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CLEAN ENERGY AND THE CIRCULAR ECONOMY: OPPORTUNITIES FOR INCREASING THE SUSTAINABILITY OF RENEWABLE ENERGY VALUE CHAINS

SCALING UP RENEWABLE ENERGY (SURE)

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DISCLAIMER
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Acronyms

BNEF	Bloomberg New Energy Finance
EC	European Commission
ENRM	Environmental and Natural Resources Management (Framework)
EOU	End of Use
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse Gas
GOGLA	Global Off-Grid Lighting Association
GW	Gigawatt
GWh	Gigawatt Hour
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
Li	Lithium
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
RE	Renewable Energy
SDG	United Nations Sustainable Development Goal
STEM	Science, Technology, Engineering, and Mathematics
SURE	Scaling Up Renewable Energy
UN	United Nations
USAID	United States Agency for International Development
WEF	World Economic Forum

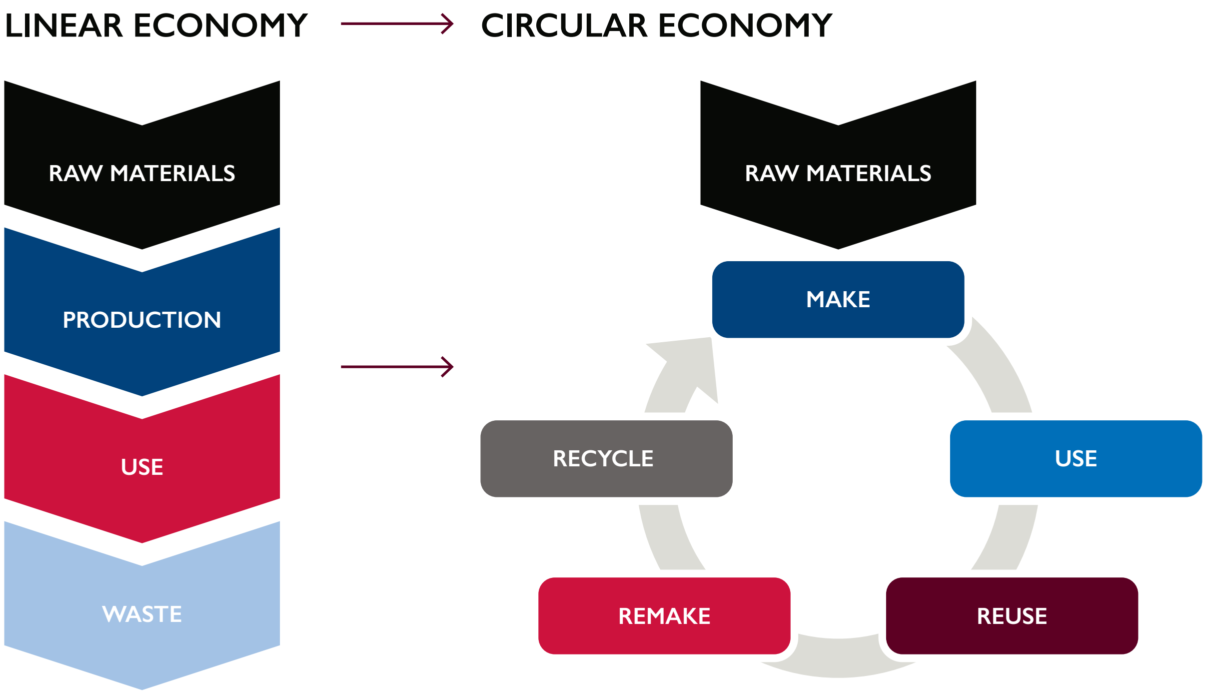
EXECUTIVE SUMMARY

Completely transforming how we produce, transport, and consume energy is imperative to reduce global carbon dioxide emissions to net zero by 2050 [1].[a] Scaling up renewable energy (RE) generation and integration is critical. But for RE to be a truly clean power source, solar, wind, and battery equipment must be manufactured, deployed, and decommissioned in a responsible, safe, and sustainable way. A circular economy for RE equipment can create a lower-emission supply chain for materials, reduce waste create jobs, empower women, and ensure that communities and workers optimally benefit from the transition to a clean energy economy.

Circular economy approaches are necessary to achieve these pathways quickly, economically, and sustainably while powering economies and creating economic opportunities for more people. In a circular economy, parts and materials have multiple life cycles and re-entry points into the market as they are systematically recovered, repaired, reused, refurbished, and remade into similar or other products. This paradigm shift changes how the industry approaches design to more easily and cost effectively facilitate earlier cycles before end of use (EOU) and to make decommissioning and recovery more economical. It also reduces the need for resources as well as supply chain risks. This is distinct from the current "linear economy," as illustrated in Figure 1.

a Net zero refers to the balance between the amount of GHG produced and the amount removed from the atmosphere. The world will reach net zero when the amount added is no more than the amount taken away.

FIGURE 1. Transition from linear to circular economy. Adapted from Wikimedia Commons by Catherine Weetman [2]



Tackling emissions requires us to make products differently. Instead of damaged and decommissioned equipment piling up in landfills, the life of materials must be extended beyond their original intended use. This is much more than redoubling efforts on recycling. Circular economy strategies that reduce the use of resources overall can cut global greenhouse gas (GHG) emissions by 22.8 billion tons [3] and relieve pressure on natural resources; in the RE sector, this includes critical metals. These strategies can chart innovative pathways to net zero economies and create sustainable economic growth and jobs in economies slowed by COVID-19.

Shifting to RE complemented by energy efficiency can cut 55 percent of global GHG emissions [4]. However, for RE to be a truly clean power source, solar, wind, and battery equipment must be manufactured, deployed, and decommissioned in a net zero, safe, and sustainable way. At current rates of production, the annual need for critical metals could endanger the transition to a clean energy economy. For example, critical metals such as indium and silver are needed for solar panels and neodymium is used in magnets in both wind turbines and electric vehicles. Mining these and other resources produces contaminated waste, contributes to biodiversity loss and ecological degradation, and involves frequent human rights abuses.

Furthermore, a significant amount of RE equipment is approaching the end of its use; the quantity of obsolete RE equipment is expected to grow exponentially over the next 30 years. In 2019, the world generated an estimated 18,000 tons of solar photovoltaic (PV) panel waste. By 2050, PV panel waste could increase to 10 million tons annually [5]. WindEurope estimates that around 14,000 blades could be decommissioned by 2023, equivalent to between 40,000 and 60,000 tons [6]. In addition, equipment such as PV panels, solar home systems, and batteries are often classified as electronic waste (e-waste) or separately (such as in the European Commission Batteries Directive), given concerns about unsafe handling of waste that results in harm to human health and the environment. By returning this equipment to be reused or recycled, circular economy strategies both keep waste out of landfills and reduce demand for the materials that make energy equipment in the first place.

The circular economy could also generate $4.5 trillion in additional economic output by 2030, according to Accenture research, which identified circular business models that will help decouple economic growth and natural resource consumption while driving greater competitiveness [7]. New business models focused on reuse, repair, remanufacturing, and sharing offer significant innovation opportunities and jobs. By 2050, more sustainable use of materials and energy could add an extra $2 trillion annually to the global economy. Global gross domestic product could grow by eight percent, with a particular benefit for low- and middle-income nations. Meanwhile, with the right sustainability and climate policies, we can slow the growth in global resource use by 25 percent by 2060 [8]. We also can reduce gender inequality by ensuring that new political, social, and economic opportunities benefit women and men equally. It is important to consider how EOU RE management may impact livelihoods, cultures, territories, and resources of Indigenous peoples as outlined in the United States Agency for International Development's (USAID) Policy on Promoting the Rights of Indigenous Peoples [9].

In this paper, "RE equipment" refers to solar PV components, batteries used for RE storage, and wind equipment. The paper breaks down each technology's material makeup and the extent of its current use. It looks at whether the technology's parts and materials, including critical metals, can be (or are being) reused and refurbished. It also assesses which parts can be recycled and the methods for doing so.

USAID has a unique and timely opportunity to help reshape the RE ecosystem and promote the adoption of a circular economy approach to the RE sector. Incentives for private industry to invest in recycling, repair, or reuse are limited due to market conditions and regulatory barriers. In partnership with governments, the private sector, civil society, academia, and communities, USAID can apply a multifaceted approach that cultivates a more inclusive and expansive RE ecosystem and places responsibility across the value chain.

The European Commission (EC) leads the promotion of circular economy strategies and actions, but action is challenging, incidental, and in its early stages elsewhere, particularly as it relates to RE. Most EC member countries have adopted the circular economy, including extended producer responsibility (EPR) frameworks that shift ownership away from the consumer to extend the responsibility for the equipment to the producer. In Latin America and the Caribbean, Colombia, Chile, and Uruguay have circular economy strategies in place. Some countries have their own policies related to EOU RE, landfill bans, and EPR. Starting in 2020, PV project owners in Japan must pay into a decommissioning fund. While the United States does not have federal policies, legislation is emerging at the state level. It is likely that existing frameworks can be adapted to developing economies. This paper covers examples of existing and emerging policies, processes, and gender-inclusive practices that promote a circular economy.

Actively engaging the RE private sector necessitates legal and regulatory requirements and financial incentives. For example, the EC's 2020 Circular Economy Action Plan covers sustainable policy frameworks, value chains, skill building, financing, and monitoring. In the absence of such frameworks, private sector companies engaged in EOU are not yet fully placed in a circular economy framework and often focus on recycling and resource recovery.

USAID can identify partner countries requiring interventions using data on installed solar and wind capacity and the average lifetime of panels. Missions can also consider countries with ambitious RE targets, strategies, and nationally determined contributions, recognizing that countries will need to adopt circular economy approaches to support the accelerated transition to clean energy. The USAID Scaling Up Renewable Energy (SURE) program can then estimate the number of panels and wind turbines that will reach their EOU in the short and medium term. Most wind turbines in developing countries have not yet reached their EOU, estimated at 30 years. Data on battery deployment are not readily available. Other indicators include the presence of a large and hazardous informal recycling sector; strong local RE industry; local secondary RE equipment markets; and existing legal or policy frameworks, among others. Countries with expected growth in RE deployment, such as Vietnam, Mexico, Brazil, and especially India, are good candidates.

USAID is in a position to convene stakeholders, assess short- and long-term risks, and develop a path forward that meets the needs of communities, the private sector, and the planet. To spark a paradigm shift from a linear economy to a circular economy, USAID must increase awareness among stakeholders, including those from the waste-handling sector, and build institutional capacity and human capital among both men and women. USAID can work with partners to foster an enabling environment for the circular economy by supporting transformational initiatives and policies with effective market signals. To systematically create circular economy solutions, USAID can conduct a risk assessment for hazardous toxic materials, map stakeholders and develop an engagement strategy, help develop regulatory frameworks, and develop trainings, tools, and resources. USAID can support the addition of circular economy considerations in RE procurements, standardization across the supply chain, and research that informs future interventions, policies, and private sector initiatives. More importantly, USAID can conduct cost-benefit analyses to form a strong business case for a circular economy, encouraging greater private sector uptake.

Reshaping the RE industry into a more circular economy is a paradigm shift that has significant potential to reduce waste and carbon emissions while extending the supply of parts and materials, including rare metals.

USAID can partner with the private sector to promote a gender-inclusive circular economy that reduces waste, makes the supply chain more resilient and less dependent on China, and extends the life of parts. This includes investing in the nascent circular economy ecosystem and cultivating new sustainable practices, innovations, business models, recycling centers, and secondary markets for partners and materials. USAID can support the development of standards to promote and ensure the quality, performance, safety, and technical viability of reused and refurbished products to encourage the orderly development of a high-quality market. A system is needed to track materials, the causes of equipment breakdown, early replacement trends due to improved efficiency, and new approaches to component collection, evaluation (triaging[b]), and safe and cheap transportation. USAID can help develop a framework for training and upskilling in equipment, triaging, and repurposing; health and safety standards and practices; and dismantling, recycling, and safe disposal. Ideal partners work at the intersection of the circular economy, RE, and waste and recycling. Table 5 lists examples of entry points for this work, including organizations such as the World Economic Forum (WEF), the U.S. National Renewable Energy Laboratory (NREL), and GOGLA, which represents the off-grid solar energy industry. USAID will need to analyze the strengths and weaknesses of each partner country and assess the resources available for each intervention.

Furthermore, the circular economy agenda is critical to make the supply chain more resilient and less dependent on imports for raw material. China is the leading producer of solar panels, batteries, and electric vehicles. The global solar industry sources about 45 percent of its polysilicon—the base material for PV cells that convert sunlight to

b Triaging is the evaluation of equipment or components to prioritize how they may be used from a circular economy perspective (reuse, repurpose, refurbish, or recycle).

energy—from factories in Xinjiang, China, according to RE research company InfoLink. In terms of the lithium-ion battery supply chain, data from Bloomberg New Energy Finance (BNEF) suggests that China controls 80 percent of the world's raw material refining, 77 percent of cell capacity, and 60 percent of component manufacturing. Critical metals such as cobalt, lithium, nickel, graphite, and manganese used in lithium batteries are finite and mined only in a few regions, mostly Bolivia, Argentina, Chile, the United States, Australia, and China [10].

Through interviews with experts from industry and leading U.S. and international associations, this paper reflects the latest knowledge and experience concerning RE equipment EOU as seen through a circular economy lens. It supplements findings with desk research and current country-level RE deployment data. While stakeholder comments and suggestions informed this paper, the positions presented here do not necessarily constitute their opinions.

