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Understanding utility-scale solar and storage operations and maintenance cost drivers

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Welcome!

pv magazine webinars

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Understanding utility-scale solar and storage operations and maintenance cost drivers

Ammar Qusaibaty, DOE SETO
Andy Walker, NREL
Jal Desai, NREL
Nicole Jackson, Sandia National Lab

Agenda

1. Introduction
2. Solar Energy Technology Office (U.S. DOE SETO) Goals and Plans
3. Best Practices in O&M Overview
4. Drivers of O&M for PV + Storage Systems
5. Q&A

SETO Goals and Plans

Ammar Qusaibaty, U.S. DOE SETO

Executive Order on Climate and Equity

- **Establishes the Administration's climate goals:** A carbon-free electricity sector by 2035 and a decarbonized economy by 2050.
- **Establishes the Justice40 Initiative:** Sets a goal that 40 percent of the overall benefits of certain Federal Investments (including clean energy and energy efficiency) are to flow to disadvantaged communities.
- **Prioritizes climate in foreign policy and national security.**
- **Requires a government-wide approach to climate**
- **Requires the Federal agencies to use authorities, public lands/waters, and financial programs to catalyze clean energy deployment**

Administration Priorities COVID Plan

BRIEFING ROOM

Executive Order on Tackling the Climate Crisis at Home and Abroad

JANUARY 27, 2021 • PRESIDENTIAL ACTIONS

The United States and the world face a profound climate crisis. We have a narrow moment to pursue action at home and abroad in order to avoid the most catastrophic impacts of that crisis and to seize the opportunity that tackling climate change presents. Domestic action must go hand in hand with United States international leadership, aimed at significantly enhancing global action. Together, we must listen to science and meet the moment.

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Energy Efficiency and Renewable Energy Office (EERE) Overview

MISSION

We accelerate the research, development, demonstration, and deployment of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions economy-wide by no later than 2050 and ensure the clean energy economy benefits all Americans

Five Programmatic Priorities

EERE's new investments directly support deployments or demonstrations of technologies that show viable pathways for achieving EERE’s five programmatic priorities

- Decarbonizing the electricity sector
- Decarbonizing transportation across all modes (air, sea, rail, and road)
- Decarbonizing the industrial sector
- Reducing the carbon footprint of buildings
- Decarbonizing the agriculture sector with focus on the energy and water nexus

Solar Energy Technologies Office (SETO) Overview

MISSION

We accelerate the **advancement** and **deployment of solar technology** in support of an **equitable** transition to a **decarbonized economy no later than 2050**, starting with a decarbonized power sector by 2035.

WHAT WE DO

Drive innovation in technology and soft cost reduction to make solar **affordable** and **accessible** for all Americans

Enable solar to support the **reliability**, **resilience**, and **security** of the grid

Support **job growth**, **manufacturing**, and the **circular economy** in a wide range of applications

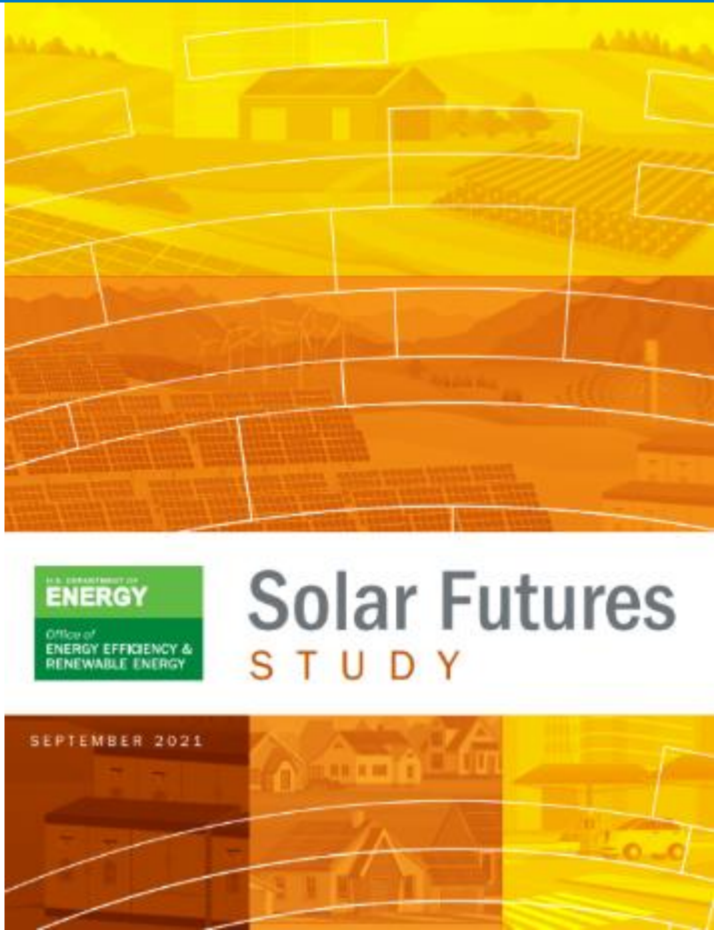
Solar Future Study

PURPOSE

- Comprehensive review of the potential role of solar in decarbonizing the electricity grid by 2035 and the energy system by 2050.
  - Addresses other large trends and activities across the U.S. economy that are necessary to achieve a zero-carbon energy system.
  - Builds analytical foundations to guide the next decade of solar research.

SCOPE

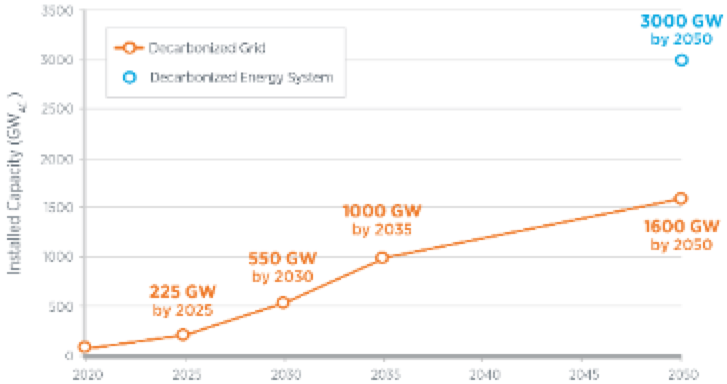
- Chapters cover future scenarios, technology advances, equity, grid integration, cross-sector interactions, supply chain, and environmental impacts.



