GOGLA

The Voice of the Off-Grid Solar Energy Industry

E-waste Toolkit Module 1 Briefing Note

Technical introduction to recycling of off-grid solar products

Executive summary

This Briefing Note gives a high-level technical understanding of how off-grid solar products are recycled, how to store, handle and transport waste, and how to identify recycling partners. It is part of the first Module of the GOGLA e-waste Toolkit.

Off-grid solar products are delivering huge social impact to customers, mitigating greenhouse gas emissions from traditional polluting lighting sources, and supporting economic development in low-income countries. However, there are environmental and health and safety concerns to manage when products reach the end-of-life.

The overall hazard of a waste off-grid solar product is minimal, the principal hazard being the battery; the other components – PV panel, control unit, cables and lights - are typically quite benign. Off-grid solar product waste is complex given the number of components and variety of constituent fractions, each requiring individual consideration.

This Briefing Note also provides a description of good practice on storage, handling and transport to manage the health and safety and environmental risks, including mitigating the toxic risks of lead-acid batteries and dangers of lithium-based batteries. When handled correctly, they are relatively straightforward to recycle and do not represent a significant risk to the consumer.

In more developed markets there are e-waste management companies and recyclers that accept the other components and their fractions – plastics, glass, aluminium, copper, PCBs, etc. However, the absence of service providers in many countries represents a major obstacle for improved recycling. For example, there is no PV panel recycler in Africa that can salvage materials beyond the aluminium frame; rudimentary dismantling renders any further separations of components not possible. This Briefing Note includes a typology of waste management companies and gives guidance on how to select a service provider.

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[1] Beyond Connections: Energy Access Redefined, SEforAll and World Bank ESMAP, 2015

Introduction

The GOGLA e-waste Toolkit aims to identify and share good practice on off-grid solar e-waste management for GOGLA members and the broader industry. The Toolkit will consist of six modules focused on different themes, including design, recycling, business models and policy. Each module contains a Briefing Note, seminar and list of key resources that are hosted on the e-waste Hub. A catalogue of service providers has also been produced with a list of e-waste management companies and recyclers serving the sector.

The aim of this Briefing Note is to give a high-level technical understanding of how off-grid solar products are recycled, how to store, handle and transport waste, and how to identify recycling partners. The target audience is staff in off-grid solar companies, namely: operations, logistics, strategy / management, product designers.

There are a variety of "business models" for managing waste - the off-grid solar company may take charge of dismantling, storage and transportation, or work with an e-waste management company or other agency for this. This Briefing Note follows the waste journey; products to components and fractions, and onward recycling. It details the key insights to the process, hazards and good practices to help companies with their own operations or to identify service providers. The product scope covers solar lanterns, SHS kits and component-based systems, and both lithium-based and lead-acid batteries.

From components to fractions

The journey of an off-grid solar product to customers is relatively linear, as with most consumer products. However, when an off-grid solar product reaches the end-of-life, it enters a complex chain of movements and processes. The ultimate goal would be for products to be fully reused and recycled with zero landfill.

The main components of an off-grid solar product include:

- Solar panels
- Batteries – Lithium-based or Lead acid
- Lamps (mainly LED)
- Control units with circuit-board-mounted electronic controls
- Cables
- Metal frames and fixtures
- Appliances (TVs, radios, fans, etc)

While a solar home system starts life as a complete unit, it is common that the individual components enter the waste stream at different times, e.g. a lamp or appliance may fail first, while the core system still functions. This has impacts for how companies plan their operations; from a waste perspective one system is not one system.

E-waste management companies and recyclers refer to and manage their product by fractions. When e-waste is collected, it is weighed, dismantled and then segregated by fraction. The segregation can vary slightly based upon which fractions that e-waste management company handles, for example, it may involve segregating PCBs between low, medium and high-quality boards (as classified by final recyclers).

Fraction (of waste)
The grouping of waste according to its properties. Each waste group or classification is called a fraction. E.g. plastics, paper and cardboard, cables.

