Clean Energy Resilience

# Designing and Adapting for Extreme Weather

**Clean energy facilities are designed to withstand extreme weather conditions, with site-specific plans developed to protect workers, keep communities informed, and maintain grid reliability.**

## Key Takeaways

1. **Clean energy projects are built to meet strict design and structural standards** intended to withstand various harsh environments, including strong winds, earthquakes, and flooding.
2. **Site-specific plans are developed to protect and inform workers** and community members during extreme weather conditions.
3. Even if a portion of a facility is damaged—such as a singular wind turbine, solar panel or string of panels, or battery storage module—the rest of **the facility can continue to operate** and generate electricity for the grid if it is deemed safe to do so following any necessary inspections.
4. **The broad geographic distribution of clean energy facilities supports reliability**, since it decreases the likelihood of a single extreme weather event impacting a significant portion of energy generation.

### Background

Clean energy facilities are designed to meet industry best practices, codes, and standards for structural integrity.[1] Companies also conduct site-specific engineering to tailor facilities to the specific weather and other natural disaster risks in an area.

Like any other type of infrastructure such as buildings and conventional power plants, facilities cannot always withstand the harshest forces of nature and can be damaged after taking a direct hit from an extreme weather event.

Strict regulations guide the facility design, installation, ongoing operations, and maintenance phases to safeguard workers and communities, coordinate with local authorities, and minimize grid impacts.

## Workers & Communities Remain Safe & Informed

**Design & Development:** Wind, solar, and battery energy storage facilities are sited with appropriate setbacks—distances between the energy generation sites and features like buildings or roads—to ensure public safety, especially during severe weather events.

- Foundations and equipment are tested and rated for wind speeds exceeding extreme weather wind speeds.
- Equipment is tested for hail and other storm-related physical impacts.
- Battery enclosures are waterproof and rated for both extreme cold and hot temperatures, well beyond temperatures that may actually be experienced in that region.

**Operations:** Facilities are generally monitored by local and remote operations staff 24 hours a day. Weather conditions are tracked in real-time, and the facilities have early warning systems that are constantly monitored. This allows for immediate action if any issues arise.

*In the event of extreme weather:*

**Communication:** The energy facilities' operators notify workers before, during, and after storms to ensure implementation of response plans and procedures that are tailored to the type and severity of the storm and support grid reliability and safety of equipment, workers, and local communities.

- Further, operators have emergency action plans that cover extreme weather conditions among other scenarios, which are collaboratively developed with local first responders during the permit process.

**Preparation:** Preparations for storms will start as early as possible based on the weather forecast.

- This includes stowing the site to mitigate damage, preparing for flooding conditions, inspecting equipment, fueling vehicles, staging supplies, and implementing communication plans.

## Managing Grid Operations for Reliability

One reliability advantage of clean energy generation lies in its broad geographic distribution. The U.S. grid operates by region, so grid operators work with power generators over large areas where weather doesn't affect generation uniformly.

**Since wind sites, solar fields, and battery storage are spread out geographically, a single extreme weather event is unlikely to significantly damage a large portion of the power generation fleet in a state or region.** If an individual turbine or inverter fails, the rest of the facility can continue to generate electricity and support resilience and recovery as long as the transmission and distribution grid remains available to power to homes and businesses.

Clean energy projects across a state will continue contributing to the grid, so in the very rare event an entire project ceases operation, available generation will remain online to help areas recover from the storm.

## Advantages of Clean Energy Technologies in Extreme Weather

### Solar Panels

Solar panels are highly capable of withstanding extreme weather conditions, due to their solid state and limited number of moving parts.

**Design & Development:** The best practices, codes, and standards to which utility-scale photovoltaic ground mounted systems are built include a site-specific assessment of the seismic, wind, and flooding risk that drives decisions on the materials, components, engineering details of the facility.

- **For Example:** Design considerations include determining snow-loading capacity, the panel height, and depth of foundations for the racking systems.

Solar panels that include tracker systems that allow for changing the positioning of the panels to be more resilient to extreme weather by positioning in such a way that may limit or minimize damage from things such as hail or wind.

- **For Example:** Panels can be angled to reduce exposure to hail and to facilitate the removal of snow or the accumulation of ice.

**Operations:** Following extreme weather, a solar facility is inspected to assess energy production and identify any instances of broken glass, detached modules or frames, warped modules, or detached electrical cabling. If any damage is detected, the affected modules are disconnected and corrective repairs are made. Modern commercial solar panels do not contain hazardous materials that pose a danger to the environment and human health.