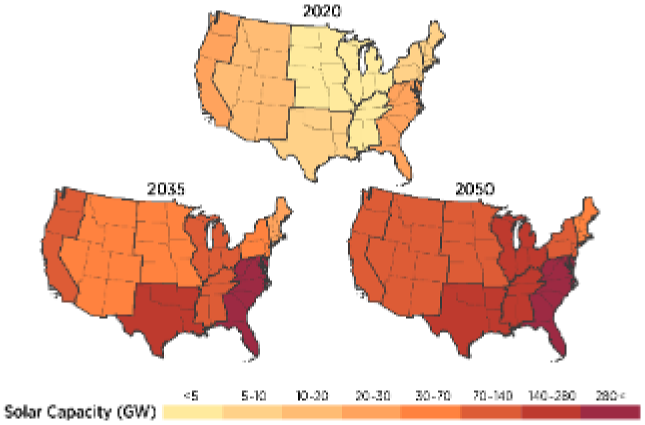
Solar Future Study Summary

1. **Deploy, deploy, deploy. An average of 30 GW** of solar capacity **per year to 2024 and 60 GW per year in 2025-2030.** (The U.S. installed 15 GW in 2020.)
    - 1 TW of solar meets 40% of electric demand in 2035, 1.6 GW meets 45% in 2050.
    - Major growth in wind and storage are also required.
2. **With continued technological advances, electricity prices do not increase through 2035.** This includes solar, wind, energy storage, and other technologies.
3. **The grid will be reliable and resilient.** Storage, transmission, and flexibility in load and generation are key.
4. **Expanding clean electricity supply yields deeper decarbonization.** Electrifying buildings, transportation, and industry reduces carbon emissions.
5. **Policy changes are necessary**. Limits on carbon emissions and/or clean energy incentives.
6. **Challenges must be addressed so that solar costs and benefits are distributed equitably.** Solar deployment can bring jobs, savings on electricity bills, and enhanced energy resilience.

Solar Deployment 2020–2050



Solar Capacity by Census Division in 2020, 2035, and 2050



PV Operations & Maintenance Research

- Establish technical standards for grid-scale PV systems reliability and availably (e.g., IEC 63265, IEC 63019)
- Reduce blind spots with field data around key topics such as operations and maintenance costs, performance ratios, failure modes in extreme weather events, cyber-physical security, and fleet storm resilience. (e.g., PV+ Battery O&M Cost drivers)
- Accelerate experiential learning using data science & analytics to characterize systemic failure modes and patterns (e.g., PV Reliability Operations Maintenance (PVROM) database).

Best Practices in O&M Overview

Andy Walker, NREL

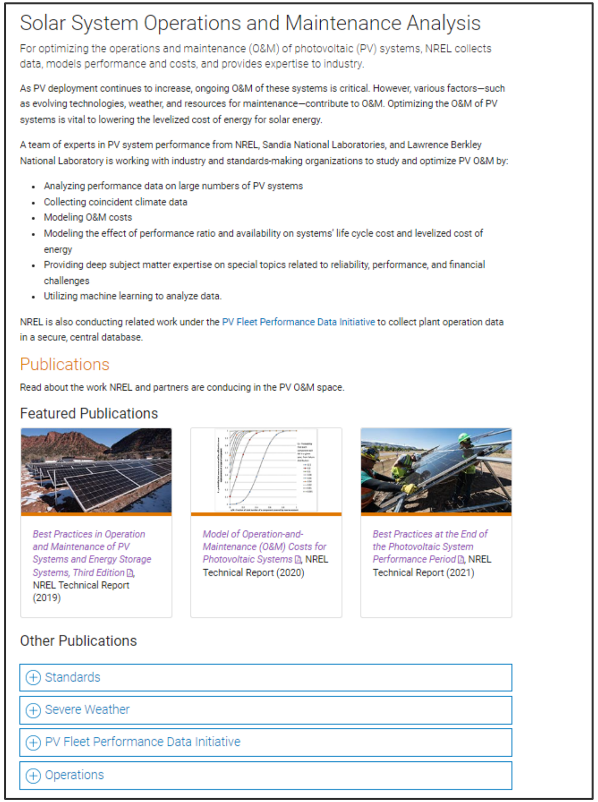
SETO Photovoltaics Operation and Maintenance (O&M)

1) Standards

- IEC TS 63019 Photovoltaic Power Systems (PVPS) – Information Model For Availability
- IEC TR 63292 Photovoltaic power systems (PVPSs) - Roadmap for Robust Reliability
- IEC TS 63265 Reliability Practices for the Operation of Photovoltaic Power Systems

2) Topical Investigations

- Best Practices in Operation and Maintenance of PV Systems
- Model of Operation and Maintenance Costs for Photovoltaic Systems
- Performance of Photovoltaic Systems Recorded by Open Solar Performance and Reliability Clearinghouse (oSPARC)
- PV Fleet Performance Data Initiative: Performance Index-Based Analysis
- Severe Weather Factors for Existing Asset Owners
- Insurance in the Operation of Photovoltaic Plants
- End of PV Performance Period / Repowering PV
- Cybersecurity in Photovoltaic Plant Operations
- Masking of Photovoltaic System Performance Problems by Inverter Clipping and other Design and Operational Practices.



Solar System Operations and Maintenance Analysis

For optimizing the operations and maintenance (O&M) of photovoltaic (PV) systems, NREL collects data, models performance and costs, and provides expertise to industry.

As PV deployment continues to increase, ongoing O&M of these systems is critical. However, various factors—such as evolving technologies, weather, and resources for maintenance—contribute to O&M. Optimizing the O&M of PV systems is vital to lowering the levelized cost of energy for solar energy.

A team of experts in PV system performance from NREL, Sandia National Laboratories, and Lawrence Berkley National Laboratory is working with industry and standards-making organizations to study and optimize PV O&M by:

- Analyzing performance data on large numbers of PV systems
- Collecting coincident climate data
- Modeling O&M costs
- Modeling the effect of performance ratio and availability on systems' life cycle cost and levelized cost of energy
- Providing deep subject matter expertise on special topics related to reliability, performance, and financial challenges
- Utilizing machine learning to analyze data.

NREL is also conducting related work under the PV Fleet Performance Data Initiative to collect plant operation data in a secure, central database.

Publications

Read about the work NREL and partners are conducing in the PV O&M space.

Featured Publications

Best Practices in Operation and Maintenance of PV Systems and Energy Storage Systems, Third Edition, NREL Technical Report (2019)

Model of Operation-and-Maintenance (O&M) Costs for Photovoltaic Systems, NREL Technical Report (2020)

Best Practices at the End of the Photovoltaic System Performance Period, NREL Technical Report (2021)

Other Publications

- Standards
- Severe Weather
- PV Fleet Performance Data Initiative
- Operations

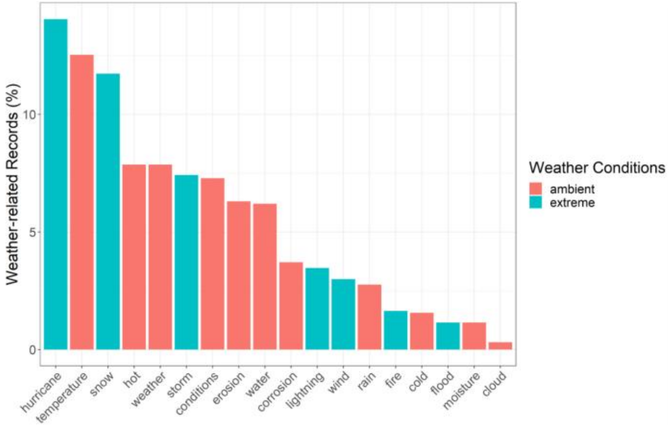
SETO Photovoltaics Operation and Maintenance (O&M)