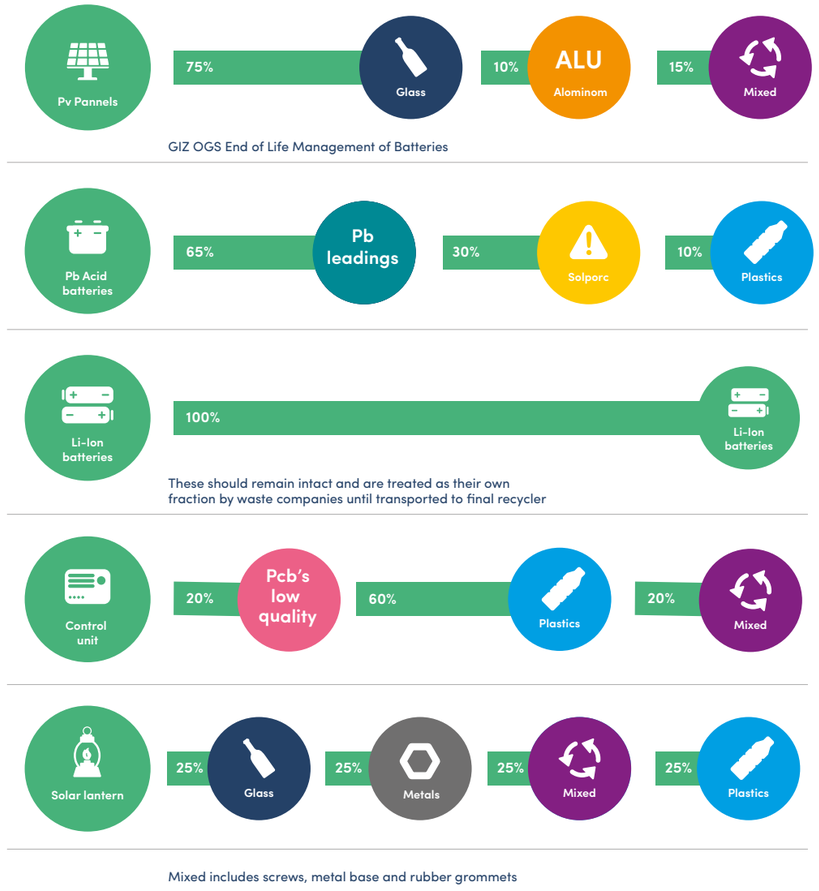
SHS kits and component-based systems are modular and therefore easy to separate components, though manual dismantling is still required for the segregation of the fractions. Solar lanterns are integrated devices and must be dismantled to segregate fractions.

Dismantling is the mechanical dis-assembly of products. Good practice entails personal workstations for workers, equipped with an array of tools and an exhaust hood for any dust or gases. Good practice also means that products should be dismantled carefully, avoiding where possible the use of hammers. The use of adhesives in many products (such as printers and some solar products) does require more brute force.

In larger scale e-waste management plants, sometimes all waste is crushed into small chips and the fractions are separated through automated mechanical and chemical processes. It is highly uncommon to see this in less developed countries.

Enviroserve Rwanda, Dismantling Stations at their facility

Treatment/Dismantling
Treatment is the general processing of e-waste and can include dismantling, segregation, washing, compressing (of metals) or compressing fractions (such as paper, plastic, metal) into bales for transport.
Dismantling is the mechanical process of separating various parts of e-waste into different fractions. This uses only basic tools and manpower, not machines or chemical processes.



GIZ OGS End of Life Management of Batteries

These should remain intact and are treated as their own fraction by waste companies until transported to final recycler

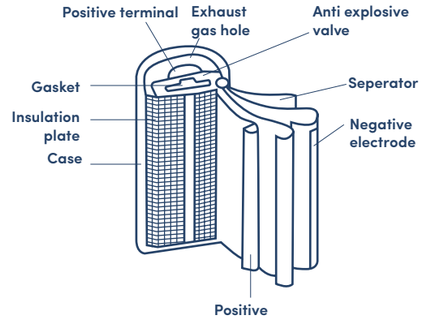
Mixed includes screws, metal base and rubber grommets

More information on the details of recycling off-grid solar components can be found here.

- Cost Benefit Analysis and Capacity Assessment for the management of Electronic waste (E-Waste) in the off-grid renewable energy sector in Kenya by Evidence on Demand and Sofies
- https://shellfoundation.org/learning/energy-storage-off-grid-trends-in-emerging-markets/

Lithium based batteries as a fraction

Lithium-based batteries have a complex anatomy that requires mechanical shredding to recycle. They are therefore considered their own fraction and should be stored safely and not opened or damaged. Only a few recycling facilities exist (in Europe and USA) that can handle the complex composition of lithium-based batteries.



Panasonic 2007

A note on Plastics

Plastics are mostly incompatible with each other due to their different melting points. It is generally not possible to recycle different types of plastic together due to their different melting points. Therefore, being able to effectively sort and differentiate between different plastic types is essential for recyclability. When considering product design and manufacture, it is recommended to not mix plastic types and to clearly label all plastics to help dismantlers identify and recycle accordingly.

Hazardous plastics refer to plastics that have hazardous additives such as BFR's (Brominated flame retardants). Although not common in off-grid solar products, these plastics should be avoided as they represent a health and environmental hazard.