USAID's SURE program seeks collaborators to reshape the RE ecosystem. Partner with SURE to promote a circular economy by cultivating new business models, innovations, initiatives, sustainable practices, policies, and markets. Contact Program Manager Amanda Valenta or Sarah Lawson to partner or co-invest with USAID.

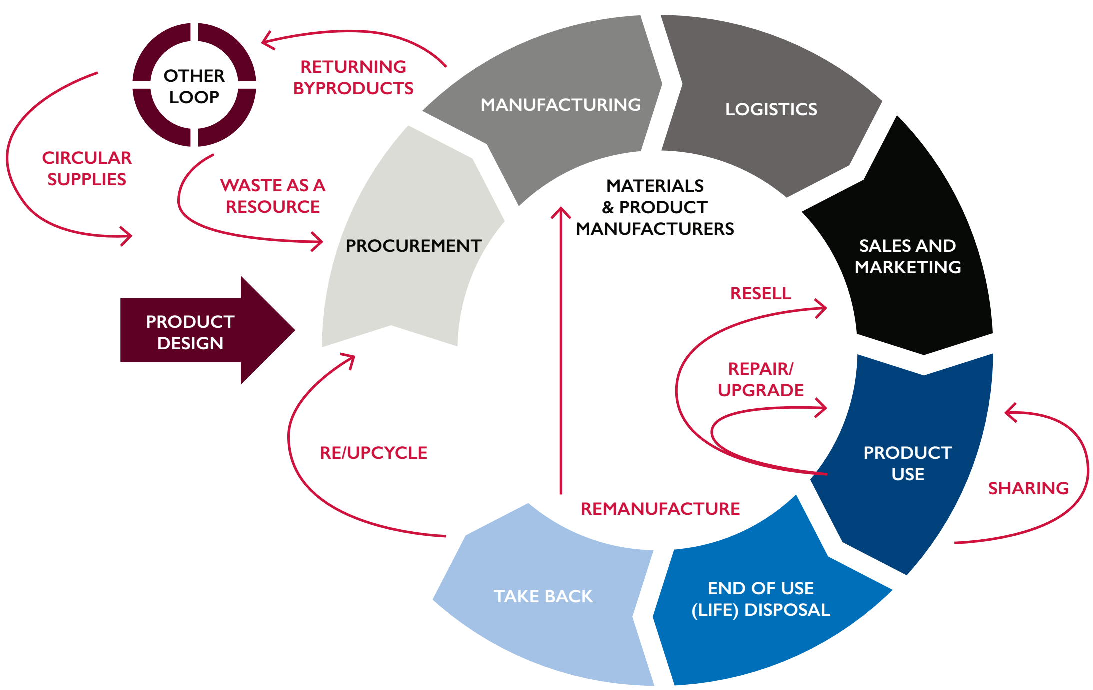
CHAPTER 1
INTRODUCTION

1.1 Transition from a Linear Economy to a Circular Economy

According to the WEF, "business, governments, and citizens around the world increasingly recognize the challenges caused by our 'take-make-dispose' approach to production and consumption." In 2019, over 92 billion tons of materials were extracted and processed, contributing to about half of global carbon dioxide emissions. The resulting waste—including plastics, textiles, food, electronics, and more—is taking its toll on the environment and human health.

A circular economy circulates materials and products instead of producing new ones. Where the linear economy disposes of waste in landfills at the end of its use, the circular economy creates multiple opportunities for "return cycles" or "loops" that avoid disposal or landfilling. This closed-loop system minimizes the use of resource inputs and the creation of waste, pollution, and carbon emissions by keeping materials, products, equipment, and infrastructure in use for longer periods, thus improving the productivity of these resources. Repairing, refurbishing, and reusing are the foundations of this approach, improving the productivity of these resources and preserving the energy and value created in the original production process. In the circular economy, recycling becomes the last resort, not the first and only option.

FIGURE 2. Circular economy loops. Adapted from Accenture, 2016 [11]



CIRCULAR ECONOMY RESOURCES

The Ellen MacArthur Foundation is registered in the United Kingdom and aims to inspire a generation to re-think, re-design, and build a positive future through the framework of a circular economy. It was founded in 2009 by Dame Ellen MacArthur and offers resources, videos, reports, roadmaps, and case studies.

In the United States, NREL has been producing helpful resources on the circular economy and the role of RE in particular [12].

The European Commission has adopted a new Circular Economy Action Plan—one of the main components of the European Green Deal, Europe's new agenda for sustainable growth. The site includes further background information.

Below are brief videos explaining the circular economy:

- Design and systems
- Systems and the environment
- Example of a business model.

1.2 The Case for a Circular Economy

Reshaping the RE industry into a more circular economy is a paradigm shift that has significant potential to reduce waste, carbon emissions, environmental degradation, and human rights abuses while strengthening the economy. Underpinned by the transition to RE sources, the circular economy decouples economic activity from the consumption of finite resources, reducing waste and pollution by keeping products and materials in use. This involves designing products that are "made to be made again." Circular economy strategies that rely on repairing and refurbishing products minimize our use of resources and can cut global GHG emissions by 39 percent (equivalent to 22.8 billion tons) [13] and reduce our long-term dependence on mining for critical metals used in RE technologies. Concurrently, work is being done on finding replacement elements, with the aim of designing out finite and toxic components altogether.

Mining not only produces contaminated waste, biodiversity loss, and ecological degradation, it also is rife with human rights abuses. The linear economy's use of critical metals depends primarily on China [14], a country that has threatened to disrupt the RE supply chain and has a record of human rights abuses [15] and poor environmental practices. Polycrystalline silicon, an intermediary product to produce solar panels, is made in China. China is also the main source of tellurium and a major source of indium, critical metals used to create some thin-film technologies for solar PV modules. China and Russia are the main producers of neodymium, dysprosium, praseodymium, and terbium, components of permanent magnets used in wind turbines. China, Zambia, and the Democratic Republic of the Congo are the main producers of cobalt, an essential part of common lithium (Li)-ion batteries and certain magnets for wind turbines.

Moving away from a linear economy toward a more circular economy will support the development of shorter, more transparent and diverse clean energy supply chains that can be more easily monitored for ethical practices. Shorter supply chains also will have a direct effect on reducing GHG emissions. Furthermore, a circular economy approach for RE equipment can help USAID uplift lives, empower women, strengthen communities, and ensure that communities and workers benefit from the transition to a new clean energy economy.

At current rates of production, the annual need for critical metals could endanger the transition to a clean energy economy. In 2050, annual indium requirements for solar panel application will be 12 times greater than current annual global production. Furthermore, global supplies of silver are not expected to be enough to meet all needs [16]. Certain components of RE equipment require the same critical metals as certain electronics components, exacerbating potential shortages. A more circular economy has the potential to enable countries to reliably source reused or recycled domestic materials. Reuse and recycling efforts can also benefit from economies of scale, because waste handlers and recyclers will find ways to handle both e-waste and RE waste where it makes economic sense. The role of e-waste in circular economy options for certain RE components is an area for further study.

In a circular economy, economic activity builds and rebuilds overall system health [17]. The International Resource Panel found that more sustainable use of materials and energy would add an extra $2 trillion to the global economy by 2050 [8]. This new paradigm would give rise to a secondary market for repair, refurbishment, and trading of used components and creates sustainable businesses and local jobs for men and women, opportunities desperately needed in economies affected by the global pandemic. New business models focused on reusing, repairing, remanufacturing, and sharing offer significant innovation opportunities. Globally, Accenture Strategy predicts a $4.5 trillion reward for circular economy businesses models by 2030 [7]. According to the International Labor Organization (ILO), a circular economy could create a net increase of six million jobs by 2030 [18]. New jobs will be created in fields such as recycling, services like repair and rental, and new enterprises that spring up to make innovative use of secondary materials. In Chile, the government set a goal to create more than 180,000 formal jobs from the circular economy by 2040. Many of these jobs are likely to evolve in the repair industry, a key part of the circular economy [19].

Moving from a linear to a circular value chain can reduce both the environmental and the economic footprint of batteries by getting more use out of them and by harvesting EOU value. This would enable a 34 megaton GHG reduction in the value chain while creating around $35 billion in additional economic value [20]. If there is rapid turnaround, repurposed batteries could "become the storage hubs for community-scale grids in the developing world," providing power to many homes currently without access [21]. Estimates suggest that reused batteries will be 30 to 70 percent less expensive than new ones by 2025 and could provide as much as 26 gigawatt hours (GWh) of power by that same year. Electric vehicles (EVs), including two- and three-wheelers, golf carts, and buses, may be good candidates for reused batteries, where "normal" cars require high-performance batteries.

1.3 Gender Equality in the Circular Economy

A circular economy approach to RE can create new opportunities for women and men as decision and policy makers, business owners, entrepreneurs, professionals, and energy users. Aging RE equipment represents a new resource that will grow exponentially and create business and job opportunities in the coming years. The question is simple: who will benefit from these new resources and opportunities?

A gender-sensitive and inclusive circular economy approach to EOU RE management will ensure that political, economic, and social resources and opportunities created in the sector are equally accessible to all. However, work on the circular economy has largely focused on the environmental and business aspects of circularity. There has been little analysis of the social implications, in particular the role of women in leading the necessary transformations in the circular economy, the skill set needed, and the impact on women's job opportunities [22]. Consequently, there is a unique opportunity to position these new and growing markets in a more sustainable and equitable way. A growing body of evidence establishes a correlation between increased representation of women in corporate leadership and stronger business outcomes for companies. Today, most organizations are working to recruit and retain more women in order to increase productivity, build resiliency, and improve their brand and reputation.

Furthermore, disruptive leadership toward more circularity combined with smart circular business models can also influence women's consumption behaviors. The European Institute for Gender Equality found that women are more sustainable consumers than men and are more willing to change their energy-related behavior in favor of sustainable options [23].

In the context of global climate and environmental urgency and growing economic inequalities, the European Union Green Deal and its circular economy component illustrate the effort to achieve environmental and social sustainability, including gender equality. [24].

THE RISK OF NOT INTEGRATING GENDER IN THE CIRCULAR ECONOMY

EOU RE management is developing at the intersection of several sectors that are highly male-dominated: waste management and recycling, energy and RE, transportation and logistics, manufacturing, mining, *etc*. There is a high risk that EOU RE management will grow as an extension of those sectors and replicate sex-segregated and gender-unequal practices where women are mostly excluded from decision- and policymaking, business and job opportunities, and consumer strategies. This happened in another pillar of the fourth industrial revolution—artificial intelligence—which grew over the past ten years as an extension of the male-dominated information technology sector. In the absence of strong commitment to social inclusion, artificial intelligence has become one of the most male-dominated fields, where men represent 78 percent of the talent pool globally, and business and marketing artificial intelligence applications express strong racial- and gender-based stereotypes across many sectors [25]. The USAID Engendering Industries program has shown that with strong commitment to social inclusion, power utilities across the world can move successfully from being highly male-dominated to being gender-equal and inclusive. The program is now demonstrating how these best practices can be implemented beyond the power sector, including to the water and the information and communications technology sectors.

CHAPTER 2
CURRENT AND EMERGING INDUSTRY PRACTICES

Large associations and their members are exploring how circular economy principles can address EOU RE. In a 2020 industry guidance document, WindEurope states that "wind turbines are a valuable source of resources that can be reintroduced into the circular economy [26]."

Other associations considering a circular economy approach include GOGLA, the WEF, and the Global Battery Alliance [27]. In the United States, NREL produces studies on the circular economy, energy-intensive materials, batteries, and global PV module recycling [12]. In practice, many private companies focus on one aspect of the circular economy, mostly recycling—or rather downcycling, which is converting a product into something of lesser value.[c]

Rapid design and material innovations are resulting in cost reductions and increased performance, including "recyclability." This innovation has various effects. For example, older technology, such as Li-cobalt, cannot compete with newer technology on cost or performance. As a result, it is likely to be landfilled or recycled. However, new wind technology innovations have created a secondary market for used wind equipment and associated repairs and refurbishment.

2.1 Private Sector Drivers

As with any major shift, the transition to the circular economy will take time, money, patience, trial and error, and first and foremost, awareness. Only recently has the WEF adopted the circular economy approach and begun to promote it. Awareness that linear approaches are ineffective for solving complex problems is beginning to sink in.

Private sector companies are embracing circular economy principles for several reasons. In most cases, legal and regulatory requirements and financial incentives are needed. Some producers retain ownership because they can better manage risk or see the benefit of maintaining a strong customer relationship. They opt to provide a service associated with their product, as opposed to selling the product outright. In this way, they manage environmental risk and stay optimally informed of customer needs. First Solar, a U.S.-based manufacturer, established a take-back program so it can better manage risk associated with its own thin-film panels, which include the critical metal cadmium that is toxic to humans. A manufacturer organizes a take-back program, often in cooperation with logistics or scrap handling companies, to collect its used product from the consumer, refurbish the product, and reintroduce it or its materials back into the original or associated production cycle, i.e., the circular economy loop (see Figure 1) [28]. Companies may also see a benefit in promoting themselves as "green," sustainable, and socially responsible corporate citizens; promoting a circular economy framework supports this goal.

