by International Energy Agency (IEA) Annex ECES 26, 2015, C. Doetsch, B. Droste-Franke, G. Mulder, Y. Scholz, M. Perrin.
- “European White Book on Grid-Connected Storage,” DER-Lab, 2012
- BatteryStandards.info
- A Good Practice Guide on Electrical Energy Storage, EA Technologies, 2017, United Kingdom
- “Battery Install Guidelines for Accredited Installers,” Clean Energy Council, 2017, Australia
- “D7.5 Methodology report for application specific design of BESS”, CEA, H2020 Osmose project, 2020.

# PERFORMANCE TESTING PROTOCOLS IN KEY GLOBAL MARKETS

- US Test Protocols
  - IEEE Test procedures and protocols featured
- China
  - No national policies were found
- EU Test Standards
  - Three officially recognized European Standardization Organizations:
    - European Committee for Standardization (CEN)
    - European Committee for Electrotechnical Standardization (CENELEC)
    - European Telecommunications Standards Institute (ETSI).
- India
  - Bureau of Indian Standards IS-1651, IS-1652
- Africa
  - African Electrotechnical Standardization Commission
- United Kingdom
  - EU and IEC standards broadly adopted
- International Standards
  - International Electrotechnical Committee (IEC)
  - International Standardization Organisation (ISO) are developing standards for storage systems.

# TEST DATA DATABASE (FROM CELL TO SYSTEM)



- Public energy storage test data is difficult to obtain. However, some does exist.
- The World Bank maintains and manages a storage mechanism for test data at energydata.info.
- Key next steps for the ESP Testing Group is to advocate for collection of data to assist with bankability, resilience and transparency.

# TEST PROTOCOL FUTURE WORK

- We strongly support the collection of existing storage technology test data under a variety of conditions from cells to systems.
- Pursuing joint knowledge exchange with World Bank and the Network of Energy Storage Testbeds.
- Now that we have summarized the current testing protocols, we seek to summarize and discuss solutions to existing gaps in testing protocols
  - Pack/Rack testing: Full-system tests will be difficult or impossible without being already installed. Temp. and DOD difficult to test in the field to test anticipated lifetime for full systems.
  - New and emerging use cases for storage technologies
  - New technologies moving to commercial deployment
  - Working with manufacturers to embed more accurate testing

# PANEL OF EXPERTS



# SAMPLING OF GLOBAL TESTING FACILITIES

## **Sandia National Laboratory (New Mexico, U.S.) – Energy Storage Test Pad (ESTP)**

- Non-biased performance evaluation to utilities and vendors of utility-scale ESS technologies, *particularly at the prototype and pre-commercial stages* so to avoid competing with the commercially developed testbeds

## **NREL (Colorado, U.S.) – Energy Storage Laboratories and Thermal Test Facility**

- Used in evaluation and design of energy storage systems from material to the system level; as well as MW-scale systems integration testing.

## **PNNL (Washington, U.S.) – Redox Flow Battery Large-scale Lifetime Testing Laboratory**

- Facility with simulated grid operation including cold start, ramping, frequency control, peak shaving.

## **ESKOM (Gauteng, South Africa) – Advanced Battery Test and Demonstration Facility**

- Test facility for parallel comparison of MW-scale ESS systems, with results reported back to the equipment supplier. 90-day tests demonstrating load shifting, wind smoothing, solar smoothing, frequency and voltage control, etc.

## **John Cockerill (Belgium) – Micro Reseau Integre Seraing (MiRIS) demonstration plant**

- Capabilities to test different battery chemistries and energy management systems with a solar photovoltaic array.
- Objective is also to offer third party testing services to commercial developers.

## **DNV-GL Testbed (New York, U.S.) – BEST Test & Commercialization Center (BTCC)**

- ISO 17025 accredited third-party performance verification to developers. Provide anonymized information on technology performance that allows the market to assess overall energy storage trends.

# GLOBAL NETWORK OF ENERGY STORAGE TESTBEDS (NESTs)

## The goal of NESTs

- Enable low cost demonstration and performance verification of pre/early-market technology in real conditions of frontier markets to reduce risks for safety, functionality, and profitability;
- Allow the pace of performance demonstration to keep up with the rate of change in the global energy storage techno-economic landscape;
- Provide performance information that informs instruments for risk reduction, such as warranties, and helps to mobilize commercial capital to the energy storage sector;
- Build local technical and institutional capacity.

## Structure of NESTs

- Facilities with the capability to operate ESS technologies with controllable system configurations, use cases, and operational and environmental conditions to verify system performance at low cost and at manageable scale. *Lower the barrier to market entry for new and commercially promising energy storage technologies.*
- Regional Testbeds share a testing regime comprised of a standardized equipment platform, testing protocols, and performance certification standards – each with modifications that reflect regional conditions.
- Tested equipment may carry the “stamp” of that Testbed.
- Primary users (manufacturers seeking to enter a market; developers/integrators seeking to confirm or signal performance); Secondary users (researchers testing novel technologies, and utilities or system operators gaining experience).