General classification of plastics

Polyethylene Terephthalate	High-Density Polyethylene	Polyvinyl Chloride	Low-Density Polyethylene	Polypropylene	Polystyrene or Styrofoam*	polycarbonate, polylactide, acrylic, fiberglass, and nylon**

* Includes HIPS (High Impact polystyrene)
** Includes ABS (Acrylonitrile Butadiene Styrene) And PC (polycarbonate)

Most common plastics founds in off-grid solar products:

	ABS (Acrylonitrile Butadiene Styrene)	HIPS ((High Impact polystyrene)	PP	PC	PVC
Function	Control unit / Housing	Control unit / Housing and packaging	Control unit / Housing	Control unit / Housing incl. lighting	Cable coating
Properties	- Thermoplastic - a shiny, impervious surface - Strong and hard	- A form of polystyrene that has high impact strength - Easy to print	- Resistant to fatigue - Non toxic - Lightweight	- Thermoplastic - Naturally transparent - The highest impact strength	- Thermoplastic - Cheap to manufacture - water, and fire resistant, and to chemical degradation. - can be very flexible
Technically recyclable	Yes, however it needs specific facilities. Generally, ABS is chipped and exported from East and West African markets to Asia for recycling	Yes, however Not recyclable at all facilities	Yes, The highest demand for PP is in China, which means most PP chips are shipped to china for recycling.	Yes	No. Due to the additives normally added to PVC, less than 0.5% of PVC is recycled. The manufacturing and recycling process releases dioxins (carcinogen) into the ground, water, and air.

Thermoplastic
Thermoplastic materials become soft when heated and hard when cooled, and have the ability to undergo this process many times without changing their chemical or material properties. This means that they can be recycled easily.

Commonly used in electrical devices as they protect against electrostatic discharge.

Thermoset
Thermoset materials are polymers that irreversibly cure. This means that once they are moulded into their final form, they cannot be reheated and melted back to a liquid form. This means they are difficult (and often not) to recycle.

Thermoset materials are stronger than thermoplastics and better suited to high-temperature applications, but tend ot be more brittle.

Commonly used in PCBs.

Environmental and safety hazards of each Fraction

This section presents the inherent hazards of each waste fraction according to the level of risk. Best practices for handling, storage and transport to mitigate these risks derived are presented in the following section.

What is the difference between hazardous and toxic?
The hazardous or toxic properties of substances within fractions or derived from their recycling process can affect 1) how they ought to be handled and 2) how they are classified by policies and regulation.

Hazardous
A substance that is potentially harmful (e.g. battery liquid is acid and always harmful to people, animals and the environment)

Toxic
A specific property of a substance that makes it poisonous (the corrosive properties of sulphuric acid) – a toxic substance is always hazardous.

E- Parisaraa Private Limited. Dismantling of solar lights

High Risks

Pb [Lead] batteries

Lead Acid batteries are hazardous because of their two primary components: Lead and Battery Acid. Most solar batteries are gel or maintenance free type PbLead batteries. If undamaged, these should be transported whole to the recycler.

- **Lead:** becomes dangerous if it is disturbed, such as when the case is opened (creating Lead dust) as part of the dismantling process by battery recyclers or when the internal lead plates are melted (creating fumes). Lead is a heavy metal that is easily absorbed by organic organisms (humans and plants), builds up in organic systems and takes many years to remove. Among other effects, in pregnant women it can cause miscarriages and foetal defects, in children it blocks normal neurological development and in adults can lead cognitive function deterioration, brain damage and cancer.
- **Battery acid:** its main component, sulfuric acid, is poisonous to ecosystems, can pollute ground water when dumped and can cause injury and illness to humans. In addition, it contains lead particles which also contaminate any environment where they are dumped and extremely difficult to clean up.

Lithium-based batteries

Lithium batteries come in many different chemistries, the most commonly used for off-grid solar products are LFP (Lithium-iron-phosphate) or LMO (Lithium-manganese-oxide). When in storage, they present a risk of fire – they are a significant and common factor in warehouse fires due to uncontrolled thermal runaways (sometimes referred to as short-circuiting). Although LFP and LMO batteries have a lower fire risk than other compositions, companies should still make sure to discharge them fully and store them properly.

Flat Panel Displays (FPDs)

The most hazardous fraction of FPDs is the backlight tubes, which contain highly toxic mercury. After the backlight tubes are removed from the TVs they must be stored in closed containers to prevent emissions.

Many of the TVs used with off-grid solar products, however, are a newer version that use LED backlighting which does not contain mercury.

Medium Risk

Mixed components

E-waste includes a lot of small or miscellaneous components, for example small rubber seals from solar lanterns to screws, stickers and labels. Due to their small size, and often unclear material composition, mixed components (i.e. what is left after dismantling) are often landfilled. They can be hazardous if the quality of segregation and dismantling is low, leading to fractions containing mercury and other components being included. If the dismantler has a high quality of operations, then these mixed components are few and low risk.

PV Panels: Aluminium and Glass

The main source of aluminium from solar products comes from the frames of PV panels. In non-established markets, these are often stripped and handled separately – this should generally be avoided.