3) Data Collection and Data Science

- Machine Learning Evaluation of Maintenance Records for Common Failure Modes in PV Inverter
- Evaluation of Component Reliability in Photovoltaic Systems Using Field Failure Statistics
- PV Hardware Vulnerabilities Revealed During Storm Stresses
- Multi-site assessment of extreme weather impacts on PV plant performance and reliability
- Inverter Faults & Failures: Common modes & patterns.
- Inverter O&M Strategies

4) Drivers of PV + Storage O&M Costs

- Subject of today's webinar…



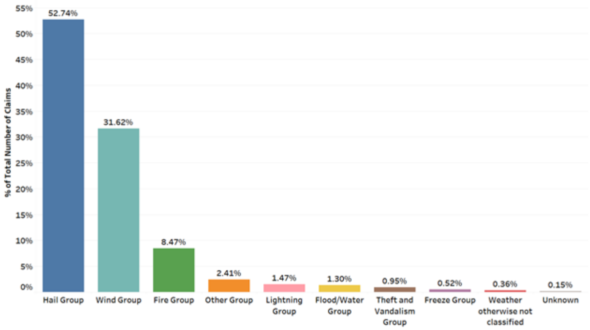


Figure 2. Percentage of claims by cause of loss

Operation and Maintenance:
https://www.nrel.gov/solar/market-research-analysis/solar-system-operations-maintenance-analysis.html

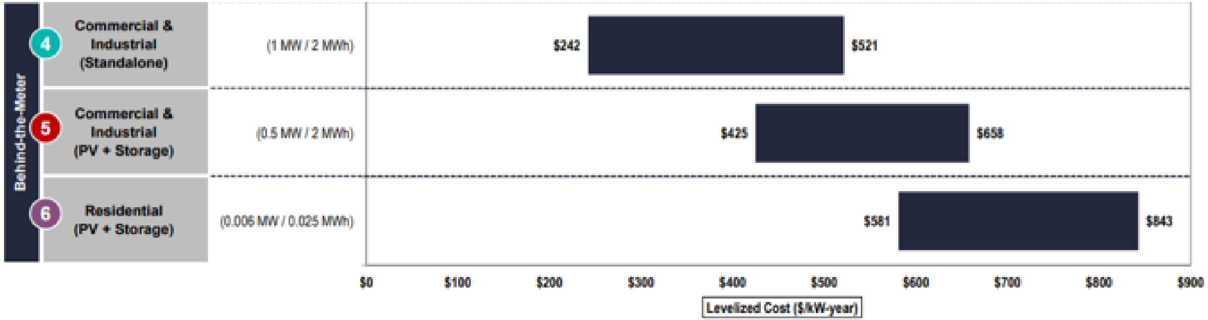
Drivers of O&M for PV + Storage Systems

Jal Desai, NREL

Nicole Jackson, Sandia National Lab

PV +Storage Study Motivation

Unsubsidized Levelized Cost of Storage comparison by capacity [1]



- Broad and variable costs
- Missing details about specific systems, activities
- Challenges to obtain PV+Storage specific O&M information

2020 O&M costs for 1 MW, 4 hour storage by technology [2]

	Lithium-ion	Vanadium Redox Flow	Lead acid
Fixed O&M ($/kW-year)	3.96-4.84	6.11-7.47	5.59-6.3
Variable O&M ($/MWh)	0.513	0.5125	0.5125
System RTE Losses ($/kW)	0.005	0.014	0.008

Study Focus:
Establish a baseline understanding of utility-scale photovoltaic (UPVS) operations and maintenance (O&M) cost drivers

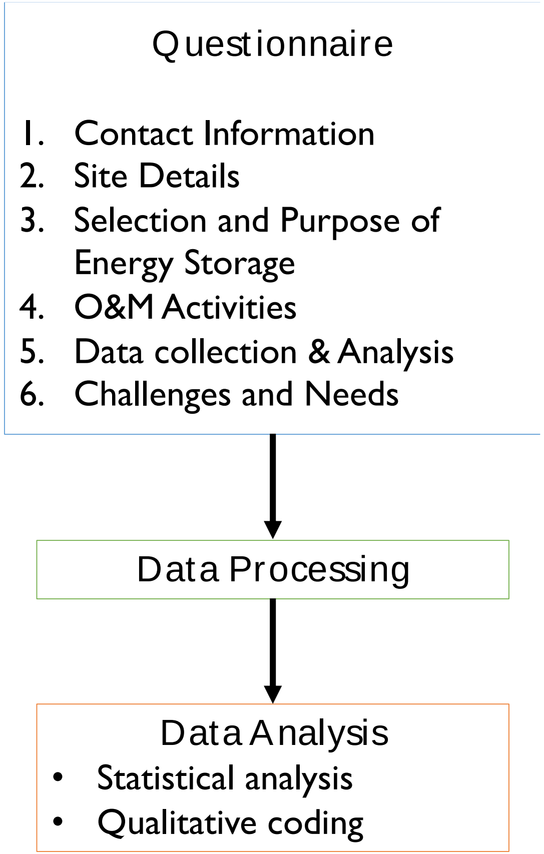
References: [1] Lazard (2019), "Lazard's Levelized Cost of Storage Analysis – Version 5.0", https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf; [2] Mongird et al. (2020), "2020 Grid Energy Storage Technology Cost and Performance Assessment", https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf

Our Methodology

- Subject matter experts help focused questionnaire
- Obtain insights from industry experts
  - Online questionnaire
  - Semi-structured interviews
  - Snowball sampling
    - Word of mouth
    - Advertising in industry publications

Number of responses by submission format.

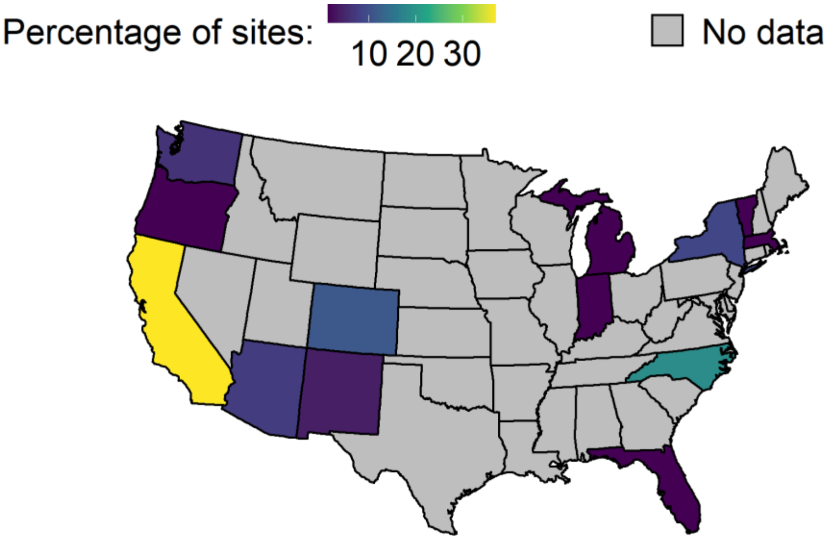
Submission Format	Number of Responses
Online Questionnaire	2
Word Document Submission	6
Conference Call	6



