Waste Management for Renewable Energy Infrastructure: Lifecycle Regulations for Disposal/Recycling

Miles Majure

As the world accelerates its transition towards sustainable energy sources, the growth of renewable energy infrastructure like solar panels, wind turbines, and batteries is rapidly increasing. However, this shift also brings forth new challenges related to the disposal and recycling of these components once their operational lifespans end. Developing and implementing comprehensive legal frameworks and regulations is crucial to mitigate the environmental impact and promote a circular and sustainable economy for this infrastructure.

Solar panel systems are a vital part of the renewable revolution, but panel disposal poses risks due to hazardous materials like cadmium and lead.[1] Improper handling can contaminate soil and water.[2] Since solar panels contain hazardous materials, legally binding regulations must mandate proper collection, transportation, and recycling processes when panels are decommissioned. This includes disassembly, safe separation of materials, and specialized recycling facilities to extract valuable components like silicon and aluminum.[3] While many of these materials are currently regulated by the EPA's implementation of the Resource Conservation and Recovery Act (RCRA), RCRA standards are both cumbersome and expensive and do not promote the recyclability of these materials.[4] As a solution, Extended Producer Responsibility (EPR) laws should be enacted requiring solar panel manufacturers to fund and manage take-back and recycling schemes.[5] This incentivizes designing for end-of-life recycling. Eco-modulated fees can further this by charging higher rates for harder-to-recycle products.[6] Legislation will also be needed at the federal level so regulations across jurisdictions will be the same, thus streamlining recycling logistics.

Wind power is another key renewable energy source, but turbine blades, towers, and components ultimately require decommissioning. Regulations should legally require wind farm operators to create and follow decommissioning plans detailing safe disassembly, transport, and disposal/recycling procedures.[7] Special focus is needed on recycling composite blades which are difficult to process.[8] As with solar, EPR policies can compel manufacturers to establish programs for turbine/component take-back and recycling when decommissioned. This provides powerful incentives to design for recycling and develop improved composite materials amenable to recycling. Complementary policies should support and finance research into composite recycling

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[1] Atalay Atasu, *The Dark Side of Solar Power*, THE HARVARD BUSINESS REVIEW (June 18, 2021). https://hbr.org/2021/06/the-dark-side-of-solar-power
[2] *Id.*
[3] *Id.*
[4] *Ten RCRA Hazardous Waste Compliance Issues*, GeoEngineers (May 19, 2014). https://www.geoengineers.com/news/ten-rcra-hazardous-waste-compliance-issues/
[5] *What is Extended Producer Responsibility (EPR)?*, World Wildlife Fund (June 18, 2021). https://www.worldwildlife.org/blogs/sustainability-works/posts/what-is-extended-producer-responsibility-epr
[6] *Id.*
[7] *Wind Project Decommissioning: Industry Recommendations*, American Clean Power Association (Sept. 2020). https://cleanpower.org/wp-content/uploads/2021/01/Decomissioning-Fact-Sheet.pdf
[8] *Id.*

and sustainable alternative turbine blade compositions.[9] Regulation at the federal level would be the most beneficial as it would standardize and stabilize the market.

Energy storage batteries enable renewable grid integration but contain toxic materials like lead and lithium that risk environmental harm if improperly discarded.[10] Robust battery recycling regulations and programs are essential across the full lifecycle from production to disposal. This includes mandating battery collection sites, transportation standards, and specialized recycling facilities to safely extract valuable metals like cobalt and nickel.[11] EPR laws for battery manufacturers are critical, making them financially responsible for recycling schemes. Legislation can further drive development of more sustainable, recyclable batteries like solid-state or those using more abundant materials.[12] Eco-fees and recycling standards can incentivize better battery designs.

For maximum effectiveness, waste management regulations should utilize the EPR principle, legally binding manufacturers into funding and managing recycling programs for their products when decommissioned. This internalizes waste disposal costs and incentivizes sustainable design. Extended Producer Responsibility (EPR) rules, which hold manufacturers responsible for the end-of-life management of their products, can potentially raise trade law issues if they discriminate against imported products.[13] For instance, if EPR fees or requirements are applied differently to domestic and imported products, it could be seen as a barrier to trade and a violation of non-discrimination principles under international trade agreements like those of the World Trade Organization (WTO).[14] Another potential legal issue is surrounding the issue of "orphan waste", which refers to products whose manufacturers are no longer in business, making it unclear who is responsible for their end-of-life management under EPR schemes. This can be a significant challenge, as it may require governments or other entities to bear the costs and responsibilities for these orphaned products, potentially undermining the intended cost-internalization and incentive effects of EPR policies. Defining the "producer" responsible for products with complex international supply chains can also be a major complexity in implementing EPR rules. Many products today involve components and materials sourced from various countries and assembled in different locations, making it difficult to determine which entity along the supply chain should be considered the "producer" and bear the EPR responsibilities. This complexity can lead to legal uncertainties, potential disputes, and challenges in effectively implementing EPR policies for globally traded products.

Complementary legal measures should include landfill/export bans on renewable energy waste, recycled content standards for new products, and legislative funding for research into sustainable materials and recycling innovations. These supportive policies can help reinforce the objectives of EPR by closing loopholes, setting clear standards, and driving innovation in sustainable product design and end-of-life management. Thoughtful policymaking carefully

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[9] *Id.*
[10] *ARE ENERGY STORAGE SYSTEMS FACING A BATTERY RECYCLING AND DISPOSAL CRISIS?*, ENERGY STORAGE WORLD FORUM (Dec. 21, 2019). https://energystorageforum.com/news/energy-storage/energy-storage-systems-facing-battery-recycling-disposal-crisis
[11] *Id.*
[12] *Id.*
[13] *Supra* note 4.
[14] *Technical barriers to trade*, World Trade Organization. https://www.wto.org/english/tratop_e/tbt_e/tbt_e.htm

balancing environmental protection and economic viability will be crucial. Meaningful conversations with manufacturers, waste handlers, environmental groups, and others is needed. A phased, gradually tightening approach can allow a structured renewable energy waste management system to develop over time.

Ultimately, comprehensive legal and regulatory frameworks governing disposal and recycling must be implemented globally as renewable energy infrastructure continues its rapid deployment. Harmonizing standards internationally will create an effective, streamlined system incentivizing sustainability through the full product lifecycle. Building a circular economy for renewable energy technologies is essential to maximize their environmental benefits over the long term.