Private sector participants include manufacturers of RE equipment, suppliers and retailers, owners and operators, transporters, maintenance and repair

c Because downcycled products are of lesser quality than the original product due to impurities and other causes, they cannot be reused to remake the original.

providers, private lenders, insurers, energy consumers (utilities or private consumers), waste management companies (including collectors), used equipment vendors, recyclers, and buyers of recycled materials. Various configurations of these entities are involved in different value chains. Companies from one or several categories might be organized in associations, which are often more forward-thinking than their individual members. Such associations are key to reaching and educating individual members about looming risks (e.g., metal shortages and EOU-associated waste, carbon, and environmental and public relations risks).

Without policy interventions, private sector participation is often product-specific, contextual, and in different parts of the value chain. With the exception of recycling Li-cobalt batteries, where transportation costs can be kept to a minimum, managing EOU of RE equipment will usually need government intervention to prevent landfilling or uncontrolled dumping.

Emerging applications from the field show how EOU RE equipment is currently handled, or likely to be handled. Most emerging applications are not yet fully placed in a circular economy framework and often focus on recycling and resource recovery. Recyclers become interested when there is enough supply in a certain area; collection and transportation costs can be kept low; and there are buyers for their recycled products. However, it is unlikely that such buyers would be the original makers of the product, truly closing the loop. For example, the glass from a recycled solar panel is unlikely to be pure enough to become a new solar panel. Nevertheless, many companies are looking at aspects of what may transform an economy toward circularity, particularly with regard to education and training, policy development and stakeholder processes, and logistics and reverse logistics. For example, regulations need to be designed so that they do not inadvertently incentivize disposal over recycling.

2.2 Current Industry Practices by Technology

For simplicity, this paper maps current industry practices for solar, storage, and wind technologies using the main building blocks in Figure 1. RE projects increasingly combine technologies such as wind, solar, and storage to offset the technology-specific intermittencies of variable RE and allow for more efficient utilization of land and transmission capacity [30]. Such system-friendly innovations create new challenges and opportunities around circular economy practices.

DENMARK: DECOMBLADES CONSORTIUM: A THREE-YEAR CROSS-SECTOR WIND TURBINE BLADE RECYCLING PROJECT

Type: Large cross-sector project to optimize recycling and innovate recovery of some materials

A consortium that includes Orsted, LM Wind Power (a GE Renewable Energy business), Vestas Wind Systems A/S, Siemens Gamesa Renewable Energy, FLSmidth, MAKEEN Power, HJHansen Recycling, Energy Cluster Denmark, the University of Southern Denmark, and the Technical University of Denmark has been awarded funding by Innovation Fund Denmark's Grand Solutions program. The ten partners represent the stakeholders required to establish a composite materials recycling value chain. This three-year project aims to provide a basis for the commercialization of wind turbine blade recycling. The scope of the project includes: 1) shredding of wind turbine blades such that the material can be reused in different products and processes; 2) use of shredded blade material in cement production; and 3) a method to separate the composite material through pyrolysis [29].

SOLAR PV

MAKE. There are several PV panel technologies, each presenting different challenges for EOU management. The most commonly produced solar modules use silicon wafer technologies with inert materials that are ubiquitous in modern life. These include silicon (glass and wafer), aluminum (frame), copper and silver (wiring), and if connected to the grid or alternating current appliances, an inverter to convert the variable direct current output of the solar panel. Another type uses thin-film technology. In 2020, thin-film modules represented around five percent of the global solar PV market, while silicon-based solar modules made up 95 percent [31]. Some thin-film technologies contain heavy metals, including cadmium, and can contain potentially critical metals such as tellurium and indium. The International Renewable Energy Agency (IRENA) estimates that by 2030, the material composition of different solar PV panel technologies, both silicon-based and thin-film modules, will evolve in response to progress in material savings and panel efficiencies [32].

The RE sector, including solar PV, is expected to grow exponentially. However, such growth in RE production capacity is not possible with present-day technologies and annual metal production. The projection of annual need for indium (just for solar panel production) by 2050 exceeds the present-day annual global production by twelvefold. Global supplies of silver are also expected to fall short of demand [14].

Interest in incorporating circular economy principles in the design of off-grid solar products is growing. Several solar home system manufacturers working in sub-Saharan Africa are moving toward selecting system components for their longevity and lower maintenance requirements, resistance to wear and tear, and greater product integrity to extend the product life and discourage disassembly, despite incurring higher costs. GOGLA's circularity working group notes design for durability and ease of maintenance and repair as dominant strategies for off-grid solar manufacturers to consider consider [33]. Such design considerations include easily replaceable components such as circuit boards.

USE. Worldwide growth of photovoltaics between 2000 and 2019 was dramatic, with global cumulative installed PV capacity reaching about 644 gigawatts (GW), of which about 415 GW (65 percent) were utility-scale plants [34]. By 2050, the International Energy Agency's (IEA) high-renewables scenario expects solar PV to reach 4.7 terawatts, of which more than half will be deployed in China and India, making solar power the world's largest source of electricity [35].

The off-grid solar industry has also been growing dramatically, with a 160 percent increase in deployment of solar lanterns and home systems from 2008 to 2017, primarily in East Africa, West Africa, and South Asia [36]. GOGLA notes that the industry serves more than 420 million people and will continue to grow.

REUSE AND REFURBISH. There are emerging local marketplaces for used solar panels, but in general, reuse and refurbishment of solar PV modules is uncommon. Grid-connected panels stay where they are or are replaced when they have reached EOU. Undamaged panels lose efficiency over time (by an estimated 0.5 percent per year); however, there is considerable uncertainty about the actual lifespan of solar panels. Some estimates project that the actual panel life is roughly 12.5 years, rather than the expected 25 to 30 years, mostly due to breakage [37]. PV module defects increased from 19 percent in 2013 to 48 percent in 2016, resulting in increasing replacement costs [38]. Defects can lead to degradation and result in early retirement. Jordan et al. observed that module degradation depends on the type of module: discoloration is more common in C-Si modules, whereas glass breakage is more common in thin-film modules. [39]. Panels placed in hot and humid climates have higher rates of degradation.

Early retirement of PV modules caused by minor damage that requires little to no repair can be potential feedstock to the reuse and refurbish market. A 2021 study by NREL found that, in practice, modules with cosmetic blemishes, modules with a lower wattage than warrantied, or early retired modules with 60 to 70 percent of their original capacity are either donated or resold for on-grid and off-grid applications. These modules also have an added benefit as educational and vocational training tools in schools, homeless shelters, and other charitable projects to help prepare aspiring solar professionals for jobs in the RE industry [40].

In sub-Saharan Africa and South Asia—where off-grid solar dominates—repair of electronic products is an everyday economic activity and includes markets for the repair and maintenance of electronics and communications technology. The existing electronics repair and maintenance markets in these regions can potentially be expanded to include off-grid solar components. According to the Efficiency for Access Coalition and the University of Edinburgh, this presents an opportunity for greater repair and refurbishing considerations in the off-grid solar industry, including but not limited to repairing broken wires, circuit boards, and other electrical components and modifying charging plugs, connectors, and cables. Increasingly, off-grid solar companies are offering in-house repair services for products under warranty. For example, Ugandan innovator Innovex manufactures a smart meter and in-house cloud-based web system that tracks solar PV production, battery status, and load consumption of solar home system products. Solar home system companies use this to diagnose and quickly respond to product breakdowns to avoid losing customers [41].

RECYCLE. In 2019, the world generated an estimated 18,000 tons of solar PV panel waste, which seems small compared to the 43.75 million tons of glass that were recycled in the same year. By 2050, however, BNEF expects PV panel waste to increase to 10 million tons annually [5].

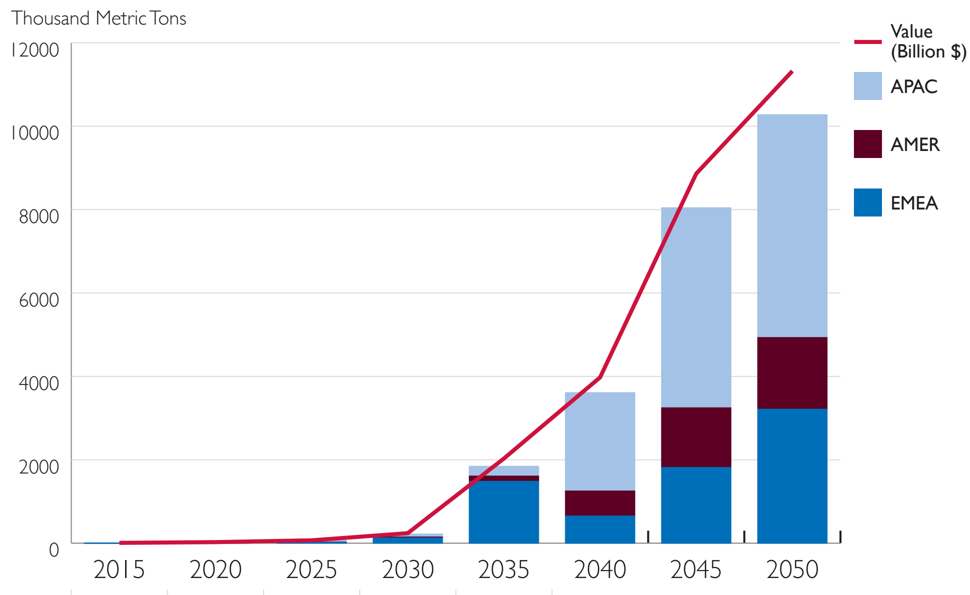
RWANDA: OFF-GRID MONITORING INFORMATION SYSTEM

Type: Markets

The Rwandan government owns an off-grid monitoring information system, an online platform in which solar companies can report deployment data for rural electrification projects. It captures data on solar home and mini-grid systems. This system informs the government where and how much off-grid solar has been deployed in the country and can be used to plan maintenance and repair. EnDev helped the Ministry of Infrastructure and Rwanda Energy Group (a government-owned electricity company) develop this tool. However, it is unclear whether the Rwandan government will have or provide funding for off-grid solar maintenance and repair.

Maintenance and repair should be the first lines of action to keep existing assets operating over the longest possible operational time. Monitoring without the additional step to actually enable the needed maintenance and repair is ineffective [42].

FIGURE 3. Projected annual PV waste in weight and value by region. Adapted from BNEF, 2020 [5]

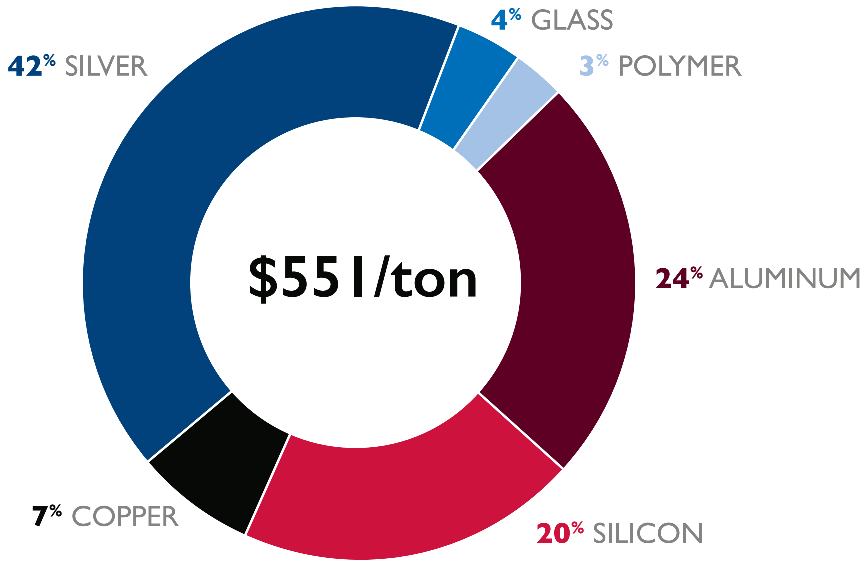


Typically, EOU solar panels are either dumped or landfilled because the cost of recovery remains economically unattractive. The better alternative would be recycling. Even though the technical and cost feasibility of harvesting and recycling is improving, it is not well understood. Anecdotal information gathered in interviews suggests that the cost to harvest and recycle a module is around $20, while the recovered materials (mostly silver and silicon) bring about $2. With landfilling costs around $1 (United States data), this amounts to a $17 net loss per module. In NREL's 2021 report, anecdotal evidence suggests that the cost of module recycling in the United States ranges from $15 to $45 per module, while one study found that disposal tipping fees at non-hazardous landfills ($26/U.S. ton) can cost less than $1 per module and less than $5 per module at hazardous waste landfills ($175/U.S. ton) [40].

BNEF estimates the theoretical value of recovered materials at $551 per ton of glass-backsheet crystalline silicon solar panels, as shown in Figure 4.[d] An important caveat is that the materials recovered in this example have low impurities, which is currently hard to achieve using mechanical recycling, the only existing PV recycling technology that is used at scale. Meanwhile, the output of a mobile recycling unit developed by La Mia Energia, an Italian manufacturer, is estimated to have a value of $241 per ton, lower than the theoretical value due to the mobile recycling unit's inability to recover silver [5].

d BNEF estimates the theoretical value of recovered materials using their scrap prices [5].

FIGURE 4. Share of theoretical value of recovered materials from one ton of glass-backsheet crystalline silicon solar panels. Adapted from BNEF, 2020 [5]



Without government intervention, such as establishing EPR or landfill bans, full recycling remains commercially unattractive. In practice, the steel (racking), aluminum (frames), cabling, and other components (e.g., inverters) are easily reused or recycled. Panel glass is discarded or downcycled, just like bottle glass. Sufficient and reliable volumes, as well as a good collection infrastructure, are necessary to bring decommissioned PV system components together for EOU treatment.

