MANAGING INDIA'S CLEAN ENERGY WASTE

A ROADMAP FOR THE SOLAR AND STORAGE INDUSTRY

With the increasing penetration of distributed renewable energy sources such as solar PV and energy storage into the Indian electricity sector, it is necessary to prepare for managing the waste generated from these technologies. The reduce, reuse, and recover approach offers multiple socio-economic benefits besides being environmentally benign. In this article, **Akanksha Tyagi** takes a closer look at the management of clean energy waste.

India is undergoing a clean energy transition. The government is consistently implementing policies to increase the share of renewables in the total electricity mix. Solar energy, in the form of rooftop and utility-scale solar, is at the forefront with significant capacity addition over the past decade. The cumulative solar capacity has grown from 3 MW in 2009 to 31 GW as of September 2019 and is aimed to reach 100 GW by 2022.[1] Energy storage is also garnering much attention with the growing share of renewable energy in the grid to overcome generation intermittency. The Union Cabinet recently approved the National Mission on Transformative Mobility and Battery Storage that includes a five-year phased manufacturing programme to set up large-scale battery and cell manufacturing giga plants in India.

Since then, several renewable plus storage tenders have been announced. The share of solar plus storage projects is only going to increase as India moves towards achieving the 100 GW target. In additional to lead-acid batteries, which have been in use for energy storage and uninterrupted power supply solutions for many decades, alternative battery chemistries such as lithium and redox flow are emerging for renewable energy applications.

Although the dramatic augmentation of solar and storage capacity ensures access to sustainable energy for all, it carries an impending issue of disposal and management at the end of their useful life. The expected useful working life of solar photovoltaic (PV) modules is between 25 and 30 years, after which they have to be discarded. In addition, some of these products are also damaged during transportation, installation, operation, or natural calamities such as typhoons and floods. So, even though most of the installed projects are well short of decommissioning, it would not be prudent to delay their waste management. According to our analysis,[2] the current 31 GW solar capacity alone would result in 107,000 tons of waste by 2022. Interestingly, none of this waste would come from the expected end-of-life of these modules. About 24,000 tons would result from damages during transportation and installation process. The remaining, about 82,000 tons, would result from early failures during the plant operation phase. This amount will continue to grow as more solar capacity is deployed in future.

[1] MNRE. 2019. Physical *Progress (Achievements)*. New Delhi: Ministry of New and Renewable Energy

[2] This number is derived by multiplying the average weight of a panel with the solar capacity under the early loss scenario assumptions of losing 0.5% of the capacity while transportation, 0.5% during installation, and 2% within 10 years of installation.

Similarly, for batteries, the expected life varies from 3 to 10 years depending on the battery chemistry. Further, several factors can result in an early life failure of batteries. Besides damage from improper handling during transportation and installation, different operational factors, such as overheating, deep discharging, and low or high surrounding temperature, can also cause an early life failure of batteries. As these technologies continue to grow, so does the cumulative waste. In the absence of a regulatory framework, this entire waste would end up in landfills, thus adversely impacting the environment.

Necessity and Opportunity of Waste Management

Dedicated waste management and recycling policies are crucial from an environmental and a resource management perspective. The environment aspect pertains to the ecological impact of these products upon disposal. Both PV modules and batteries contain metals as an active component. In PV modules, two different technologies are prevalent: crystalline silicon and thin-film. The major components of a crystalline silicon module are silicon, aluminium, copper, and silver. Thin-film modules contain compounds of tin, cadmium, and lead besides aluminium, copper, and silver. In parallel, the battery sector is dominated by different chemistries of the lithium-ion technology, the main metallic components of which are lithium, manganese, nickel, iron, and cobalt. They also contain a solution of metals as electrolytes such as lithium hexafluorophosphate ($LiPF_6$).

Each of these metals has distinct environmental impact, entailing specific handling and disposal procedures. While aluminium and silicon are relatively less toxic, the heavy ones such as cadmium, tin, and lead are an environmental hazard. In addition to these visible metallic parts, some bulk components such as module glass are threats to the environment. Glass in PV modules contains antimony to improve the module's stability under light irradiation. Antimony is a potent human carcinogen. Intuitively, none of these damaged products should be dumped directly into the environment or sent for secondary consumption without proper treatment. However, this is the prevalent practice that leads to the second issue of resource management.