Study sites summary

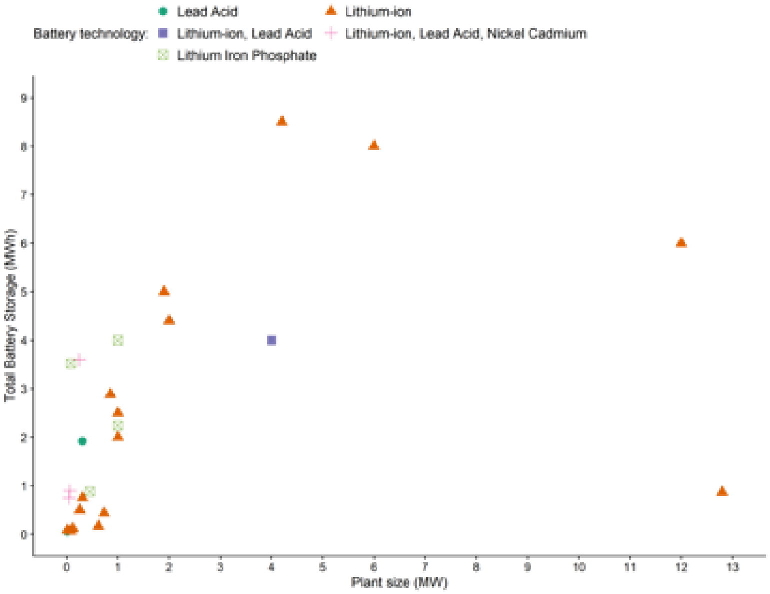
- Insights from 81 sites (14 partners) were captured
- Geographic distribution spans 13 states

Distribution of sites by state in this study



- Total PV system size: 51.1 MW
- Total battery storage size: 64.1 MWh
- Note: PV+Storage is co-located

Comparison of site-level plant size versus battery size by battery technology type



Key descriptive parameters vary by storage technology

Capacity, Age, Storage Location, Energy source

Storage Technology	Study Sites (%)	Mean MW/MWh	Mean Age (Years)	Mean Storage Location Relative to Meter (%)			Mean storage energy from site (%)
				Behind	Front	Not Reported	
Lead Acid	7.4	0.2	1.8	100	0	0	—
Lithium-ion	43.2	4.4	3.2	68.8	25	6.2	70.5
Lithium-ion, Lead Acid	1.2	1	7	0	100	0	—
Lithium-ion, Lead Acid, Nickel Cadmium	43.2	0.1	8	100	0	0	45
Lithium Iron Phosphate	4.9	0.3	3.2	50	0	50	33.8
All Technologies	100	2	5.2	81.5	6.2	12.3	50

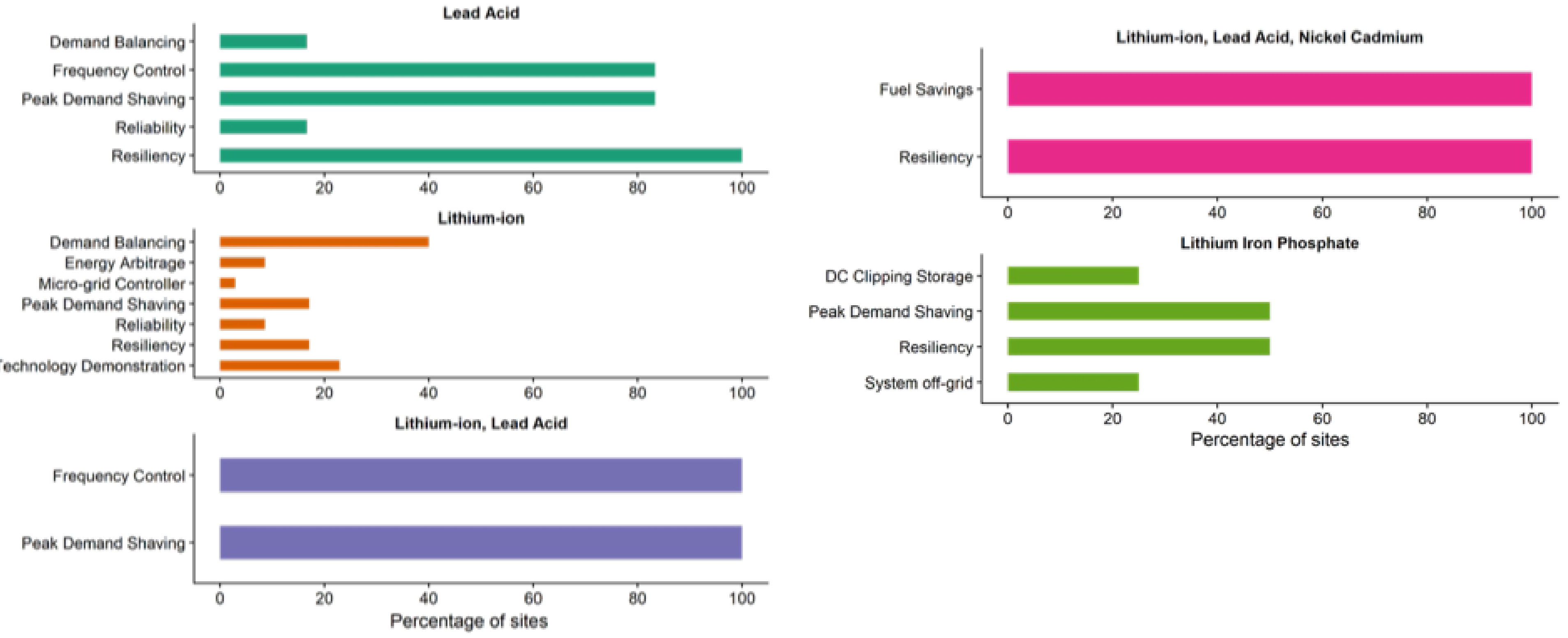
Capital costs, Lifetime, Degradation Rate

Storage Technology	Mean Storage Capital Cost ($ per kWh)		Expected Lifetime (years)	Degradation Rate (% per year)
	Low	High		
Lead Acid	1000	1000	7.5	0.33
Lithium-ion	933	962	10.3	1.01
Lithium-ion, Lead Acid	1000	1000	7	2
Lithium-ion, Lead Acid, Nickel Cadmium	400	600	17	1.76
Lithium Iron Phosphate	700	800	13.8	0.5
All Technologies	646	766	13.1	1.27