An effective harvesting system would need to collect and aggregate modules, then test and sort (triage) them into three groups: 1) those in good shape to be reused, albeit at a lower market value; 2) those damaged but repairable to be treated as reusable; and 3) those to be recycled. A key element of such a harvesting system is a process or standard for evaluation to ensure safe and reliable reuse of PV panels. Standardization is addressed in a separate section in the report. The aforementioned triage system exists in very few places but is an easily learned skill.

The cost of transport may be the single largest cost in EOU management; developing options to reduce it is necessary. For example, one company uses small transportation containers and provides intelligent, real-time information using Internet of Things and global positioning system technologies to transmit real-time location, condition, and security information [43]. Another company designed a reusable pallet especially for shipping and handling solar modules. One U.S. RE company, Recycle PV Solar, has been working on overcoming the transportation cost barrier by looking at developing and using a mobile recycling plant.

With more than 180 million installations worldwide to date and growing attention from investors and large corporations, the off-grid solar sector is rapidly growing. As companies develop their business models and differentiate their products and services from one another, companies, investors, and donors are increasingly focused on the life cycle of solar home system products, resulting in opportunities to incorporate circular economy practices. Off-grid solar home systems often consist of a solar panel combined with a storage system, and it is the value of the storage system (battery) that drives innovation. There are ongoing initiatives to extend the life of batteries by improving methods for repairing, refurbishing, and repurposing them. In the off-grid solar sector, governments, donors, and companies are encouraging and developing recycling schemes for solar and battery products to prevent the release of hazardous chemicals, reduce e-waste, and maximize value. Some companies, such as d.light and Aceleron, implement take-back or third-party collection schemes. In Kenya, Aceleron takes the collected waste cells, re-designs them, and builds new recyclable and serviceable clean energy battery packs [44]. However, implementing such schemes in remote areas is costly for small off-grid solar companies. This creates an opportunity for donors and governments to offer assistance [45].

ENERGY STORAGE

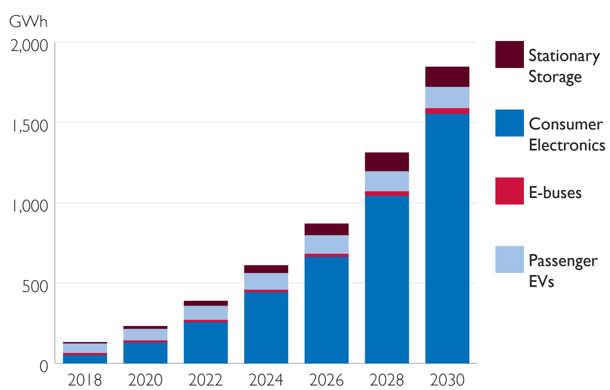
MAKE. The dominant type of Li-ion batteries is Li-cobalt oxide, but many other Li-ion configurations exist and the types and uses of batteries continue to evolve. Steve Christensen of the Responsible Battery Coalition [46] assumes that for the next few years, Li-cobalt oxide battery systems will make up the predominant waste stream. Cobalt oxide is classified as a hazardous material. It is a carcinogen, may cause asthma-like allergies and skin rashes, may ignite spontaneously, and is harmful to aquatic life [47].

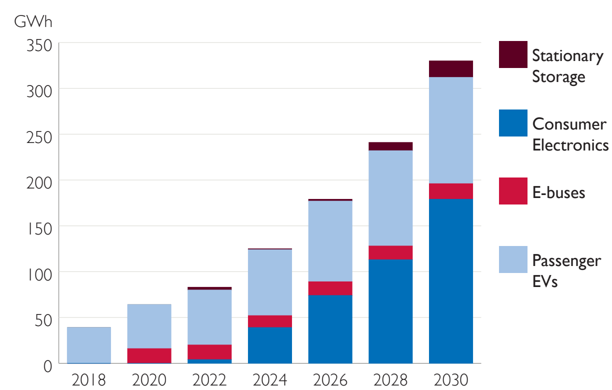
USE. Many countries continue to use lead-acid batteries, effectively recycling lead and reusing it for new batteries. This showcases a mature example of a circular economy. However, if not regulated adequately (informal sector), this practice is known to cause major health and environmental hazards because of the toxicity of lead. Due to their lower performance compared to Li-ion batteries, lead-acid batteries are not used in EVs and are being replaced in advanced RE storage systems [48].

Extending battery life is a way to avoid breakdown, reduce waste, and postpone recycling. USAID's Global LEAP Award, managed by CLASP, is an international competition to identify and promote innovation. In the latest round in early 2021, the award focused on batteries and circular economy solutions for solar home system battery systems, battery management systems, and battery life extension.

Although most batteries available for recycling in the early 2020s came from consumer electronics (e-waste), passenger EVs and stationary storage will account for 90 percent of the recycling market by 2030. This demand will create two million metric tons of Li-ion battery scrap per year by 2030 [49].

FIGURE 5. Projected global annual Li-ion battery deployments (left) and global annual Li-ion battery retirements reaching EOU (right) by end-use. Adapted from BNEF, 2019 [49]





INDIA: DEPLOYING SECOND-LIFE BATTERIES IN RURAL AREAS

Type: Markets/technology, repurposing

Nunam (www.nunam.com), a company based in India, develops second-life batteries and is currently deploying these battery systems in rural areas. SELCO Foundation, a non-profit that champions off-grid energy appliance testing business models, supported Nunam with a pilot project. Nunam is also receiving funding from the Audi Environmental Foundation.

REUSE AND REFURBISH. Once a battery is used, it can be recycled or repurposed in a different storage project. Two- and three-wheelers, golf carts, and buses are good candidates for repurposed batteries, as they have lower performance demands in terms of speed and acceleration than passenger vehicles. Stationary storage with used Li-ion batteries is new and likely to follow EV trends. Off-grid applications, including solar home systems and community-scale grids, can also provide power to homes without electricity access where demand on the battery is not heavy [50].

Reuse is still largely unexplored from a practical research perspective. The Energy Sector Management Assistance Program (ESMAP) estimates that reused batteries will be 30 to 70 percent less expensive than new counterparts by 2025 and could provide as much as 26 GWh of power by that same year [51]. NREL recently published a report on barriers, drivers, and enablers for a circular economy for Li-ion batteries in the United States [52]. Challenges to Li-ion repurposing include:

- Availability of cheaper and more accessible disposal options compared to reuse and recycling options. There are limited services and infrastructure in place for efficient and cost-effective reconditioning or recovery of materials.
- Costly and potentially hazardous disassembly and reassembly because of the wide range of Li-ion batteries and the lack of standardized regulations (with the exception of China and Europe) governing recycling and reuse practices and technologies [51].
- Limited publicly available information and data available regarding the value of, and markets for, reused and recovered Li-ion batteries.
- Lack of standards in design, shape, and size of equipment that limit interoperability and erode consumer trust in refurbished equipment.
- Inability of used batteries to compete with better and cheaper new batteries.

RECYCLE. Lithium battery recycling is viable but depends on adequate and consistent volumes and requires a centralized location. Setting up a collection system while keeping the costs for safe transportation, storage and disassembly down is the challenge. Another current challenge is the limited revenue from material recovery, according to Li-Cycle, an international Canada-based Li-ion battery recycler that is keenly following the developments of EVs and anticipating international opportunities.

According to BNEF, another key long-term driver for Li-ion battery recycling will be reducing manufacturers' reliance on mined materials, with cobalt being especially affected by the availability of recycled material between now and 2025 [49].

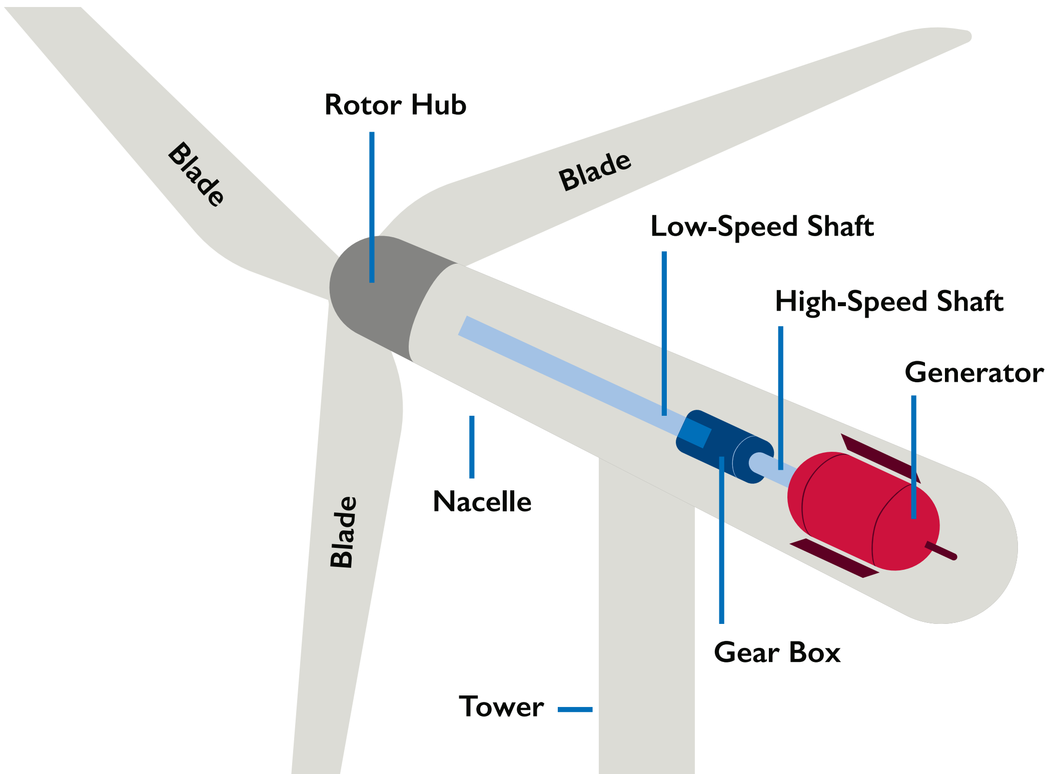
Additionally, recyclers and new equipment manufacturers are currently not designing with recyclability and repairability in mind. For example, EV design focuses on costs and performance rather than taking circular design into consideration [54]. There are also limited financing mechanisms and incentives to make collection and environmentally sound management viable.

Note that recycled materials are currently unlikely to return to a battery manufacturer because of impurities and are downcycled for use in other markets.

WIND

MAKE. Wind equipment consists of the rotor—blades, generator, control electronics, and most likely a gearbox—and the surrounding and supporting structure, including the steel tower, as shown in Figure 6. Some turbine designs, mostly those containing gearboxes, employ permanent magnets that typically contain critical metals primarily sourced from China and Russia. On average, a permanent magnet contains 28.5 percent neodymium, 4.4 percent dysprosium, one percent boron, and 66 percent iron and weighs up to four tons. There is also some minor use of critical metals in magnets within the turbine tower for attaching internal fixtures [26].

FIGURE 6. Wind turbine schematic. Adapted from Solar Schools [53]



Redesign is especially focused on making aged-out blades more easily recyclable. Blades mainly consist of fiberglass or carbon fiber. Technological advances in wind blade composites are trending toward materials that can be harvested and returned to the manufacturing cycle for re-combination with other chemicals for making new wind blades.

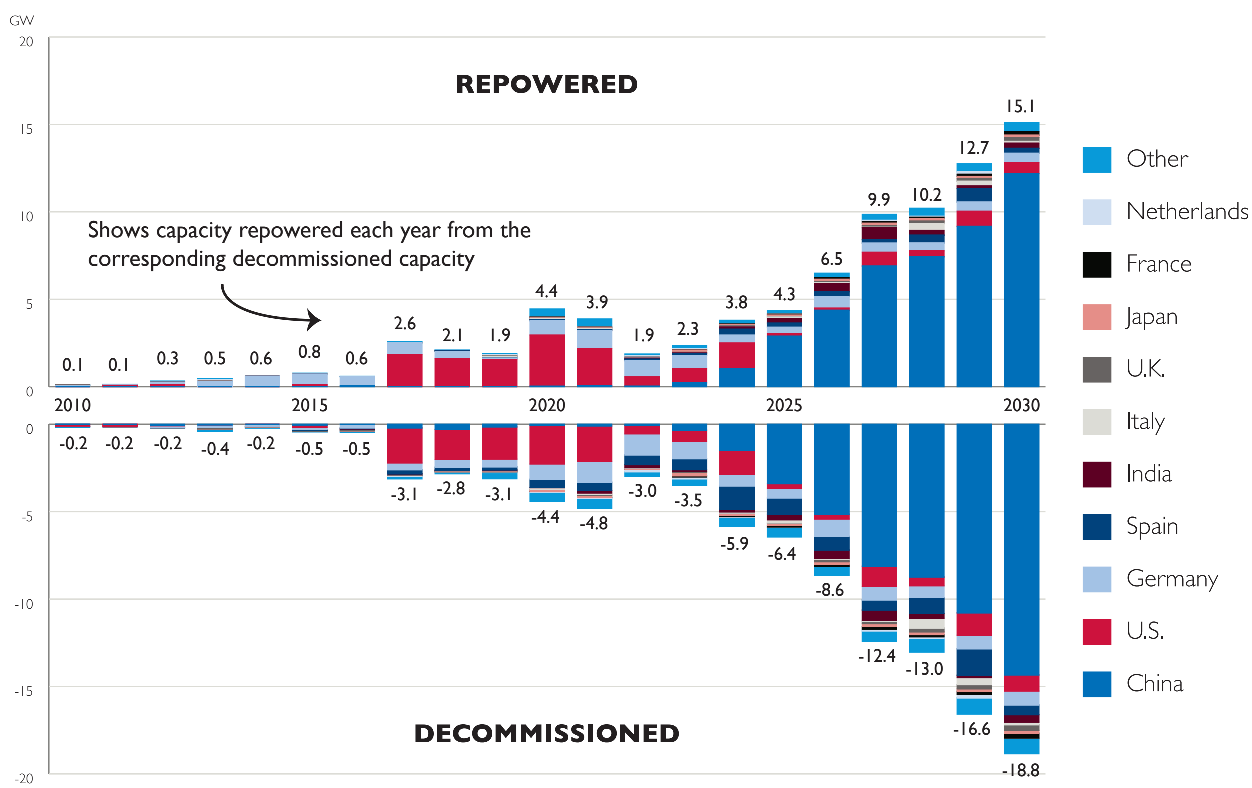
Extending the life of wind schemes is an important circular economy principle. According to Joseba Ripa of UL Renewables, "Only a few countries have currently established formal legal regulations or even guidance that require providing evidence of the status of the assets whose life will be extended. Without regulations, asset owners must address the economic benefit of lifetime extension and the commitment to security and corporate responsibility. In this situation, life extension protocols emerge as the best self-regulation mechanism to comply with corporate standards and values. Such a protocol would have to define how the company intends to extend the life of assets safely [and] generate indirect benefits for the company in the form of risk reduction, improvement of the commitment and productivity of the workers and even financial benefits insofar as the protocol helps third parties (insurers, financers, investors, buyers) to understand that the operation of the assets is being extended correctly" [55].