### Wind Turbines

Wind turbines are designed to meet robust industry best practices, codes, and standards that require them to withstand extreme weather conditions during specific periods of time for site-specific seismic, wind, flooding, and/or oceanographic conditions (the latter for offshore wind turbines).[2]

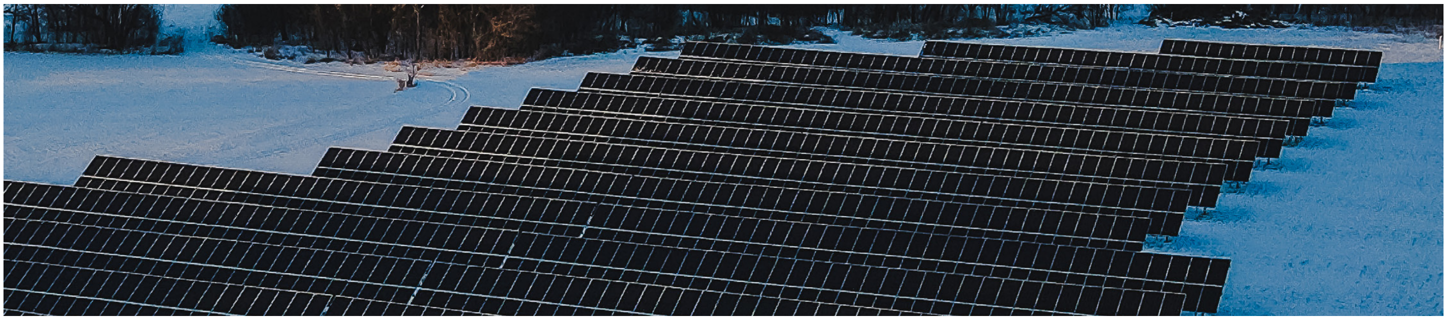
**Design & Development:** Site-specific assessments drive decisions on turbine foundation depth and reinforcement, tower height, tower shell thickness, blade length, and turbine locations.

Wind turbines include lighting protection systems and can be optimized to operate in cold and hot environments—from North Dakota winters to Arizona summers.

- **For Example:** Wind turbine cold weather packages include special low temperature lubricants and heating and/or enhanced insulation of specific mechanical components in the nacelle (gearbox, hydraulics, control systems, and power electronics). A cold weather package generally includes cold-resistant steel or heating elements to protect electrical systems.

**Operations:** Turbines include safety features for pausing or stopping operations to reduce the environmental impact and likelihood of damage to components if the weather is too extreme. Maintenance on wind facilities is dependent on wind speeds at the site; workers cannot perform inspections or repairs on wind turbines if wind speeds exceed specific thresholds.

- If wind turbines experience a storm that exceeds site-specific thresholds, an inspection of the turbine is conducted to assess damage and any needed repairs.
  - The inspection assesses structural damage, safety, back-up power systems, lightning protection, and drainage.
  - If the turbine is located offshore, an inspection of the seafloor is also conducted to evaluate whether any erosion has occurred at the base of the turbine.
  - Turbines are equipped with oil-storing and containment systems to prevent oil, fuel, or lubricant from spilling.[3]
- If repairs at individual wind turbines are necessary, the remaining wind turbines in the facility can continue to operate and provide power to the grid.



## Energy Storage

Battery energy storage systems (BESS) are particularly useful for withstanding extreme weather disruptions by providing capacity stability to the grid when transmission or other resources are disrupted. Energy storage has the unique ability to store and dispatch energy during the hours of the day when it is most needed, reducing power outages when the grid is under stress.

**Design & Development:** BESS are deployed in outdoor enclosures that provide protection from heat, cold, wind, and moisture and are equipped with systems to moderate and control the internal temperature of the equipment for efficient operations regardless of the temperature outside. They include hazard detection, thermal runaway protection, fire suppression, and other systems to promote safe operations.[4]

**Operations:** When assessing damage following a storm, protocols are in place to confirm the condition of the battery equipment to ensure operational safety and system performance as storm recovery begins. These environmental and electrical protocols consider historical performance and the type of damage that has occurred.[5] BESS are de-energized and visual inspections, advanced imaging, and electrical testing may be conducted to assess structural damage or voltage abnormalities. Developers and/or system operators will also re-inspect safety systems to ensure compliance with national and local permitting bodies and manufacturers.

Photo credit: AES

1 See, for example, American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) 7-22 Minimum Design Loads and Associated Criteria for Buildings and Other Structures; ASCE/American Wind Energy Association (ASCE/AWEA) Recommended Practice for Large Land-based Wind Turbine Support Structures (2011); American Clean Power Association (ACP) 61400-6:2023 Wind Energy Generation Systems – Part 6: Tower and Foundation Design Requirements – Modified Adoptions of IEC 61400-6:2020; International Code Council, International Building Code (IBC), Chapter 16 Structural Design; IEC Technical Specification 63397, Photovoltaic Modules – Qualifying Guidelines for Increased Hail Resistance; UL61730-1 Standard for PV Module Safety Qualification and UL61730-2 PV Module Safety Qualification Part 2: Requirements for Testing; National Fire Protection Association (NFPA) 855, Standard for the Installation of Stationary Energy Storage Systems; and UL 9540, Energy Storage System Requirements.

2 See IEC 61400-01 Design Requirements and IEC 61400-3 Design Requirements for Offshore Wind Turbines

3 Ibid.

4 https://cleanpower.org/resources/battery-energy-storage-safety-faqs/

5 https://cleanpower.org/resources/energy-storage-codes-standards/; https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-32789.pdf