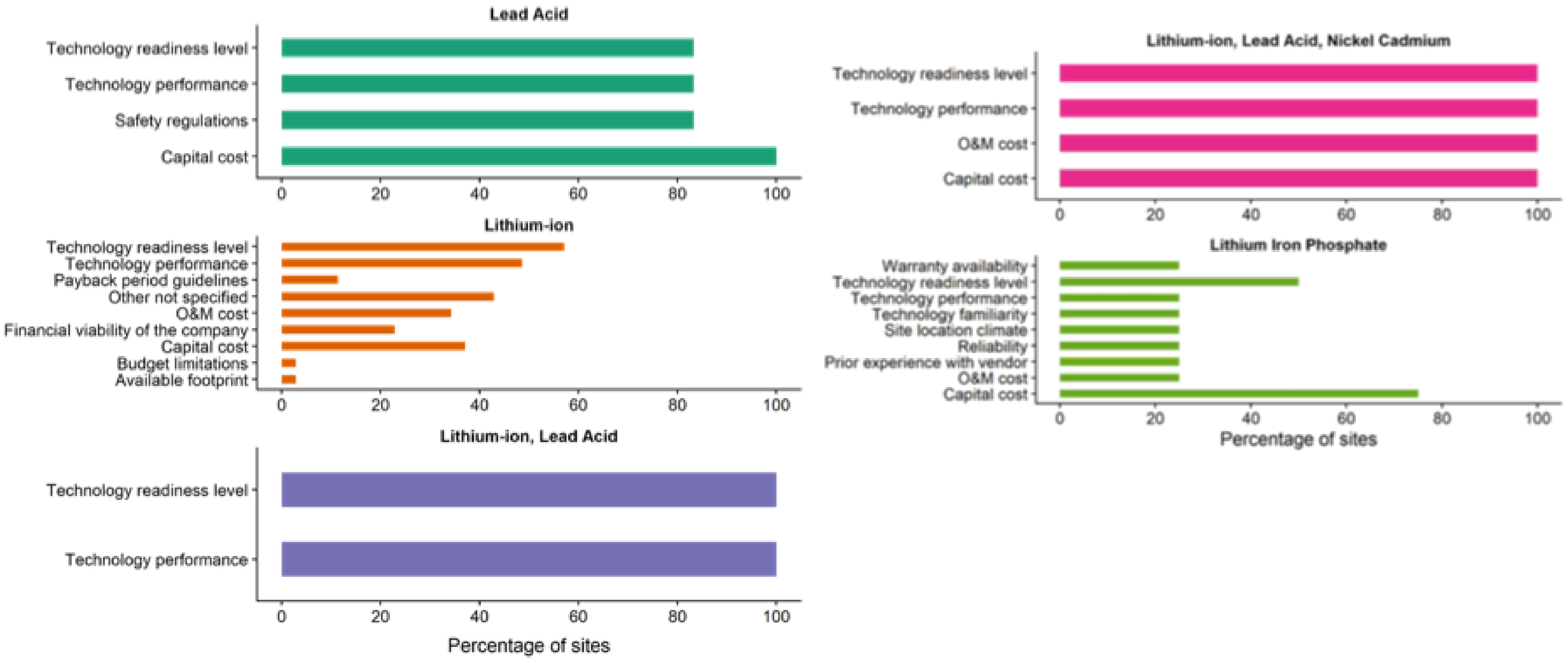
Storage Cycling

Cycling rate	Lead Acid	Lithium-ion	Lithium-ion, Lead Acid	Lithium-ion, Lead Acid, Nickel Cadmium	Lithium Iron Phosphate	All Technologies
Daily	16.7	65.7	—	100	50	75.3
Every few days	83.3	25.7	100	—	—	18.5
5x per month	—	—	—	—	25	1.2
Weekly	—	—	—	—	25	1.2
Not often, no regular schedule	—	8.6	—	—	—	3.7

Resiliency is a key primary storage function for most storage technologies

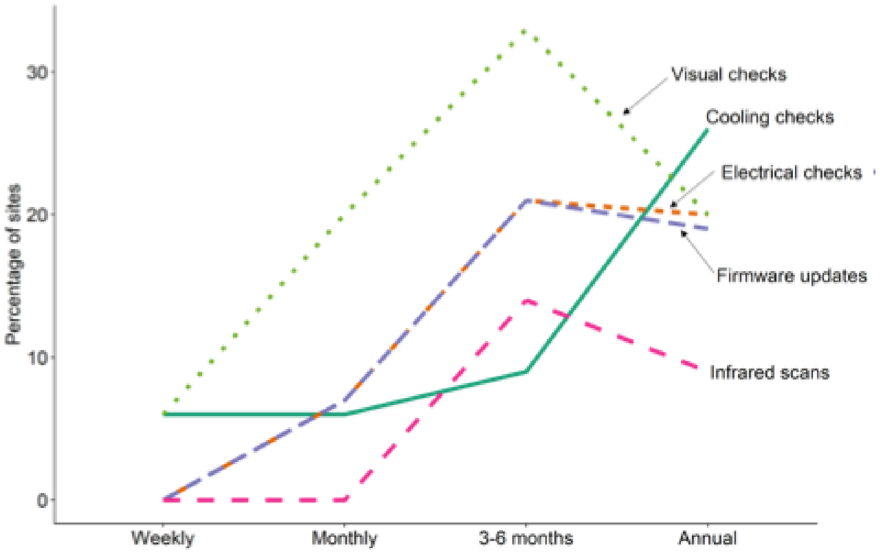


Technology readiness level and capital costs drive the choice of battery storage technology