# Trends in BESS Testing in emerging markets



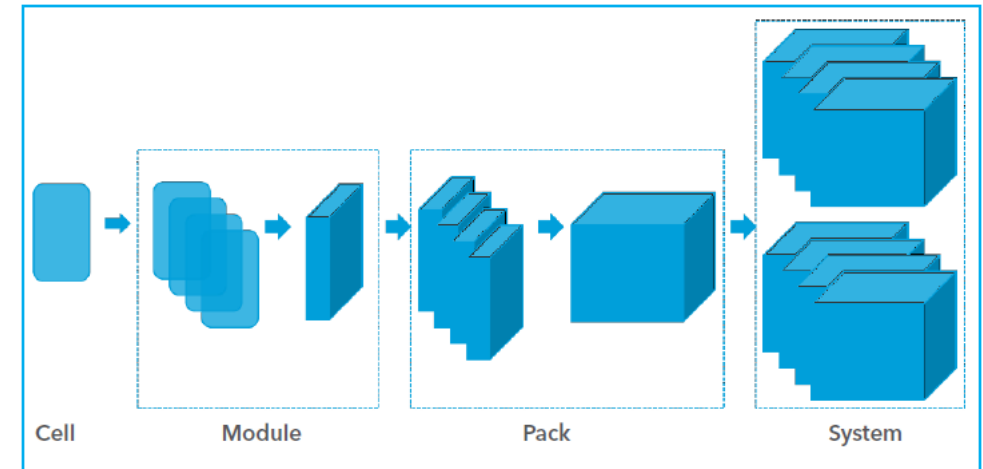
# Evolving codes and standards

- IFC 2018 (and draft 2021)
- NYC Fire Code Development
- UL 1973
- UL 9540
- **UL 9540A Burn Testing**
  - Cell-level
  - System-level
  - Unit-level
  - Outputs used to drive design requirements
- NFPA 855



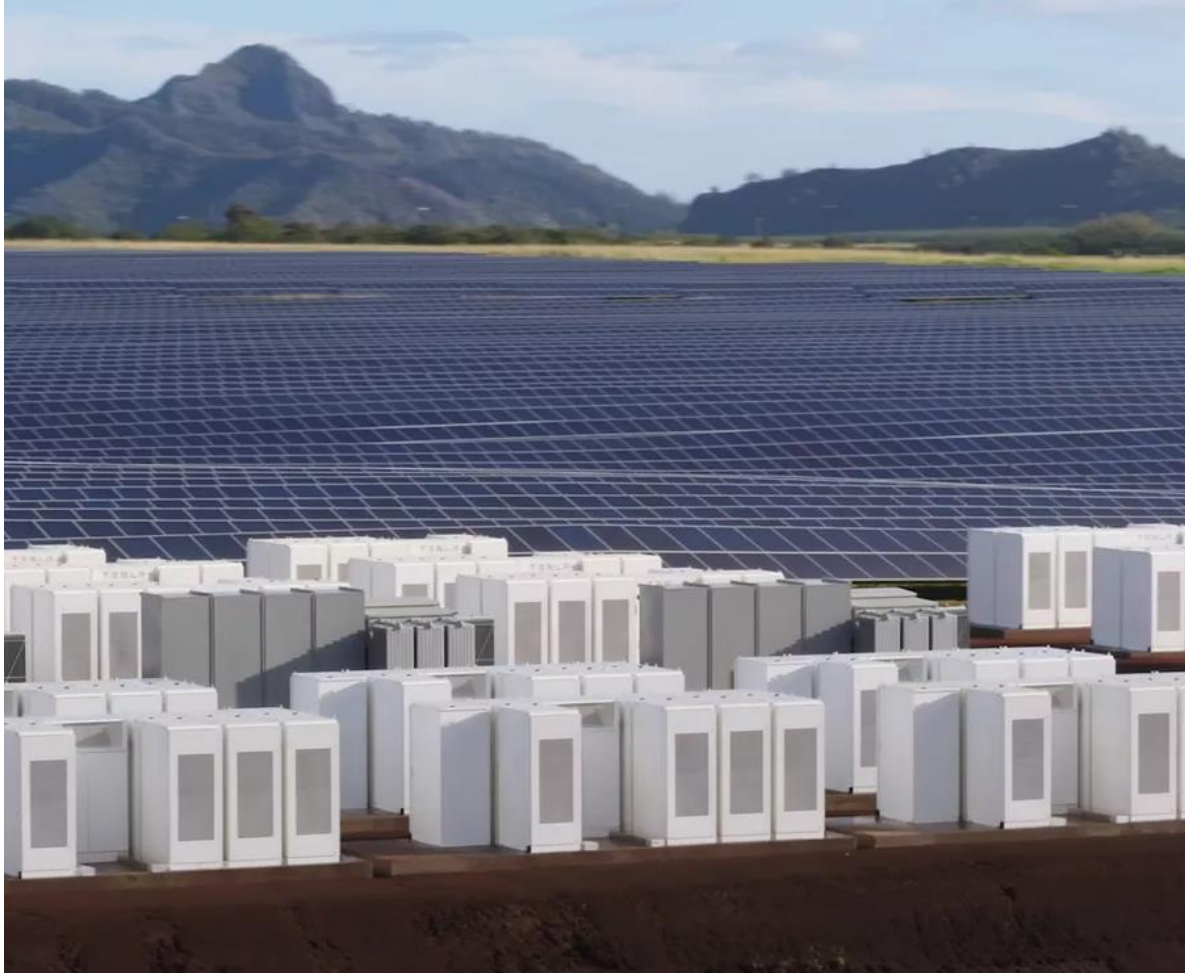
## Cell vs. system-level testing

- Cell level generally pursued by cell manufacturers, integrators, or large-scale energy storage projects
- Cell-level best for producing degradation modeling results
- System-level testing and warranties are the typical level reviewed by developers and projects
- System-level warranties becoming standard as industry shifts away from containerized storage and toward proprietary enclosures





## Industry Testing and Warranty Trends



- Products with strong warranties and balance sheets have driven bankability proposals
- Augmentation strategies reflect testing uncertainties
- Performance-based warranties becoming more common
- Driven by shift toward proprietary enclosures such as Tesla, Wartsila, Fluence, and even Chinese cell OEMs, and away from containerized installs



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