THE EXPANDING LIABILITY CURVE: EMERGING END-OF-LIFE EXPOSURE IN SOLAR AND BATTERY STORAGE

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The conversation about clean energy decommissioning has, until now, been almost entirely a conversation about wind.

But the wind fleet is not the only asset class approaching the end of its operational life. The first generation of utility-scale ground-mounted solar PV installations — many consented and built in the subsidy-driven expansion of the late 2000s and early 2010s — is entering its final operational decade. And behind it, a vast and rapidly growing fleet of lithium-ion battery energy storage systems (BESS), most of which have projected lifespans of ten to fifteen years, is on a trajectory to generate decommissioning obligations at a pace and complexity that the industry has barely begun to consider.

The dynamics are different from wind. The cost structures are different. The waste streams are different. The hazard profiles are different. And the regulatory frameworks — immature even for wind — are, for solar and storage, still being written.

Solar: simpler, but not simple

A utility-scale ground-mounted solar PV plant is, at first glance, a simpler decommissioning proposition than a wind farm. There are no hub-height operations. No heavy-lift logistics. The components are modular, relatively light, and accessible at ground level. The intuition is that taking a solar farm apart should be straightforward and comparatively cheap.

The intuition is not wrong in its direction. It is wrong in its magnitude. The cost and complexity of solar decommissioning are routinely underestimated, for reasons that become apparent only when the scope of the work is examined in detail.

Physical scope of solar decommissioning

A typical utility-scale solar installation consists of tens of thousands — in many cases, hundreds of thousands — of individual photovoltaic modules mounted on steel or aluminium racking structures, connected by kilometres of DC and AC cabling, fed through string inverters or central inverter stations, and supported by concrete foundations, access roads, security fencing, and drainage infrastructure. The site may cover hundreds of acres. The electrical collection system runs underground across the full footprint.

Removing the modules is the most visible task and, paradoxically, one of the smaller cost components. The real cost lies in the volume of material that must be handled, sorted, transported, and either recycled or disposed of — and in the regulatory framework that governs how each material stream must be treated.

The panel problem: recycling economics

The modules themselves present the most significant challenge. A crystalline silicon solar panel is a laminated assembly of glass, encapsulant polymers (typically ethylene-vinyl acetate), silicon cells with silver and aluminium metallisation, a polymer backsheet, and an aluminium frame. The layers are designed to be bonded for thirty years of outdoor exposure. They are not designed to be separated.

Recycling a solar panel is not like recycling a steel tower. The valuable materials — silicon, silver, copper — are embedded in thin layers within a laminated structure that must be mechanically or thermally delaminated before any recovery is possible. Current commercial recycling processes recover the aluminium frame and the glass with reasonable efficiency. The recovery of silicon, silver, and other materials from the cell structure is technically achievable but economically marginal at current volumes and commodity prices. The cost of processing frequently exceeds the value of the recovered materials.

This creates a disposal cost, not a recovery revenue. Unlike wind turbine steel, which generates meaningful scrap value, solar panel recycling is, for most operators in most markets today, a net expense. The panel is not a commodity to be sold. It is a waste stream to be managed.

Scale and regulation: Europe and the United States

The scale of that waste stream is about to change dramatically. The International Renewable Energy Agency has projected that global cumulative PV panel waste could reach eight million tonnes by the early 2030s under an early-loss scenario, and substantially more by mid-century. Europe, which led the utility-scale solar build-out, will see the wave first. The installations that drove Germany's Energiewende, Spain's solar boom, and Italy's Conto Energia are approaching the end of their economic lives — some well before the end of their technical lives, as degradation, insurance costs, and the declining competitiveness of older module technology accelerate retirement decisions.

The regulatory framework is evolving but uneven. The European Union (EU) classifies end-of-life solar panels as electronic waste under the WEEE Directive, which imposes extended producer responsibility obligations on manufacturers. Producers must finance the collection, treatment, and recycling of panels sold in European markets. In practice, compliance is managed through collective schemes that organise logistics and processing — but the infrastructure to handle the volume of panels approaching end-of-life does not yet exist at the scale that will be required. Collection capacity, specialised transport, and processing facilities are concentrated in a handful of locations, and the logistics of moving hundreds of thousands of fragile glass-and-semiconductor panels from remote rural sites to recycling centres is a cost that most decommissioning estimates have not fully accounted for.

In the United States, the framework is even more fragmented. Solar panels may be classified as hazardous waste under RCRA depending on their chemistry — thin-film cadmium telluride modules, in particular, contain cadmium, a regulated heavy metal. Crystalline silicon panels may contain lead solder that can exceed toxicity thresholds in leachate testing. The regulatory treatment varies by state: Washington has established a photovoltaic module stewardship and takeback programme requiring manufacturers to finance recycling at no cost to owners. California has solar-specific recycling regulations. North Carolina requires decommissioning plans for projects above two megawatts (MW) that include consideration of recycling. Most states have no specific framework at all.

For operators and investors, the practical consequence is that the end-of-life cost of a solar asset is genuinely uncertain — and it is almost certainly higher than whatever figure is currently embedded in the financial model. The cost is not principally the labour of removing panels from racking. It is the downstream processing cost of a waste stream that the recycling industry is not yet equipped to handle at scale, governed by regulations that are still being written, with a net material recovery value that may be negative.

Battery storage: an uncharted liability

If solar decommissioning is underestimated, battery storage decommissioning is something closer to uncharted.