USE. With year-over-year growth of 53 percent, 2020 was the best year in history for the global wind industry. Despite disrupted global supply chains and project construction due to the pandemic, more than 93 GW of wind power was installed [57]. IRENA predicts that onshore and offshore wind will generate 35 percent of total electricity needs by 2050, becoming the world's prominent generation source [56].

Wind equipment has a much longer lifetime than batteries or off-grid solar and a somewhat longer life than solar modules. Because of this longer lifespan, the Global Wind Energy Council has not looked at EOU issues (although its individual European members certainly have). Instead, the Global Wind Energy Council has focused on promoting growth for new equipment [57]. While there are markets for used wind equipment components, such as in India and Europe, there is very little information on circular economy EOU initiatives for the wind sector (without significant government intervention).

REUSE AND REFURBISH. Because new wind machines are so much larger and differently designed than they were 20 to 30 years ago, there is no reuse and refurbishment, with the possible exception of (parts of) the turbines and ancillary electric components. Instead, the industry is actively working on repowering and decommissioning with associated recycling. BNEF predicts that 15 GW of turbines will be repowered, and 19 GW will need to be removed or replaced this decade (Figure 7) [58].

FIGURE 7. Projected repowered and retired onshore wind capacity by 2030 (GW). Adapted from BNEF, 2020 [58]



Repowering typically involves replacement with new equipment. WindEurope estimates that around 14,000 blades could be decommissioned by 2023, equivalent to between 40,000 and 60,000 tons [59]. Repowering offers growth opportunities and is less likely to meet with resistance from the public.

RECYCLE. Well-planned decommissioning is paramount. Several European countries have a landfill ban in place, while France has set recycling targets and offers financial incentives to help cover the cost of decommissioning [26]. The German Institute for Standardization has published DIN SPEC 4866, which addresses decommissioning of wind machines. However, an international standard for decommissioning wind turbines does not exist yet.

Decommissioning a large wind turbine is a complicated operation with multiple stakeholders. To help guide such a project, WindEurope has produced the industry guidance document ***Decommissioning of Onshore Wind Turbines***. There are many steps, all of which can be perceived through a sustainable circular lens, including permitting formalities, project management, data requirements, risk assessment, monitoring, site restoration, a communications plan, and an environment, health, and safety plan.

Although practically the entire tower and nacelle are recycled, recycling and associated handling of obsolete wind blades has been challenging. Most blades are landfilled. Currently deployed blades are mostly fiberglass and wood; recovery processes shred the fiberglass to use as an input for concrete or road construction. Table 1 shows the treatment of wind turbine materials according to a study by Tazi et al that assumes wind turbines' blades, hubs, and nacelles are made from fiberglass [60]. Up to 50 percent of polymer materials and fiberglass are incinerated.

Blade chemistry is evolving, and in the future, blades may be more easily recycled. One innovative concept is to make fully recycled composite panels for the building industry out of decommissioned wind blades, while minimizing environmental and carbon emissions [61].

TABLE 1. Wind turbine materials and treatment [60]

WIND TURBINE MATERIALS	TREATMENT
Steel	90% recycled + 10% landfill
Aluminum	90% recycled + 10% landfill
Copper	90% recycled + 10% landfill
Polymer materials	50% incinerated + 50% landfill
Lubricants	100% incinerated
All other materials (including concrete)	100% landfill

CHAPTER 3
EMERGING POLICIES, LEGISLATION, AND REGULATORY FRAMEWORKS TO CULTIVATE A CIRCULAR ECONOMY

The EC is a leader in promoting comprehensive circular economy strategies and actions. Most of its member countries have adopted the circular economy framework and are developing roadmaps and piloting possibilities. In March 2020, the EC adopted a new Circular Economy Action Plan [62]. It is one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth, and is a strategy to foster innovation. Objectives include: 1) reduce pressure and dependence on natural resources, including critical metals; 2) create sustainable growth and jobs; 3) work toward the European Union's (EU) 2050 goal of climate neutrality; 4) reduce waste; and 5) halt biodiversity loss [24]. The action plan covers multiple policy areas and is an umbrella for various initiatives and directives.

In December 2020, the EC published the ***Proposed European Regulations for Batteries Directive***, which aims to ensure that the EU's legal framework will regulate all stages of a battery's life cycle within the overall Circular Economy Action Plan. The regulation intends to mandate labeling requirements and a carbon footprint declaration. Another important EU policy is the directive requiring waste from electrical and electronic equipment, such as solar PV modules, to contribute to sustainable production and consumption.

Application of the circular economy framework to RE equipment EOU challenges is in its very early stages. The WEF has adopted circular economy terminology but is early in its implementation and is still looking at the situation from an economic growth perspective.

In Latin America and the Caribbean, Colombia, Chile, and Uruguay have circular economy strategies (roadmaps) in place. Mexico, Brazil, Peru, Ecuador, Paraguay, El Salvador, Cuba, and the Dominican Republic are conducting preliminary work on circular economy roadmaps [63].[e] There is a complex array of drivers that are often specific to certain regions or contexts, including socioeconomic pressures. For example, Colombia's roadmap aims to transform production chains, efficiently manage resources such as water and energy, and spur new business models, innovating a change in lifestyles.

e Colombia is an example of needing to reactivate the economy by strengthening small and medium-sized enterprises and helping create added-value jobs. To a lesser degree, the transition is driven by environmental concerns. It is more purely driven by the need for competitiveness, innovation, productivity, and sustainability.

Colombia intends to first chart the flow of industrial materials and mass consumption products and then introduce sustainable circular packaging materials. While RE equipment is not explicitly mentioned, building materials will follow [64].

There are country-specific policies related to EOU RE, landfill bans, and EPR. Starting in 2020, PV project owners in Japan must pay into a decommissioning fund. In the United States, policies are emerging at the state level. Arizona is considering a bill that requires panels to be recycled at dedicated recycling facilities. Washington implemented a stewardship and takeback program. Several other states are forming legislation on PV waste or establishing PV collection programs. [34].

> **Most EC member countries have adopted the circular economy framework and are developing roadmaps and piloting possibilities.**

CHAPTER 4

OPPORTUNITIES FOR USAID ENGAGEMENT

In 2020, the world experienced a global economic downturn with a disproportionate impact on low-income and emerging economies. The COVID-19 pandemic erased the equivalent of 255 million jobs that year, with losses particularly high in Latin America and the Caribbean, Southern Europe, and Southern Asia [65]. Developing economies are projected to lose at least $220 billion in income [66]. The pandemic-induced poverty surge will also widen the gender poverty gap, with more women pushed into extreme poverty than men. This is especially the case among people ages 25 to 34, who are at the height of their productive period. In 2021, there are an estimated 118 to 121 women for every 100 men in this age range in extreme poverty globally [67].

At the same time, the world faces a profound sustainability crisis, with our climate changing faster than we can adapt. Based on the first part of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report released in August 2021, human-induced climate change is already affecting weather and climate extremes in every region across the globe; in the future, these extremes will become larger as global warming intensifies [68]. We have a narrow window of opportunity to cut GHG emissions and avoid the most catastrophic impacts of that crisis by tackling climate change. In April 2021, the United States and other countries announced ambitious new climate targets at the Leaders Summit on Climate, committing to the global emission reductions needed to limit global warming to a 1.5° C increase. However, our current economy is steering us toward a 3° to 6°C increase [69].

Completely transforming how we produce, transport, and consume energy is imperative to reduce global carbon dioxide emissions to net zero by 2050 [1]. Shifting to RE complemented by energy efficiency can cut only 55 percent of global GHG emissions [4]. Tackling the remaining emissions requires us to make products differently. Circular economy approaches are necessary to achieve these pathways quickly, economically, and sustainably by keeping materials and products in use while reducing the need for more resources, as well as reducing supply chain risks. In a circular economy, parts and materials have multiple life cycles and market re-entry points as they are systematically recovered, repaired, reused, and remade. This drastically cuts global GHG emissions, playing a crucial role in averting the dangerous impacts of climate change.

In 2019, USAID launched the Environmental and Natural Resources Management (ENRM) Framework to coordinate, unify, and elevate environment, climate change, and natural resource management work across the Agency. A circular economy approach supports the ENRM Framework, as it helps reduce waste and emissions [70].

Today, incentives for private industry to invest in recycling, repair, or reuse are limited due to market conditions and regulatory barriers. A multifaceted approach that cultivates a more inclusive and expansive RE ecosystem and spreads responsibility across the value chain is needed to spur a paradigm shift to a circular economy.

4.1 Increasing Awareness and Capacity Within USAID and its Implementing Partners

To spark that paradigm shift, USAID must start the transformation within its workforce. USAID can train its environment officers, particularly energy officers, and private sector engagement officers through live trainings or via USAID University. USAID can also host public webinars that will be available to its implementing partners. Experts can speak on circular economy challenges, opportunities in the region, emerging trends, and options for USAID and partner countries to move forward. USAID already offers multi-day educational workshops and training opportunities for energy sector stakeholders interested in designing and developing competitive procurement and can leverage this expertise to successfully build the capacity of its implementing partners.

Introducing the circular economy framework to USAID and its implementing partners is an initial step to stimulate change management and instill the habit of looking at the realities they face using a circular economy lens. This is followed by a targeted effort to engage USAID Missions with messaging that is culturally sensitive and includes local and compelling examples of EOU management, such as recycling, and how these may be developed into more circular approaches.

4.2 Assessing Regional Opportunities

USAID has an opportunity to lead the advancement of the circular economy approach. Partner countries needing interventions can be identified with data on installed solar and wind capacity and the average lifetime of panels; SURE can then estimate the number of panels and wind turbines that will reach their EOU in the short and medium term. Most wind machines in developing countries have not yet reached their EOU, estimated at 30 years. Data on battery deployment are not readily available.

Countries with strong expected growth in RE deployment are also prime candidates. Other relevant characteristics include a large and hazardous informal recycling sector; strong local RE industry; local secondary markets for RE equipment; and existing legal or policy frameworks, among others. Table 2 shows examples of countries and regions with these characteristics.

TABLE 2. Characteristics of potential target regions or countries

CHARACTERISTICS	OPPORTUNITY AND RISK	POTENTIAL USAID PARTNERS
Battery waste Solar PV module waste Off-grid solar product waste Defunct wind equipment Anticipated EOU batteries Anticipated EOU solar PV Anticipated EOU wind	If there is already much waste, there is an acute environmental problem that needs to be addressed	Sub-Saharan Africa, Vietnam (off-grid) Thailand, South Africa (on-grid solar); Mexico, India, (Redacted) (wind)
Large, and hazardous informal recycling sector	Acute environmental and health hazard	Sub-Saharan Africa, Southeast Asia
Existing local battery, solar, wind industry OR local waste industry, including recycling; local RE associations	Local stakeholders may be more easily approached and convinced of benefits of circular economy or needs and opportunities around EOU	Kenya, Rwanda, Tanzania (mainly refurbishing and making used battery packs; often encouraged by donors)
Local informal waste industry Local secondary markets for RE equipment	Local informal market sectors may be formalized to build robust circular opportunities	Sub-Saharan Africa Rwanda, Kenya, Benin, Burkina Faso
Growth in RE applications, e.g., EV	Aged-out EV batteries will offer opportunities, (such as second-life applications or a battery refurbishing industry) or may become a potential hazard	India
Need for local RE or ambitious RE targets	Country leaders, industry, or citizens (in the case of off-grid) may recognize need for RE	India, South Africa
Need or desire to create jobs and growth in RE field	Opportunities for industries and services involved with recycling, repair, and reuse, as well as waste collectors	Most countries
Awareness of or familiarity with sustainability, "green" procurement, circularity	If there is already an awareness of sustainability, it becomes easier to build capacity around the circular economy	South Africa
(Redacted)	(Redacted)	(Redacted)
Awareness of supply chain risks or political risks re: critical metals	Countries neighboring China or heavily dependent on China or similar regimes	India
Existing sustainability, "green" procurement, circularity regulations	Countries with existing regulations (e.g., via donor influence) to build on	South Africa

Figure 8 and Figure 9 include specific emerging economies that show significant cumulative grid-scale solar and wind capacity installed and forecasted for 2022.