As metals are vital for PV modules and batteries, they should be used efficiently. Some of them have limited reserves and are also used competitively in other industries. Researchers at the Council on Energy, Environment and Water (CEEW) have conducted an assessment on the criticality of different metals for Indian

manufacturing industry.[3] The analysis identifies silicon, germanium, lithium, and cobalt as critical minerals based on their economic importance in the renewable sector and the risk associated with their geographical reserves. Further, metals such as cobalt, nickel, and iron have relatively low supply risk, but they are extensively used in other industries, such as chemicals, aerospace, and electronics. The competitive consumption of these metals in other industries, coupled with limited availability and geopolitical uncertainty in the supply chain, can increase the cost of end products. A PV module represents almost 50% of the overall cost of solar PV systems. Batteries, on the other hand, represent almost 70% of the total cost of two-wheeler electric vehicles and 50% of four-wheelers. The cost trajectory of these technologies will be driven by the availability of these critical minerals and their replacement by alternative materials or technologies. While the latter might take time, the supply crunch of these critical minerals threatens the future of these clean energy technologies.

In this context, the end-of-life management and recycling of these products are crucial. It will ensure sustainability by adhering to the concept of circular economy, support new industries, and create employment opportunities. The metals can be reused within the industry to locally manufacture more products in future that can bring down the cost of these technologies. Further, as mining of these metals creates as much waste as landfilling, material recycling will decrease the environmental impact at the manufacturing stage as well.

Current Recycling Procedures

PV Modules

Much of the PV module mass comprises aluminium frames and glass, followed by the metallic components in solar cells and wires. The main steps of recycling PV modules include dismantling, combustion, and etching. *Dismantling* involves removal of metal frames and terminal boxes from modules. *Combustion* involves burning modules to remove the organic encapsulant. This process ensures recovery of glass and solar cells (silicon or thin-film) with minimal breakage. *Etching* involves treating the residual mixture of glass and metals with acid or alkali for the separation of these two components. After recovering glass, the composition of acid or alkali solution is changed to recover the different metals.

Lithium-ion Batteries

Depending of the application, lithium-ion batteries come in varying sizes and chemistries. The basic structure has a cathode, an anode, and an electrolyte. These components are packed in an aluminium or plastic case. Broadly, the battery recycling process involves dismantling, crushing, and processing. *Dismantling* refers to the removal of the externalities such as aluminium or plastic case encasing the cell. *Crushing* refers to the process of grounding the cell to powder. This is followed by sieving to remove tailings and other waste from fine metal particles. *Processing* is a broad term for recovering metal components. This is a multi-step process involving treatment with alkali or acid, extraction, and stripping. The metal ions recovered by treatment with acid and alkali are dissolved in organic solvents. As each metal has a different level of solubility in these solvents, we get a mixture of metal solutions. Then, the solution is brought in contact with solid metal or alloy, which reduces the ions present in the liquid phase. The resultant solution is heated at ambient temperature and pressure to remove the organic solvent and get metals.

Owing to multiple steps, these methods are energy intensive and less efficient. So, the focus of the recycling processes should be to decrease the number of steps. Also, because of the presence of different metals, there is a strong possibility of metal contamination in the recovered mass. Therefore, module and battery recycling requires separate recycling processes to efficiently recover and reuse materials.

Way Forward for India

India is yet to have a dedicated PV waste management and recycling policy. At present, solar module and battery waste is treated as general electronic waste and comes under the Ministry of Environment, Forest and Climate Change. However, given the distinct nature of this waste and the economic value of components, it is necessary to have a separate regulation in place. At present, India's PV module manufacturing industry is underdeveloped and majority of the modules are imported from countries like China. Having a module recycling policy in place can make India self-reliant by ensuring a sustainable supply of raw materials and creating employment opportunities.