The utility-scale battery energy storage market has grown at extraordinary speed. In 2025, the United States installed over 57GWh of new battery storage capacity, bringing total U.S. installed storage to roughly 137GWh. Europe, including the UK, added 30GWh in 2025, with total installed storage approaching 90GWh. The global fleet is predominantly lithium-ion — first nickel-manganese-cobalt chemistries, now increasingly lithium iron phosphate — housed in containerised or cabinet-based enclosures deployed across thousands of sites.

The projected operational lifespan of a utility-scale lithium-ion BESS is ten to fifteen years, depending on chemistry, cycling regime, and operating conditions. Degradation rates of 3%-7% per year are typical. Systems regularly require partial module replacements after six to eight years. The assets being installed today will begin reaching end-of-life in the mid-2030s.

Almost none of this fleet has been decommissioned yet. The industry has no meaningful body of actual cost data for utility-scale BESS decommissioning. What exists are engineering estimates, and they reveal a cost structure that is qualitatively different from either wind or solar.

The hazard dimension

A wind turbine is heavy and tall. A solar panel is fragile and voluminous. Neither, in its end-of-life state, is actively dangerous. A degraded lithium-ion battery is. The cells retain residual charge. They contain flammable electrolytes. Under mechanical damage, short-circuit conditions, or thermal stress — all of which can occur during dismantling — they can enter thermal runaway: a self-sustaining exothermic reaction that produces temperatures exceeding a thousand degrees, toxic gas emissions including hydrogen fluoride, and in enclosed spaces, explosive gas concentrations.

This is not a theoretical risk. Battery storage installations have experienced thermal runaway events during normal operations — the McMicken incident in Arizona, multiple container fires in South Korea, the Moss Landing incidents in California. The failure mode that operators and fire services are learning to manage during the operational life of a BESS is the same failure mode that decommissioning crews will need to manage during dismantling, when battery modules are being physically handled, disconnected, and transported.

Cost structure of BESS decommissioning

The practical consequence is that BESS decommissioning requires specialist hazardous materials handling at every stage. The system must be electrically isolated and discharged to a safe state of charge — a process that is itself non-trivial for degraded cells that may not respond predictably to discharge commands. Modules must be disconnected, removed, and packaged in compliance with hazardous materials transport regulations. Lithium-ion batteries are classified as Class 9 dangerous goods for transport under UN standards. Damaged or defective cells require additional packaging and labelling. The logistics chain from site to processing facility must comply strict jurisdiction-specific regulations.

The cost structure of this process is dominated by labour and logistics, not materials. One estimate for decommissioning a 1MWh NMC battery system attributes roughly 40% of total cost to on-site dismantling and packaging, 30% to transportation, and 30% to recycling and processing. The density and weight of battery modules — far greater than solar panels per unit of energy capacity — drives both the handling complexity and the transport cost.

Recycling economics and chemistry risk

Recycling itself is a developing capability. Hydrometallurgical and pyrometallurgical processes can recover cobalt, nickel, lithium, and other materials from spent lithium-ion cells. The economics depend heavily on cell chemistry: NMC cells, with their cobalt and nickel content, have higher recoverable material value than LFP cells, which contain no cobalt and use abundant, low-value iron and phosphate. As the market shifts toward LFP — which now dominates new utility-scale installations globally — the economic case for recycling weakens, and the risk that end-of-life processing becomes a net cost rather than a net revenue increases.

Regulatory and infrastructure gaps

The regulatory framework for BESS decommissioning is, in most jurisdictions, effectively non-existent as a standalone regime. Battery systems fall under general hazardous waste, transport, and environmental regulations, but there is no equivalent of WEEE producer responsibility obligation specifically governing the end-of-life treatment of utility-scale battery storage. Financial assurance requirements, where they exist, are typically embedded in the same planning or permitting conditions that govern the broader project — and those conditions were often drafted with solar or wind in mind, not battery storage.

The pace of deployment is outrunning the development of end-of-life infrastructure. Recycling capacity for lithium-ion batteries at the scale that will be required by the late 2030s does not exist today. The supply chain for specialist dismantling, hazardous materials packaging, and regulated transport is nascent. The cost estimates being used in project financial models are, by necessity, based on extrapolation from small-scale decommissioning and pilot recycling operations — not on demonstrated costs at utility scale.

There is a pattern here that should be familiar

The clean energy industry has, for a third time, deployed a technology at scale before fully understanding the cost and complexity of retiring it. Wind was first. Solar is next. Battery storage will follow. In each case, the end-of-life obligation was acknowledged in principle at the point of development, provisioned for with an estimate that reflected the knowledge and cost assumptions of the time, and then left largely unexamined as the asset generated revenue for two or three decades.

The difference with solar and storage is that the warning is visible earlier. The wind industry's decommissioning data gap became apparent only as the first-generation fleet reached end-of-life. For solar and storage, the gap can be identified now — before the bulk of the fleet has aged out — and the provision assumptions can be tested before they are proven inadequate.

End-of-life cost needs to be treated as a first-order input to investment decisions, not a residual line item that will be dealt with later. The cost of decommissioning a solar farm is not the cost of removing panels from racking. It is the cost of managing a regulated waste stream at industrial scale, through a recycling infrastructure that does not yet exist, under regulations that are still being drafted. The cost of decommissioning a battery storage facility is not the cost of disconnecting containers. It is the cost of safely dismantling a hazardous energy system, transporting Class 9 dangerous goods, and processing a waste stream whose recycling economics are deteriorating as the dominant chemistry shifts away from high-value cathode materials.

The organisations that will navigate this well are those that understand the cost structure before the bill arrives. The ones that will not are those that assume the number in the financial model is the number that will be paid.