As the figures indicate, India is showing strong growth in RE (utility-scale solar and wind), as are Vietnam, Mexico, and South Africa.[f]

FIGURE 8. Capacity of utility-scale solar PV generation in selected emerging economies (GW). Adapted from BNEF, 2021 [71]

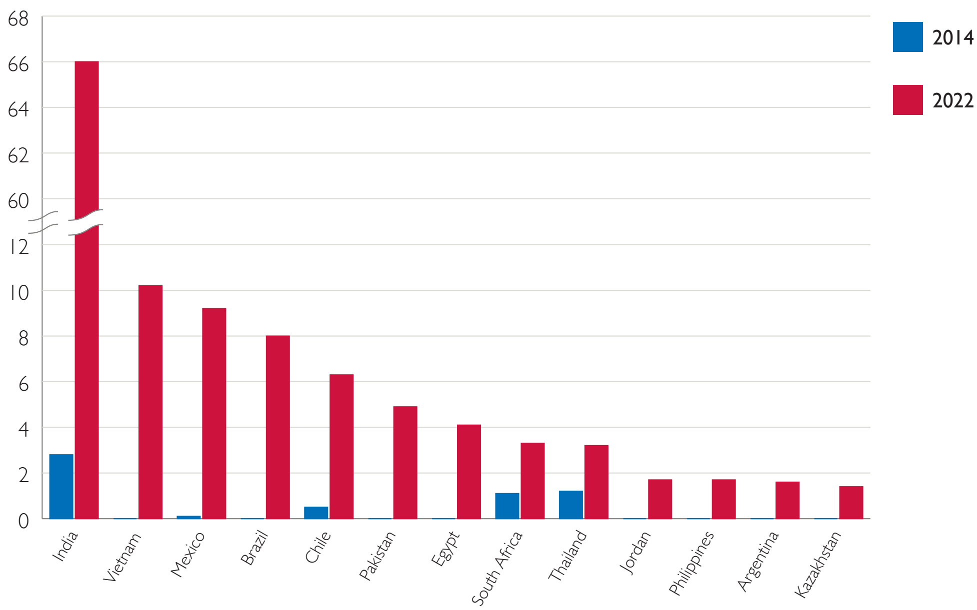
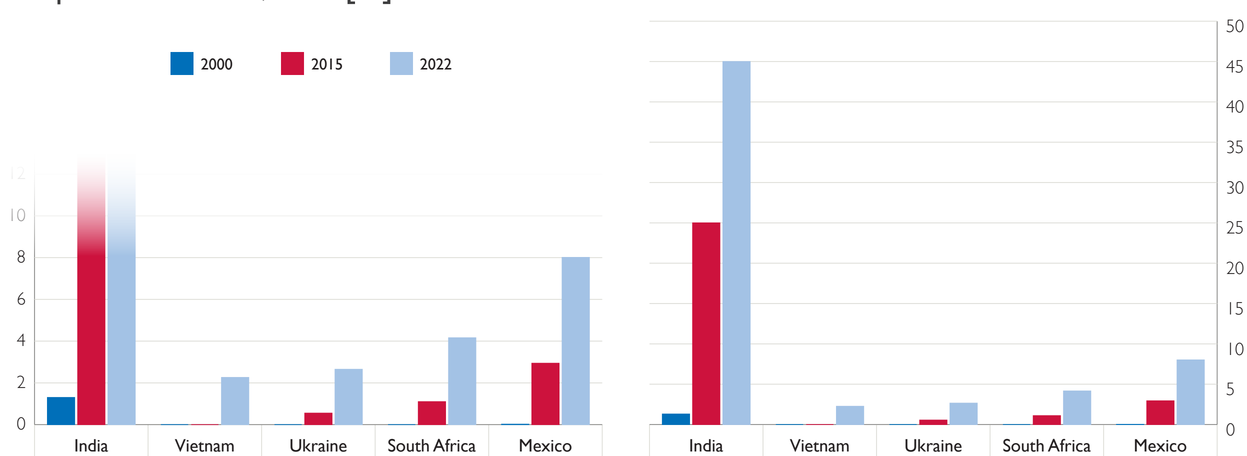


FIGURE 9. Cumulative installed wind power in selected emerging economies (GW). Adapted from BNEF, 2021 [71]



f India's expected solar PV generation capacity in 2022 is 66 GW (Figure 8) and its cumulative installed wind power is expected to rise from 25 GW in 2015 to 45 GW in 2022 (Figure 9) [71].

4.3 Cultivating an Enabling Environment

USAID has a unique and timely opportunity to help reshape the RE ecosystem. In partnership with governments, the private sector, civil society, academia, and communities, USAID can promote a circular economy to reduce pressure on natural resources, including critical metals; create sustainable growth and jobs; and chart innovative pathways to net zero economies.

There is a need and an opportunity to develop smart policies, incorporate circular economy considerations in RE procurements, develop data, conduct research to inform the road to a circular economy, and adopt standards that reflect international best practices.

DEVELOPING AND ADAPTING POLICY OPTIONS WITH EFFECTIVE MARKET SIGNALS

Policies are needed to frame the secondary market for RE equipment components, including importation of affordable, quality-assured spare parts. Policies are also needed to encourage RE companies to change product designs to facilitate easier, safer, and more cost-effective collection, disassembly, repair, and reuse of materials. Product redesign has the potential to keep products and their materials at their highest value for the longest time.

Policy options must provide market signals and ultimately voluntary markets that would cause the private sector to choose reuse or recycling over disposal. A coherent market system has only recently been established in the EU and is under development in several U.S. states, while other states may inadvertently be continuing to make disposal the preferred option. Policymakers can provide penalties or incentives to lead the private sector to choose longer-term, sustainable solutions. Policy options that USAID can explore with partner countries include:

1. Discourage disposal of PV modules, Li-ion batteries, and wind blades in landfills or in uncertified disposal locations. Establish a fee that reflects the cost necessary to transport the component to a triage or recycling center plus any fee for recycling, even if that location is not in the country. USAID can also explore frameworks where responsibility is distributed over additional contributors in the value chain. For RE companies serving low-income customers, such a practice would need to be VERY carefully designed so as not to pass on costs to customers and undermine affordability, risking the very RE benefits we aim for, slowing growth, and allowing low quality and free riders to gain more access to markets.

2. Require transport and recycling costs to be included in decommissioning plans necessary for installation of new RE systems. Responsible decommissioning policies require the project company to bond or guarantee the cost of removing the equipment at the end of its useful term, so the cost of recycling can be viewed as an incremental additional cost.

3. Build into the power purchase agreement tariff a "ratepayer contribution" to the cost of decommissioning to cover a portion of the recycling cost.

4. Adapt procurement and auctions to support the policies listed here, especially the tracking of RE equipment system components, acceptance of responsibility for decommissioning to include recycling costs, and repairability in general.

5. Establish "last resort" extended producer liabilities on the manufacturer to take back the components if the project company fails to responsibly manage EOU equipment.

USAID can help partner countries design policies based on their specific policy goals, adapt policy designs to local framework conditions, address the unique opportunities and risks presented by the specific RE equipment, and take into account the available institutional capacities needed to successfully implement the policies. A fundamental challenge is the cost and value of RE equipment components at the end of their useful terms. USAID can help partner governments identify areas within the policy framework that need to be adapted to distribute responsibility and cost across equipment and service providers and consumers.

A paper published by the Ellen MacArthur Foundation in January 2021 defines five universal circular economy policy goals that provide a framework for national governments, cities, and businesses to foster innovation and decouple growth from finite resource consumption and environmental degradation [72]. The goals recognize that the relevant policies are interconnected, which helps avoid creating a patchwork of fragmented solutions. If we can align nationally and internationally, we can reduce friction across borders and lower costs. Close cooperation also minimizes the risk of individual policy measures remaining isolated in a wider, unchanged economic system based on a linear "take-make-waste" approach. The policy goals defined by the Ellen MacArthur Foundation include:

1. **Stimulate design for the circular economy**
2. **Manage resources to preserve nature**
3. **Make the economics work**
4. **Invest in innovation, infrastructure, and skills**
5. **Collaborate for system change**

INCORPORATING CIRCULAR ECONOMY CONSIDERATIONS IN RE PROCUREMENT

USAID is at the forefront of competitive procurement design and implementation, helping developing countries strengthen national energy sectors through increased transparency and greater private sector participation. With USAID support, partner countries have transformed how they procure RE, transitioning from feed-in tariffs and negotiated tenders to auctions. By 2019, 109 countries around the world had held RE auctions, up from 98 in 2018 [73].

USAID can leverage its expertise in competitive procurement to develop policy goals that cultivate a circular economy, conduct market and regulatory analysis, and support procurement design and implementation. Circular economy considerations in RE procurement are important to achieve an efficient use of resources in the scale-up of RE. However, it is important to differentiate between what is part of the auction design and what can be better reflected in the broader regulatory and legal framework outside procurement. In particular, incorporating specific circular economy elements increases the complexity of the auction and may require a trade-off with least-cost procurement.

PROMOTING RESEARCH AND DEVELOPING MARKET DATA

Research transforms lives and industries. It helps us understand complex problems and create solutions across cultures, regions, and sectors. USAID has been investing in research to promote the use of data for decision-making, support evidence-based policies, and help the private sector assess opportunities and enter markets.

Historic and projected data on deployment of RE equipment can help estimate the anticipated volume of retired components entering the waste stream or secondary use market, which will show the urgency of country-level management of RE equipment EOU. Governments typically collect specification data about RE equipment as part of the process of approving solar PV, wind, and storage systems, particularly those connected to the grid. When possible, RE equipment data should be publicly available.

Additional data regarding formal and informal recycling sectors, local RE industry, and local secondary markets for RE equipment can help drive public and private interventions. When relevant, data should be sex-disaggregated to identify and address women's and men's different situations and needs.

Directing attention to sustainable circular economy practices can create momentum to enact strategies for managing EOU renewables. This momentum can spur the establishment of a secondary market to avert consequences from mishandling RE equipment.

It is also important to understand recycling costs and benefits, especially those related to collection and transportation—particularly for solar PV and Li-ion battery recycling, which is in its infancy [74]. As of yet, cost barriers for solar PV and Li-ion battery recycling are not well researched and tend to be region-specific challenges. Recycling technology costs are likely to fall due to innovation that can be accelerated through intentional, international, concerted action. Under task 12 of IEA's Implementing Agreement Photovoltaic Power Systems Program, IRENA and NREL developed relevant and in-depth studies with inputs from the major trade groups and could leverage existing collaboration with USAID. Research in the following areas could create market drivers by informing market opportunities, reducing uncertainty and investment risks, and increasing consumer confidence:

- Technology: RE equipment design; the volume, condition, and composition of RE equipment materials; and appropriate refurbishment processes and recycling technologies. Which technical solutions best resolve issues around safety and environmental impact relating to the collection and transportation of these goods?
- Techno-economic analysis: What is the value of reused and recovered Li-ion battery materials? What circular business models are feasible? What infrastructure and services are needed to enable circular business models?
- Regulations: What changes or additions should be made to regulations on the international trade of expended batteries, and do those regulations serve as barriers or incentives for recycling and reuse?
- Metrics and requirements: What is the threshold of a "first life" before users give their batteries and other RE equipment for collection? Which collectors are favored over others and why?
- Classification: What are the most effective modalities in developing countries for the disassembly, sorting, and classification of Li-ion batteries and solar equipment?
- Best practices: What are emerging practices for supply chain management and effective key performance indicators?

PROMOTING STANDARDIZATION AND BEST PRACTICES

Standardization across the supply chain will serve a key role in promoting the circular economy. USAID has experience working with partner countries to tailor international standards, including energy efficiency standards and labels and quality standards for off-grid products.

Standardization is much needed, starting from the upstream segment of the RE equipment supply chain. This includes standardized labeling for manufacturers (e.g., in developing management software). Voluntary standardization has many limitations, but compulsory standardization will only become possible if the market can support it [50]. Quality assurance is also associated with standards. Capacity-building around quality assurance and verification is crucial and can use USAID's support. Verification and quality assurance imply metrics, monitoring, and reporting, including developing the right metrics and having the capacity to execute them. GOGLA is working on this and would welcome technical assistance.

Standardization and verification are also key to promoting safe repair and refurbishment. Interoperability is not a priority for governments or companies. According to an interview with CLASP, the market will not do this alone, so some type of government intervention is needed for cooperation.

A standard solar module management system data stream—or, at minimum, a provision that allows access to the manufacturer's technical data—is critical to ensure that secondary installations of reused PV modules are deployed in a sustainable and safe manner. Such a system is particularly important for developing countries that may not have the means to evaluate the overall integrity of these products [51].

As far as wind EOU is concerned, what is lacking is decommissioning guidance. WindEurope is developing standardized decommissioning guidance that includes identifying pertinent types of permits, regulations, and issues concerning ownership and handling of metals. USAID can help U.S. companies play a prominent role in decommissioning projects, looking to countries with older wind equipment, such as India, Vietnam, (Redacted), South Africa, and Mexico.