Unlike India, several countries are already working on addressing the impending waste disposal problem. Some noteworthy mentions are the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive, the U.S. module manufacturer First Solar, and pilot projects by Japan's New Energy and Industrial Technology Development Organization (NEDO). India can learn a lot from these countries to frame a regulation for its rapidly developing clean energy market.

First, working on the lines of EU's WEEE Directive, India can revise its existing electronic waste management framework to include PV modules and batteries. The revised regulation, an expansion of the extended producer responsibility (EPR), should set the targets for collection and recovery efficiency of waste and lay out financing schemes for the same. Under the extended EPR, developers should report the sale of their products, collect the

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[3] Gupta, V., T. Biswas, and K. Ganesan. 2016. *Critical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030*. New Delhi: Council on Energy, Environment and Water (CEEW) and NSTMIS

damaged or discarded products from consumers free of cost, and update the status of their targets. They should also maintain transparency and inform consumers of the procedures and the economics of module and battery waste management. This information should be mentioned on the products to be easily accessible to consumers.

Second, as the current recycling processes are capital intensive, access to finance is crucial. Depending on the market share, Indian developers can choose any of the globally available financing models, such as pay-as-you-go, pay-as-you-put, and joint-and-several liability scheme. In the pay-as-you-go model, the developer pays for the process at the time of waste creation. This model is often implemented with a last-man-standing insurance. The insurance covers for an unforeseen event of a developer going out of business. In such scenario, the insurance company finances the waste collection and recovery. On the contrary, the pay-as-you-put model requires pre-allocating a fixed amount for the waste management process. First Solar, a leading solar module manufacturer in the United States, uses this approach for recycling the waste from its modules. With the sale of each module, it sets aside a lump sum to meet the estimated future collection and recycling cost of its modules. In addition to these two models, developers can also opt for a collective producer responsibility scheme. Here, they jointly set a financing guarantee with last-man-standing insurance to pay for the collection and recycling costs corresponding to the market share of their products. Then, they use the pay-as-you-go model to cover the cost of managing the waste from their products. This model is successfully implemented in Germany.

Third, a market-driven initiative is important for a thriving waste collection and recycling industry. The various stakeholders of the Indian solar industry should take responsibility to invest in recycling technologies, finance routes, and feasibility examination by pilot projects. They can learn from the Solar Energy Industries Association (SEIA) in the United States and Japan's New Energy and Industrial Technology Development Organization (NEDO), which have taken a lead on clean energy waste collection and management. SEIA, a not-for-profit trade association of the U.S. solar energy industry, is maintaining a corporate social responsibility committee to develop and review the research in recycling technologies. It introduces developers to recycling vendors and provides financing options for waste collection and management. Some of the members are already operating the take-back and recycling programs for their products. In Japan, NEDO has been undertaking extensive research activities for PV recycling. In 2014, it developed an automated PV recycling technology that separates different types of panels (crystalline Si, thin-film) to recover valuable materials such as aluminium, Si, glass, and metal semiconductor. This technology is currently in the experimental phase.

In India, the Ministry of New and Renewable Energy (MNRE) has endorsed several solar associations, such as the National Solar Energy Federation of India (NSEFI), the Indian Solar Manufacturers Association (ISMA), and the Federation of Indian Chambers of Commerce & Industry (FICCI) Renewable Energy. These associations can collaborate to develop guidelines for reporting the sale and damage of modules, invest in new recycling technologies and examine the feasibility of existing services, and create a financing scheme for the same.

As distributed renewable energy sources such as solar PV and energy storage penetrate deep into the Indian electricity sector, it is necessary to prepare for managing the waste generated from these technologies. In addition to being environmentally benign, the 'reduce, reuse, and recover' approach offers multiple socio-economic co-benefits. The local manufacturing industry will benefit from decreased dependence on the import of raw materials. It is imperative for the government to introduce a holistic policy framework for handling the waste from clean energy technologies, highlighting the responsibility of different stakeholders, and creating an enabling environment to implement the same. EF

Dr Akanksha Tyagi is Research Analyst, Council on Energy, Environment and Water (CEEW), New Delhi.