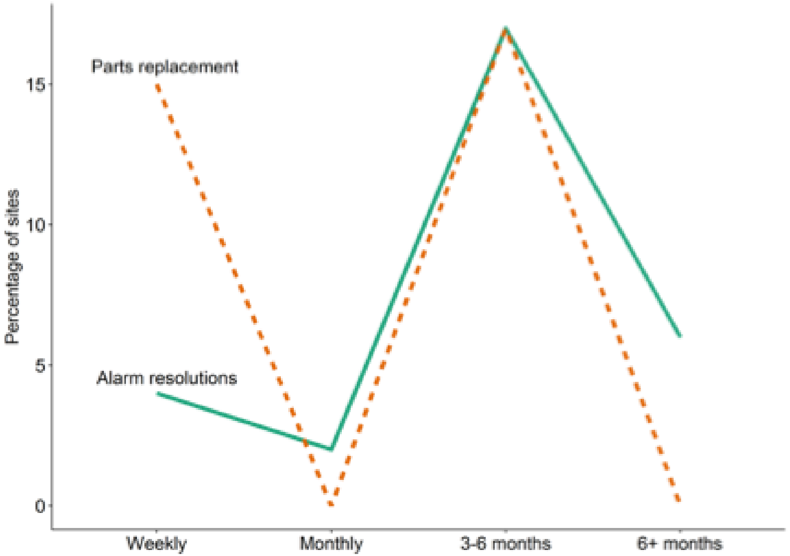


There is variability in the frequency of O&M activities and who performs them

Preventative maintenance activities



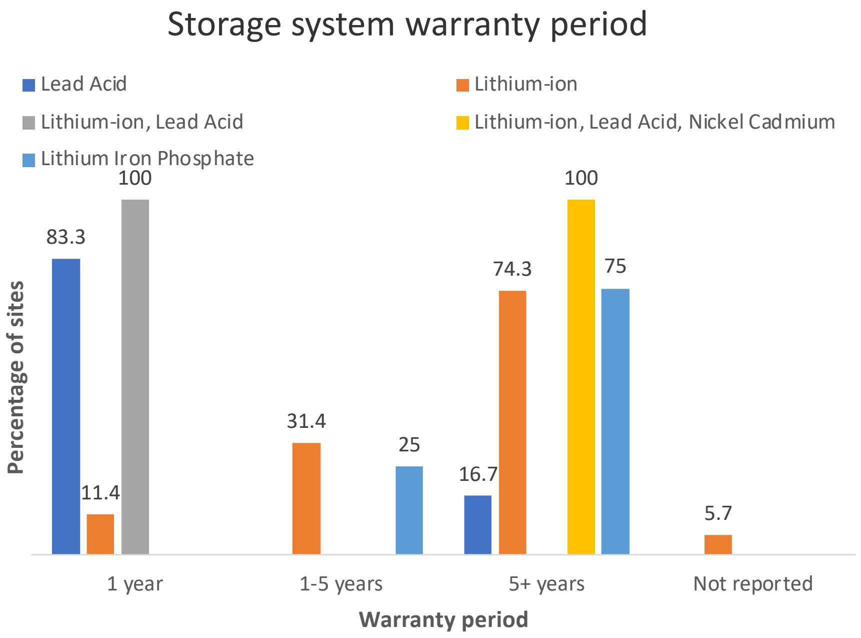
Corrective maintenance activities

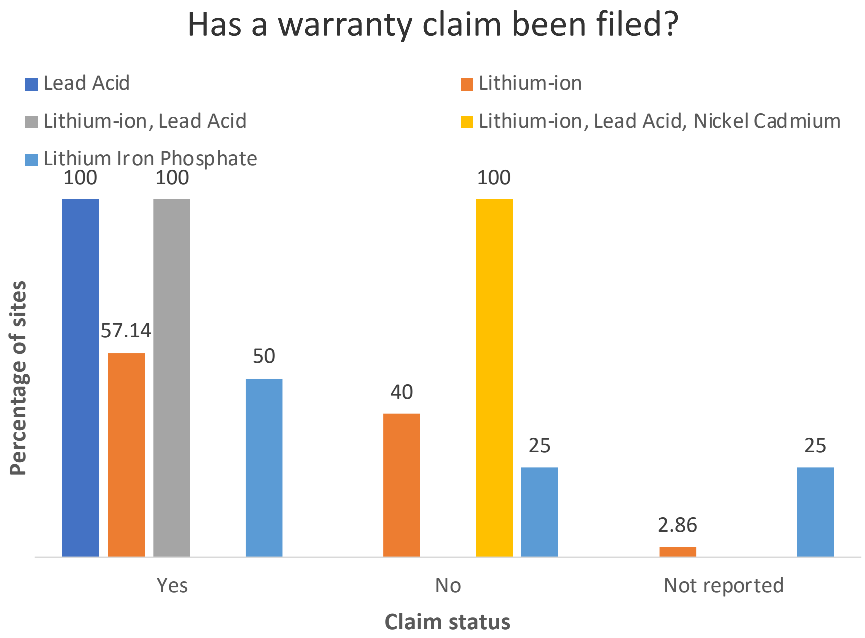


Responsible parties for O&M activities

Provider	Lead Acid	Lithium-ion	Lithium-ion, Lead Acid	Lithium-ion, Lead Acid, Nickel Cadmium	Lithium Iron Phosphate	All Technologies
In-house	83.3	54.3	100	—	100	35.8
System Vendor	83.3	94.3	100	100	75	95.1
3rd Party Contractor	16.7	28.6	—	—	—	13.6
Not reported	—	2.9	—	—	—	1.2

Wide range of warranty periods and filing claim status across storage technologies

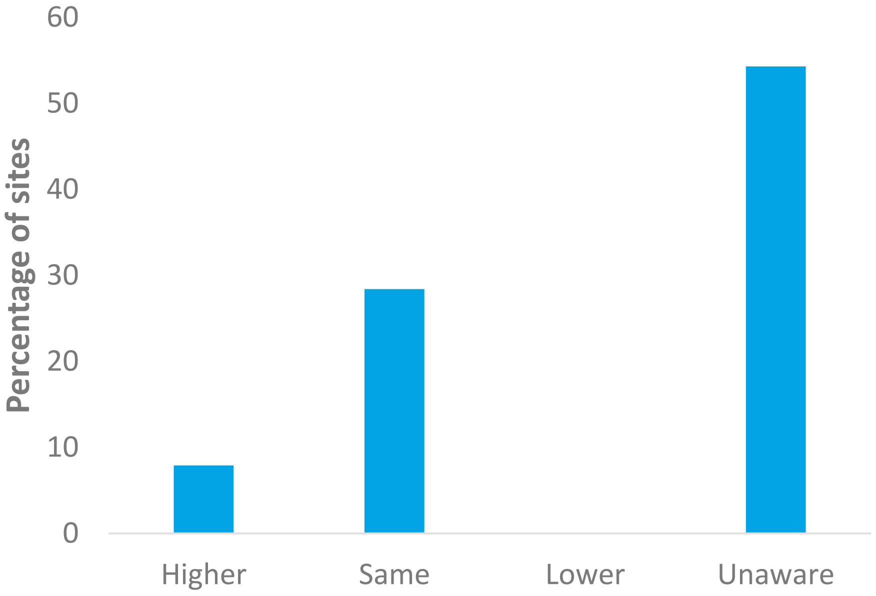




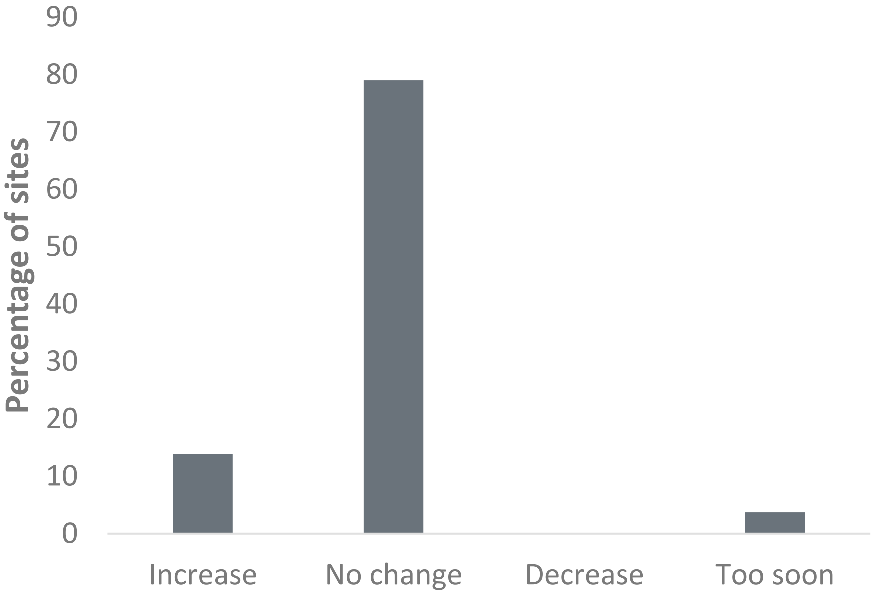
- 80.2% of all sites report at least a 5 year warranty period
- 10 year warranties available to some owner-operators
- 1-2 year warranty extensions often considered cost prohibitive
- 61.7% of all sites have not filed a warranty claim yet