BATTERY STORAGE RECOMMENDATIONS IN AFRICA

In cooperation with the Global Battery Alliance, the WEF conducted a comprehensive study on energy (storage) access in Africa in 2021. Findings from this study use circular economy principles, and potential outcomes were linked to the United Nations' Sustainable Development Goals (SDGs). Pertinent findings include [20]:

- Recycling and repurposing batteries will be key to ensure a sustainable battery supply chain (SDGs 7, 8, 9 and 12).
- Batteries support access to clean energy (SDG 7), enabling additional positive development outcomes such as improved education, health, and productivity. The battery supply chain has negative side effects, however, if waste is not collected or well-managed.
- High-quality and increased recycling and repurposing (as well as repairing for re-use) ensures African countries achieve economic growth (SDG 9), sustainable production (SDG 12), and industrial activity (SDG 8) from the expanding battery supply chain.
- Due to low material values and high logistics costs, Li-ion batteries are not collected and recycled (un-controlled disposal). The only profitable way to manage EOU Li-ion batteries generated in Africa is local reuse and repurposing.
- Though pilots of second-life battery use are emerging, the repurposing supply chain is limited and relies on imports from foreign manufacturers of second-life modules, except for two facilities in Kenya and Nigeria.
- Key challenges for Li-ion recycling are high costs for safe handling, transport and recycling, and the limited revenue of material recovery. Additional financing mechanisms are needed to make collection and environmentally sound management viable.
- Solutions include:
    - Development and rollout of battery collection using take-back and incentive mechanisms; and
    - Setting up a Circular Battery Center that 1) conducts applied research on handling and processing used Li-ion batteries locally; 2) implements environmentally sound solutions for collected batteries; and 3) develops and pilots sustainable financing for battery collection and recycling, feeding into policy development and locally adapted models of EPR.
- Pilot projects are necessary in the short term to inform battery quality certification for energy access applications and supplier warranties. These will ensure greater confidence in performance and safety and alleviate concerns around waste shipments.

4.4 Promoting Private Sector Initiatives

USAID can partner with the private sector to promote a gender-inclusive circular economy that reduces waste, makes the supply chain more resilient and less dependent on China, and extends the life of parts. USAID can invest in the nascent circular economy ecosystem and cultivate new sustainable practices, innovations, and business models, such as usability and impact of results-based financing programs [75].

CULTIVATING BUSINESS MODELS

USAID can help country partners and companies develop new circular business models and practices that clarify ownership and responsibilities. Without the right business model, it is simply not possible to design products that are easily reused or recycled or to have an effective system for reclaiming and rechanneling products into alternative uses. USAID can provide venture and acceleration assistance for partners that demonstrate they have the greatest impact, helping them reach more end users and financial sustainability.

There is a lack of coordination and harmonization with respect to the issue of liability and the roles and responsibilities of the initial manufacturer and the eventual users as a battery makes its way from the EV to a stationary source. Common liability practices should be formally developed and agreed upon, covering the full life cycle of RE products, including collection and transportation practices ([50] and [51]).

FUNDING INNOVATION AND PILOTS

USAID has a history of leveraging the promise of innovation and technology to improve the lives of millions of people. USAID's Grand Challenges for Development, the Development Innovation Fund, and other initiatives have opened development to local partners everywhere with promising ideas to make scientific and technological advances.

For the RE industry to fully transition to a circular economy, new innovations are needed to overcome technical and economic challenges. USAID can provide grant opportunities for local partners, U.S. companies, international organizations, and problem solvers around the world to source, pilot, test, and scale proven solutions. USAID can invest in the nascent circular economy ecosystem and cultivate new sustainable practices, innovations, business models, and secondary markets for partners and materials. This approach also needs a tracking system for materials and new businesses and processes for component collection and transportation.

PROMOTING U.S. BUSINESSES

U.S. companies interviewed for this paper did not indicate readiness to step into the international RE circular economy arena, describing the sector as nascent. However, U.S. associations welcomed cooperation with USAID, including the Solar Energy Industries Association and the American Clean Power Association. Engaging the Department of Commerce and the U.S. Trade and Development Agency (USTDA) can also help finance pilots and feasibility studies to support companies in creating U.S. jobs through the export of U.S. goods and services.

4.5 Promoting Gender Equality in a Circular Economy

The USAID Gender Equality and Women's Empowerment Policy and ADS Chapter 205 specify the three following outcomes to achieve gender equality [76]:

1. Reductions in gaps between males and females in access to and control over economic, political, and social resources;

2. Reductions in the prevalence of gender-based violence; and

3. Reductions in constraints that prevent women and girls from leading, participating fully in, and influencing decisions in their societies.

Examples of gender-inclusive practices to promote a circular economy are emerging. Kenya's 2018 national sustainable waste management bill created a National Waste Management Fund with specific "procedures to ensure gender and intergenerational equity in access to monies from the Fund" [77]. Inclusive procurement can also be a powerful tool to achieve gender equality. According to United Nations Women, research suggests that procuring entities wishing to level the playing field for small businesses, including those owned by women, should consider awarding contracts to firms whose offers represent the best overall value to the procuring entities, rather than simply the lowest price. Best-value determinations take into account non-price factors, such as technical merit, quality, cost-effectiveness, and after-sales service in addition to price [78].

Inclusive procurement gives preference to organizations that demonstrate a strong commitment to gender equality and inclusion (including the participation of women in jobs in science, technology, engineering, or mathematics (STEM); leadership teams; and other parts of the workforce), prevention of gender-based violence and sexual harassment, and equal pay. For example, PV Cycle France is a nonprofit organization created by trade associations and private energy producers (including Électricité de France) that commissioned Veolia, a multinational water management, waste management, and energy services provider, to create the first crystalline silicon PV panel recycling plant in the world. Veolia was selected based on four criteria: cost, technical quality, environmental impact, and social impact. The Veolia Rousset plant recycles 4,000 tons of PV equipment every year [79].

A gender-inclusive approach to the circular economy and RE means that women and men have the same access to political, economic, and social opportunities offered by the sector today and tomorrow.

PHILIPPINES: INFORMAL WOMEN WORKERS ORGANIZE AND LEARN TO SAFELY RECYCLE E-WASTE [80]

To help prevent pollution and to effectively and safely process non-recyclable hazardous substances, a United Nations Industrial Development Organization project provided a new facility and safety training for female and male recyclers. The existing municipal waste facility in Bagong Silang was upgraded into an e-waste treatment, storage, and disposal facility. Women and men working as e-waste collectors and dismantlers received education and training on safe processing practices. In addition, workers were supported to obtain required licenses and formalize their employment with the municipality, thereby enabling them to increase their income.

TABLE 3. Principles and good practices for a gender-inclusive circular economy

	DECISION MAKERS	BUSINESS OWNERS, ENTREPRENEURS, PROFESSIONALS	ENERGY USERS
Challenge	Women and gender considerations are mostly excluded from decision-making and policymaking in the energy, RE, and waste management and recycling sectors.	Women are underrepresented in the sectors operating EOU RE management, especially in the RE and waste management sectors.	Women and girls are more exposed to energy poverty than men in both the developed and the developing worlds. Women tend to be more sustainable consumers and more inclined to circularity than men.
Equal Access	…to decision-making opportunities for gender-responsive and inclusive energy, environmental, waste management, and recycling policies that create opportunities for women as business owners, entrepreneurs, and professionals and address girls' and women's specific needs as energy users.	…to business opportunities across local and global value chains through inclusive practices and procurement that give access to women-led organizations and create incentives for organizations committed to gender equality and inclusion. …to job opportunities, including STEM-related jobs, and leadership roles and the corresponding training and skills development opportunities.	…to affordable and clean energy through policies and business models that address energy poverty and leverage women's consumption behaviors and adherence to circularity.
Good Practices	Give priority to gender and inclusion sensitization for all stakeholders and leaders to make sure gender equality and inclusion are part of their agenda. Support gender-responsible decision- and policymaking based on sex-disaggregated data and data on girls' and women's needs. Ensure women are represented in all meetings with stakeholders. Engage women in stakeholder engagement activities through focus groups and women's organizations (including cooperatives and informal organizations).	Support trade associations and other organizations to design gender-responsive and inclusive business, supply chain, and procurement standards. Support trade associations and other organizations with initiatives to promote gender equality: mentorship programs, awards, etc. Support female entrepreneurship programs and access to investment and funding. Support gender and inclusion interventions within EOU RE management to increase the participation of women in the workforce, including STEM-related jobs, the participation of women in leadership teams, the prevention of gender-based violence and sexual harassment, and equal pay. Develop training and skills development programs to increase women's participation in STEM. Engage informal workers and ensure their access to business, jobs, and training opportunities, possibly with the intermediation of civil society organizations.	Assess circular business models' potential impact on energy tariffs and energy poverty. Engage female energy users in designing circular business models through focus groups and gender-responsive consumer surveys. Support gender-sensitive media campaigns to promote sustainable and ethical business practices and to encourage responsible consumer behavior.

CHAPTER 5

RECOMMENDATIONS FOR IMPLEMENTATION

Commercial, policy, and technology interventions are needed to transform the secondary market for RE technologies. To determine where to start, it is necessary to analyze strengths and weaknesses and assess the resources available for each intervention. This will vary by country.

5.1 Entry Points for Implementation

Many stakeholders are addressing the challenge of cultivating a circular economy in the RE sector. While circularity seems to be the most appropriate way forward, it is not a major consideration, let alone a priority for most countries outside of Europe, nor for private enterprises. Applying the circular economy framework to RE equipment EOU challenges is even more rare, incidental, and in its very early stages, often residing with one or a few passionate champions. Figure 10 is a high-level illustration of potential organizations, governments, or people that USAID can work with. The figure shows the three partially overlapping spheres: circular economy, RE, and waste and recycling. There is a nexus of promising stakeholders, including organizations that truly understand and use circular economy approaches. Next, there are three areas where two of the spheres overlap. Then there are the three spheres themselves, each of which may offer entry points for USAID. These categories and correlated organizations are included in Table 4, which can be used to evaluate whether USAID Missions have affinity with these entities and whether they are active in areas where USAID is also working.

FIGURE 10. Intersection of circular economy, RE sector, and waste sector stakeholders

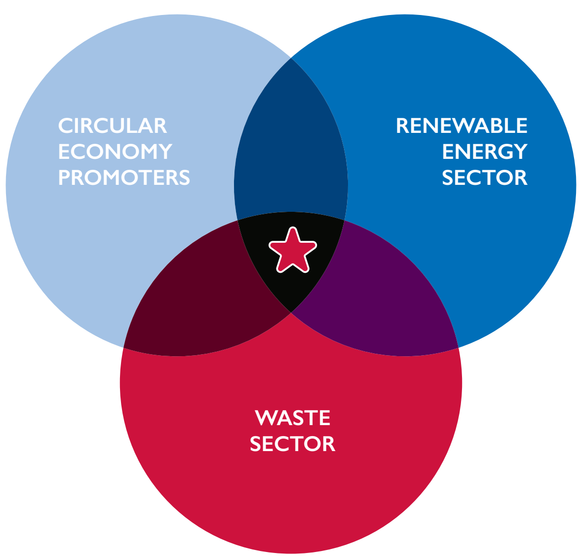


TABLE 4. Entities that can offer entry points for USAID's circular economy EOU RE work

CATEGORY	STAKEHOLDER OR COLLABORATOR	NOTES TO SUPPORT CHOICE OF STAKEHOLDER OR COLLABORATOR	RE SECTOR
Nexus (star)	IRENA	Stephanie Weckend is a champion of EOU RE and circular economy	All
	GOGLA	Has a circular economy EOU working group. Leading a project to pilot the first off-grid solar producer responsibility organization in Kenya, with the aim of building a scalable model.	Off-grid solar
	NREL	Broad range of activities in EOU RE and circular design; existing collaboration with multiple stakeholders	Solar, wind, batteries
	WindEurope	Great source for recycling and decommissioning information because it is subject to EU regulations	Wind and batteries
	European Commission	Battery directive; uses circular economy to address prevention of and recycling of battery waste	Batteries
	CLASP	Awards program and collaborator with USAID	Off-grid solar
	Electric Power Research Institute (EPRI)	EPRI Renewables and Battery End-of-Life Strategic Initiative produced a variety of knowledge products on EOU RE	All
	Platform for Accelerating the Circular Economy (PACE)	PACE is part of World Resource Institute's (WRI) Center for Sustainable Business	All
	Ellen MacArthur Foundation	Offers resources, videos, reports, roadmaps, and case studies on the circular economy.	All
RE and Waste	Redwood Materials, United States	Provides cost-sharing solutions to reduce transportation costs	Batteries (Li-ion)
	RE Associations	Members that are aware of looming EOU issues may also be collaborators	Any
	American Clean Power Association, United States	Recycling program	Wind
	Solar Energy Industries Association (SEIA), United States	SEIA National PV Recycling Program, collaboration with NREL on standardization	Solar
	First Solar, United States	Voluntary EPR, recycling of panels	Solar
	Global Electronic Council (formerly known as Green Electronic Council)	The Global Electronic Council's EPEAT ecolabel is the leading Type I ecolabel covering products and services from the technology sector. The EPEAT PV Modules and Inverters category addresses the full product life cycle, including managing substances in the product, manufacturing energy and water use, product packaging, EOU recycling, and corporate responsibility. EPEAT also requires manufacturers to commit to continuous improvement in environmental and social responsibility, including labor and human rights, across their operations and supply chain. This helps ensure that PV modules and inverters as well as their components are not produced using forced labor and that producers adhere to fair and safe labor practices. https://www.epeat.net/	All

CATEGORY	STAKEHOLDER OR COLLABORATOR	NOTES TO SUPPORT CHOICE OF STAKEHOLDER OR COLLABORATOR	RE SECTOR
Circular economy and waste	Waste collectors and recyclers	Businesses mandated by governments (e.g., in Europe or certain U.S. states) or by donors to embed circular practices	
	WEF	Is actively conversing about the circular economy	
Circular economy and RE	WEF	Produced report with Global Battery Alliance	Batteries
	IEA	PV Collaboration Program	Solar
Circular Economy	Colombia, Chile, Ecuador, WEF, European countries and institutes	Leaders in these companies that are already cultivating the circular economy may be open to EOU RE issues	All
	BNEF	Circular economy database	All
Waste Sector	General	Leading companies will see business opportunities to expand into RE waste and innovate accordingly	
	Nunam, India	Second-life batteries	Batteries
	Aceleron, UK	Second-life batteries	Batteries
	Rwanda	Enacting policies to address waste issues	
RE Sector	General	Various companies are likely to be aware of looming EOU waste issues	All

5.2 Cultivating a Learning and Enabling Environment

The following suggested interventions describe proposed concrete actions to manage EOU RE equipment using a circular economy lens. The interventions can be conducted as standalone tasks, yet they remain part of a systemic approach to create sustainable circular economy solutions.

RISK ASSESSMENT

Engage environmental and health experts to clearly define, specify, quantify, and locate hazardous and toxic materials related to EOU RE equipment. Compile data on EOU hazards, including material data safety sheets. Draft location and concentration maps. Differentiate between types of solar panels, ancillary equipment, and types of batteries.

MAP STAKEHOLDERS AND DEVELOP STAKEHOLDER STRATEGY

Facilitate identification of all stakeholders and create engagement processes, collaborating with appropriate government entities supported by external process managers. Strengthen grassroots circular economy actors by forming strong associations—e.g., waste collectors, micro-enterprises in repairs, informal sector engagement.

Although stakeholder mapping is a common exercise, EOU RE issues are complex, especially in a circular economy context. Waste management professionals are very different from energy stakeholders, so different strategies may be needed. Develop stakeholder engagement strategies for policy and commercial sectors, identifying negative and positive impacts that drive interest.

STANDARDIZATION

Facilitate voluntary efforts working with pertinent stakeholders (commercial sector) and the national standards office. Help develop a regulatory framework if the country prioritizes mandatory standards and help develop regional frameworks or guidance. Assess options based on international experience. (Several international organizations can offer support, and the EU is working on standardization already.) More specifically, we recommend to develop minimum circularity performance standards and a circularity label—with stars

or levels of circularity. It may be possible to partner with organizations that have developed or maintain existing eco labels and associated registries and build on these. For example, the Global Electronics Council has the EPEAT registry for sustainable electronics, including PV modules and inverters [81].

TRACKING SYSTEM

Pilot a project to develop a sharing platform for materials and components. Encourage governments to create databases with specifications available for components and systems used in deployed projects, including GHG accounting and verification systems.

COLLECTION AND TRANSPORTATION OF EOU RE COMPONENTS

Evaluate the logistics and cost of reaggregating the main materials, components, and products. Facilitate setup of a collection and transportation network. Assess commercial aspects of the secondary market; determine policy drivers (incentives, penalties) to promote commercial viability.

CONNECTING CIRCULAR ECONOMY TO SDGS

TRAINING. Develop educational and training resources to create awareness of the circular economy and how it can be connected to the SDGs. Help implement the transition from the current linear business model to sustainable circular business models. Build on the increasing worldwide awareness of the circular economy concept and connect it with the achievement of SDGs, to which many countries already subscribe.

GHG "CARBON" CALCULATOR—LINKING THE CIRCULAR ECONOMY TO SDG 13.
Engage local experts or consultants to develop GHG footprints using established protocols (e.g., Global Reporting Initiative or the World Business Council for Sustainable Development). Develop and disseminate a calculator or tool to capture GHG footprints. Map supply chains and processes, establish borders, and calculate footprints.

GENDER AND INCLUSION—LINKING THE CIRCULAR ECONOMY TO SDG 5.
Systematically use circular EOU RE management interventions as an opportunity to build gender equality and inclusion. Assess the opportunity to create equal access to decision-making and policymaking opportunities, business and job opportunities, and affordable clean energy for women and men.

5.3 Promoting Pilots and Private Sector Initiatives

TRIAGE EVALUATIONS

Resources are currently lacking due to a number of factors, especially inadequate compensation for the level of engineering expertise required as well as insufficient recognition of the risks to workers. USAID can help develop a framework for training and upskilling in triaging, leading to a classification of products and components for resell, repair, refurbishment, remanufacture, and recycling (see Figure 2 in section 1.1). This will add value to secondary markets. Harvesting deteriorated distributed PV modules and batteries and replacing them with new or refurbished ones would be an opportunity to include women entrepreneurs.

A system for reporting the causes of equipment breakdown could be established within the triage system. This would be a significant contribution to manufacturers' understanding of equipment failure and could spur improvements to both component life and recyclability.

ORGANIZE SECONDARY MARKETS

Pilot project support could help organize markets. Pilots need to be executed on a local scale and are therefore interesting for USAID to support. Examples include:

- Distance training of an initial cadre of individuals to perform triage of EOU RE components in selected countries. A key element is creating secondary use markets for utility PV modules and transport Li-ion batteries to extend useful life, thus reducing the need for new original equipment. Training may target different people for each technology, as their waste streams are not likely to converge.
- The cost of transport may be the largest single cost element of EOU management; therefore, introduce, develop, and test options to reduce transport costs (e.g., by introducing an easy-to-use logistics platform) in the context of EOU strategies.
- Mobile PV recycling could bring the processing plant to the modules, thus reducing transport costs. This could be done by truck in some cases, or by ship. The possibility needs to be investigated for wind blades and Li-ion batteries.
- In the short term, pilots are necessary to test the best ways to set up quality certification of batteries for energy access applications and supplier warranties, which will ensure greater confidence in performance and safety and alleviate concerns around waste shipments. Manufacturers and policymakers must work together to improve first-life design and battery traceability through onboard battery management systems and data transfer measures, which will help lower re-manufacturing costs. USAID may consider supporting such efforts [82].

RECYCLING CENTERS

USAID can help set up recycling centers and raise awareness of access to recycling centers (for PV and storage), transportation hubs, collection stations for owners, and penalties and incentives associated with compliance. Dedicated consumer education drives and product stewardship programs would be useful tools.

USAID can develop and roll out battery collection using take-back and incentive mechanisms at a regional level. For example, for storage, which often represents the most acute environmental hazards, USAID can help set up regional Circular Battery Centers that 1) conduct applied research on handling and processing of used Li-ion batteries; 2) implement environmentally sound solutions for collected batteries; 3) develop and pilot sustainable financing of battery collection and recycling; and 4) feed into policy development and locally adapted models of EPR. Such centers can fund and conduct pilots of second-life batteries in energy access applications, using both local supply of retired batteries and second-life modules manufactured in developed countries.

CHAPTER 6
TAKEAWAYS

For RE to be a truly clean power source, solar, wind, and battery equipment must be manufactured, deployed, and decommissioned in a responsible, safe, and sustainable way. A circular economy for RE equipment will result in a more resilient, lower-emission supply chain for materials while powering economies, creating further use, and redirecting waste away from landfills and back into the market. It has the potential to create meaningful jobs, uplift lives, empower women, strengthen communities, and ensure that communities and workers optimally benefit from the transition to a new clean energy economy. Key takeaways include:

1. This new paradigm will give rise to a secondary market for repair, refurbishment, and trading of used components and will create sustainable businesses and local jobs for men and women, opportunities desperately needed in economies affected by the global pandemic.

New business models focused on reusing, repairing, remanufacturing, and sharing offer significant innovation opportunities. New jobs will be created in fields such as recycling, services like repair and rental, and new enterprises that spring up to make innovative use of secondary materials.

2. Obsolete RE equipment is expected to grow exponentially over the next 30 years. Instead of damaged and decommissioned equipment piling up in landfills, the life of critical RE materials must be extended beyond their original intended use.

In a circular economy, parts and materials have multiple life cycles and re-entry points into the market as they are systematically recovered, repaired, reused, and remade. USAID has a unique and timely opportunity to help reshape the RE ecosystem to increase material sustainability and the stability of clean energy supply chains by leading the advancement of a circular economy approach.

3. Reshaping the RE industry into a more circular economy is a paradigm shift that has significant potential to reduce waste and carbon emissions while extending the supply of parts and materials, including critical metals.

A circular economy approach has the potential to reduce mining of critical RE materials, which produces contaminated waste and contributes to biodiversity loss and ecological degradation. At current rates of production, the annual need for critical metals could endanger the transition to a clean energy economy. For example, critical metals such as indium and silver are needed for solar panels and neodymium is used in magnets in both wind turbines and EVs. Furthermore, disruptive leadership toward more circularity combined with smart circular business models can also influence women's consumption behaviors and participation in a circular economy.

In partnership with governments, the private sector, civil society, academia, and communities, USAID can apply a multifaceted approach that cultivates a more circular, inclusive, and expansive RE ecosystem and distributes responsibility across the value chain, including waste management. To determine where to start, it is necessary to analyze strengths and weaknesses and assess the resources available for each intervention. This will vary from country to country.

USAID'S SURE PROGRAM SEEKS COLLABORATORS TO RESHAPE THE RE ECOSYSTEM.

If your Mission or organization is interested in partnering or co-investing with USAID, contact Program Manager Amanda Valenta or Sarah Lawson. Partner with SURE to promote a circular economy by cultivating new business models, innovations, initiatives, sustainable practices, policies, and markets. For more information, visit https://www.usaid.gov/energy/sure/circular-economy.

4. USAID can apply a systematic approach to cultivate an enabling environment for a circular economy by pursuing some or all of the following:

- Environmental and health risk assessment
- Stakeholder mapping and engagement
- Regulatory frameworks
- Monitoring and tracking system for materials and components
- EOU component collection and transportation services
- Training, resources, and tools
- RE greenhouse gas footprint calculator

5. USAID can lead enterprise-driven development by supporting pilot and private sector initiatives that will transform the secondary market for RE technologies. Possible interventions include:

- Developing a framework for training and upskilling in triaging, leading to a classification of products and components for resell, repair, refurbishment, remanufacture, and recycling (see Figure 2) ([51] and [83]). A system for reporting the causes of equipment breakdown within the triage system would support manufacturers' understanding of equipment failure and could spur improvements to component life and recyclability.
- Setting up recycling centers and raising awareness of access to recycling centers (for PV and storage), transportation hubs, collection stations for owners, and penalties and incentives associated with compliance. Consumer education drives and product stewardship programs would be useful.
- Providing venture and acceleration assistance for partners who demonstrate the greatest impact, helping them reach more end users and financial sustainability.
- Funding innovations, pilots, and feasibility studies that cultivate new sustainable practices, business models, and secondary markets for partners and materials. A tracking system for materials and new businesses and processes for component collection and transportation are also much needed.

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Annex 1 List of Interviewees

The following table lists the most relevant interviewees to this report. Some but not all are cited specifically in the paper.

TYPE	ORGANIZATION INTERVIEWED
International Organization	CLASP, Interview by authors with Monica Wambui. Video conference. Remote, February 2, 2021.
International organization	Africa Clean Energy Technical Assistance Facility. Interview by authors with Ewan Bloomfield. Video conference. Remote, February 10, 2021.
U.S. association	Energy Storage Association. Interview by authors with Mark Chupka. Video conference. Remote, February 11, 2021.
International organization	European Association for Storage of Energy. Interview by authors with Jacopo Tosoni. Video conference. Remote, February 10, 2021.
International organization	GOGLA. Interview by authors with Drew Corbyn. Video conference. Remote, February 17, 2021.
Industry	Li-Cycle (Canada)). Interview by authors with Kunal Phalpher. Video conference. Remote, February 23, 2021.
U.S. association	Solar Energy Industries Association (SEIA). Interview by authors with Evelyn Butler. Video conference. Remote, February 17, 2021.
U.S. association	American Clean Power Association. Interview by authors with Michele Myers Mihelic. Video conference. Remote, February 19, 2021.
Industry	Recycle PV Solar. Interview by authors with Sam Vanderhoof and Otto Gunderson. Video conference. Remote, March 11, 2021.
International organization	ESMAP via the World Bank. Interview by authors with Charles Alexander Miller and Johanna Christine Galan. Video conference. Remote, February 23, 2021.
Government agency	Minnesota Pollution Control Agency (MPCA). 2021. Interview by authors with Amanda Cotton and John Gilkeson. Video conference. Remote, March 1, 2021.
Private sector	Andrew Stevenson (former Chief Financial Officer of Redwood Materials). 2021. Interview by authors. Remote. March 29, 2021.
International organization	International Renewable Energy Agency (IRENA). 2021. Interview by authors with Stephanie Weckend. Video conference. Remote, April 13, 2021.

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CLEAN ENERGY AND THE CIRCULAR ECONOMY: OPPORTUNITIES FOR INCREASING THE SUSTAINABILITY OF RENEWABLE ENERGY VALUE CHAINS

SCALING UP RENEWABLE ENERGY (SURE)