Owner-operators note O&M costs are independent of location with no change over time

O&M and insurance cost variability by location

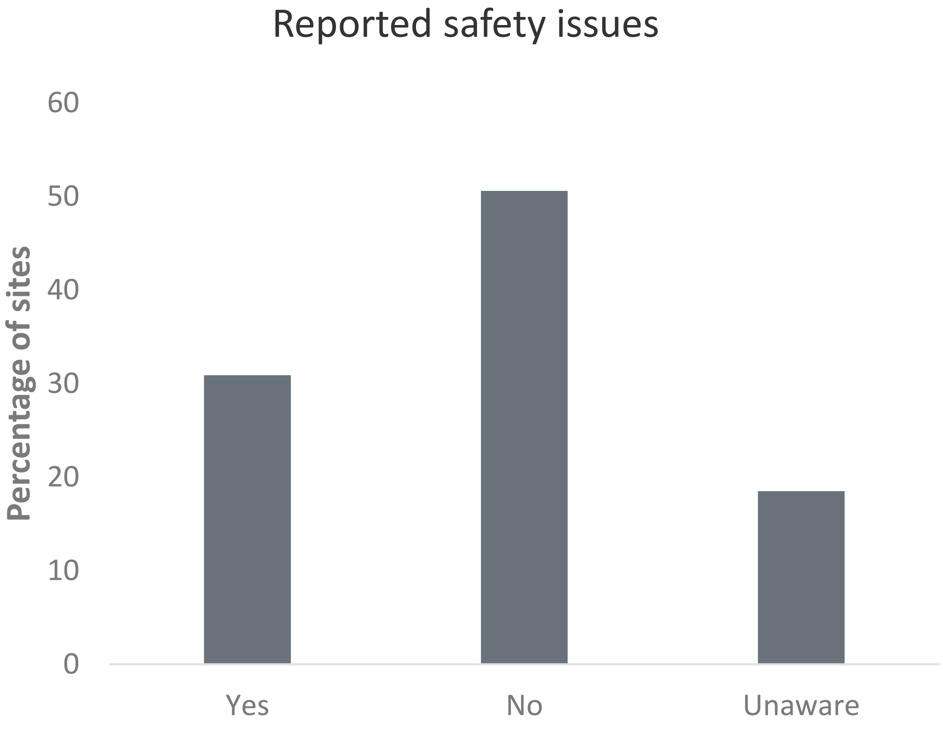


O&M and insurance cost variability over time



- Regional costs differences in some locations can be up to 10 times higher than other locations
- Additional factors affecting O&M costs
  - Choice of vendor: 9.9%
  - Plant production size: 1.2%

Few safety issues reported but additional safety systems have been added over time



General concerns

- Venting
- Change in safety codes during design process
- Dust

Fire

- 12.3% concerned about fire
- Hired additional fire protection experts

Safety remediation

- 42% have added additional safety systems
    - Sprinklers
    - Dry hose installation
    - Fire suppression systems
    - Additional ventilation

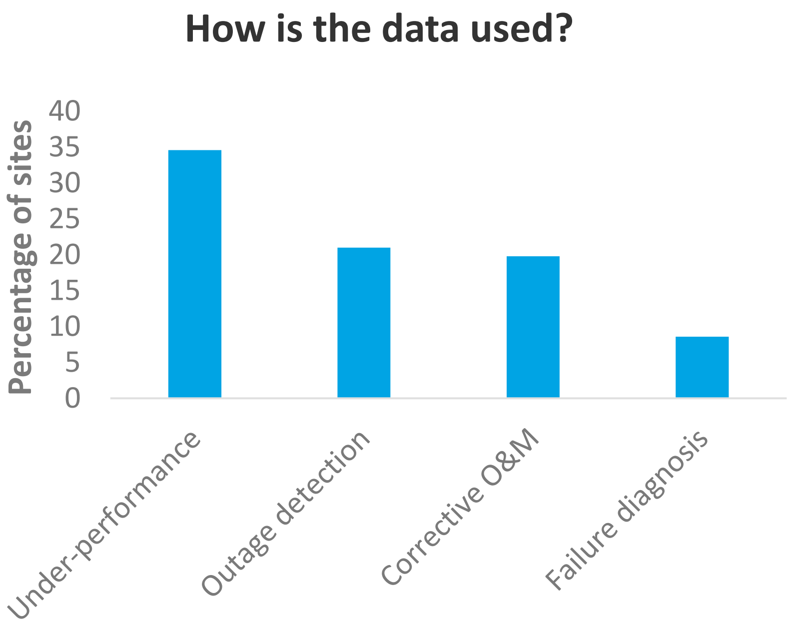
Data collection and analysis practices

How frequent is data collected?

- 90.9% of sites use automated collection systems
- Manual fault code collection
- Most common recording time step: 1-minute (55.5%)

What types of data are collected?

- Generally collect similar information across portfolio sites Power-related parameters
  - Reactive power, power factor, apparent power
- Clipping energy capture (1.2%)
- Fault codes (2.5%)
- Charging, discharging status (3.7%)



Owner-operators face several ongoing challenges and needs for PV+Storage sites

Challenges

- new processes needed to set up PV+storage contracts
- missing PV+storage performance metrics
- limited experience with combining technologies
- long-term vendor availability and reliability.

Needs

- data management and handling
- expected versus actual storage lifetimes
- long-term field performance
- limiting storage technology obsolescence
- locally available technicians and parts for servicing O&M needs
- consistency in standards and codes to minimize impacts on equipment availability

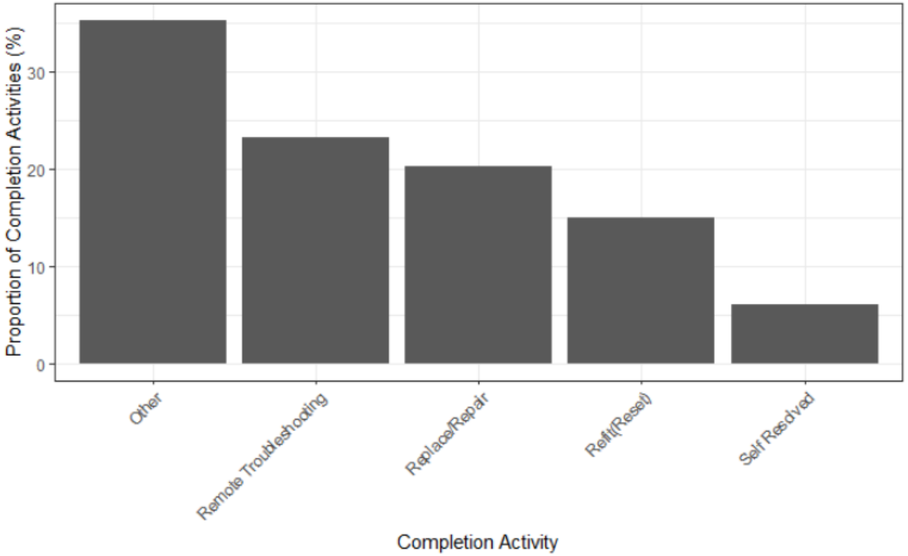
PV+Storage insights from PVROM

- 14 sites located in North Carolina
- Installed solar capacity
  - 12 sites with < 1000 kW (string inverters)
  - 2 sites with > 4000 kW (central inverters)
- 152 O&M records related to
  - “Energy Storage/Battery”
  - “Battery (Solar + storage facilities)”

O&M ticket duration summary statistics

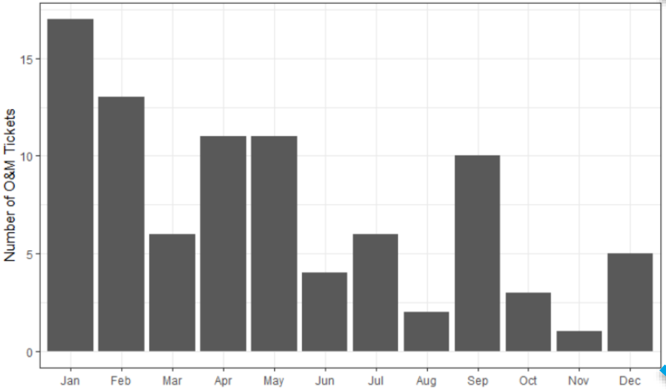
	Ticket Duration (minutes)		
Completion Activity	Minimum	Maximum	Median
Other	480	81,120	8,340
Refit (Reset)	114,240	114,240	114,240
Remote Troubleshooting	1	14,880	567
Replace/Repair	75	109,920	3,487
Self Resolved	480	3,360	1,200

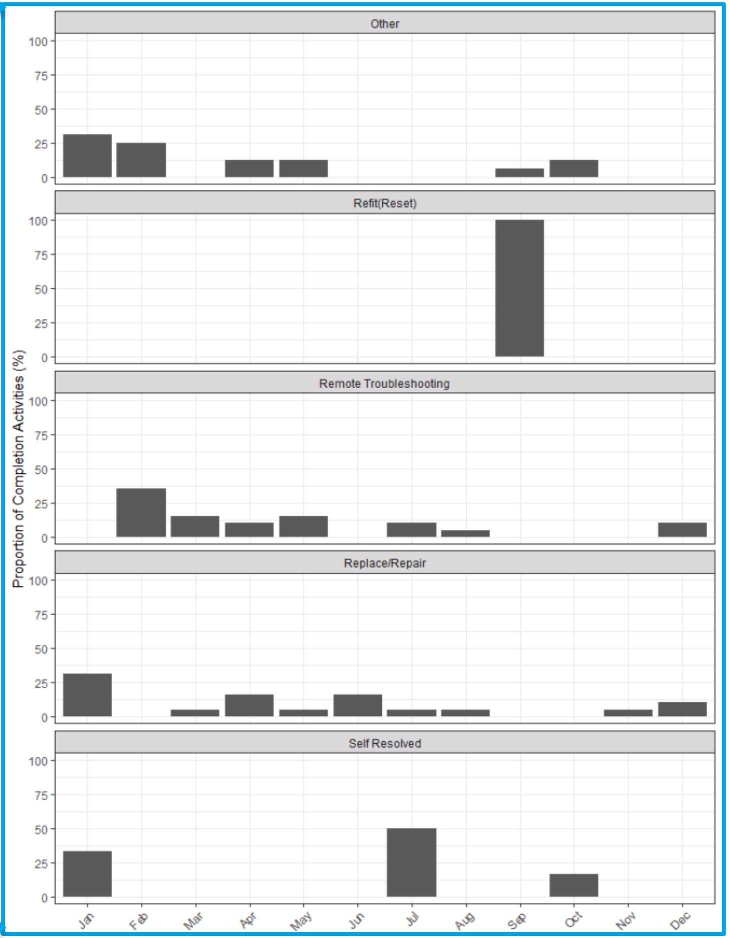
Completion activities for corrective O&M



Corrective O&M activities for PV+Storage sites occur throughout the year

Distribution of PV+Storage O&M tickets by month



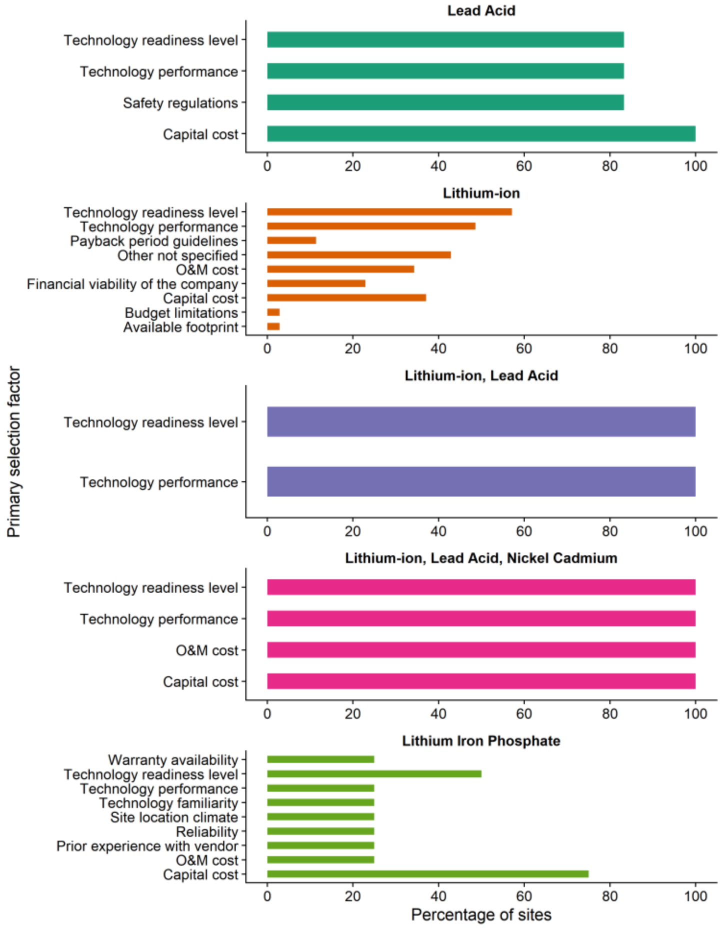


In conclusion, responses from industry professionals provide insights into O&M cost drivers of PV+Storage systems

- Insights gained from 81 sites and 14 partners in the United States
- Key descriptive parameters vary by storage technology
- Storage used for resiliency
- Technology readiness level, capital costs drive storage technology choice
- Range of corrective, preventative O&M activities occur throughout the year

Future work

- PV+Storage specific performance metrics
- Improving vendor reliability, parts availability
- Enhanced data collection for additional statistical analysis



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Understanding utility-scale solar and storage operations and maintenance cost drivers

Q&A

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Researcher
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Andy Walker
Senior Research Fellow
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Nicole Jackson
Technical Staff, Energy Water Systems Integration
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SETO

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Thursday, 8 December 2022
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Ryan Kennedy
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pv magazine USA

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