Low Risk

Plastic

General e-waste plastic can be hazardous as it often contains brominated flame retardants (BFRs) and heavy metals such as lead and cadmium (often in PVC). These additives can be extremely hazardous in ingested and should not be recycled but safely disposed of in a lined and managed landfill. However, off-grid solar products, generally do not contain BFRs and can thus, once fully dismantled, be chipped and sent to plastic manufactures. The risk with off-grid solar products is the lack of technical capability to recycle the plastics used and thus the plastic gets disposed of rather than recycled. For example, there are limited ABS plastic recyclers in East Africa and the majority of it is disposed in unmanaged and unlined landfills.

Printed Circuit Boards (PCBs)

PCBs should only be processed by a reputable recycler. PCBs come in various grades, although the majority of solar are "low quality". They are classified by the recycler according to the amount and types of metals present. If stored and transported to a recycler, PCBs are low risk.

Informal recycling normally consists of burning or use of acids to strip the gold from the board. This comes with extremely high hazardous to the environment and workers and should be avoided.

Cables

Off-grid solar cables mostly consist of copper surrounded by PVC. As long as open burning and incineration are not used to strip the copper of the PVC, cables do not contain many hazards. If burnt, the PVC releases dioxins (one of the most potent carcinogen) into the atmosphere.

Phenix Recycling, example of chipped plastics

Incineration is the process by which waste materials are burned or gasified. Depending on the product, this process may or may not generate fuel or energy. The original product, fraction or component is destroyed during this process as the high temperatures break down material at the molecular level. Incineration should be a controlled process with dust, effluent and fumes captured and processed to avoid safety and environmental impacts.

Open burning however is an uncontrolled process that has severe impacts on the workers and the environment and should be avoided at all times.

E-Waste stories

Mobisol is a vertically-integrated Solar Home System provider; it manufactures, distributes and services large home and commercial solar systems, integrated with proprietary PAYG software. In seven years, they have grown to a team of over a thousand, with the majority of their customers in three countries – Tanzania, Kenya and Rwanda. Their commitment to e-waste management is rooted in the values of their founding members and their code of ethics: Mobisol considers protecting the environment and people's health part of their vision. Which is why an efficient, environmentally responsible use of resources can be translated to their day-to-day operations.

Mobisol has a close relationship with its customers thanks to the PAYGo contract and remote control and monitoring functionality. They know the exact location of the customer and system and the performance of the system – a huge strength for preventative maintenance, replacement of parts (such as battery) and collection at end-of-life.

Starting with a high-level e-waste management policy, Mobisol began a scoping phase to identify recyclers in every country where they were operational. In 2018, they announced in a press release three recycling partnerships: Phenix Recycling (Tanzania, subsequently ceased operations), Enviroserve (Rwanda), and Associated Battery Manufacturers (ABM, Kenya).

By working together with experts in the field, Mobisol has been able to set up recycling networks for off-grid solar components recycling (waste from solar products, consumer electronics, and lead-based batteries). PCBs, plastic cases and DC appliances, for example, can be recycled locally by partners with good quality operations. The quality of Mobisol's operations is further highlighted by ISO 9001 and ISO 14001 certifications in Germany and Tanzania. Other country operations (Kenya and Rwanda) are following the same quality and environmental principles.

For lead-acid batteries however, in one of the countries of operation it has proven impossible to find a recycling partner that complies with the desired health, safety and environmental standards, despite a number of recyclers being issued a licensed to operate from the regulator. This challenge is compounded by a law that restricts the transboundary movements of batteries to a neighbouring country that hosts a trusted recycler. In this case, Mobisol stores the batteries safely until a sound recycler can be found in country, or the batteries can be transported to a recycler elsewhere. To address these challenges, Mobisol underwent a battery recycling workshop together with ABM and received training from the International Lead Association (ILA) on their benchmarking tool. Mobisol uses their knowledge of the benchmarking tool to keep working with local recyclers toward improved operations and lower environmental impact.

Storage and handling of components

While handling e-waste, health and safety and environmental considerations are relevant for both regulatory and operational reasons. Although there are some general principles to be upheld when handling and storing e-waste, risks derived from fraction handling (not inherent hazards of fractions) can be mitigated by following good practices and a focus on quality operations. For example, while Pb [Lead] acid batteries should be transported whole, plastics should often be chipped and sent to plastic manufactures. This section will dive into how handling needs differ for each fraction, as well as provide practical information for storage and transportation.

Staff safety – equipment and training

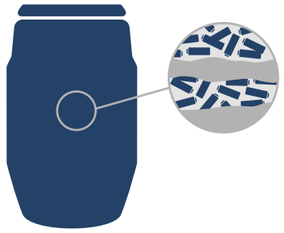
Staff health and safety is paramount; staff should be properly trained and use the correct personal protective equipment (PPE). The appropriate PPE depends on the components or fractions being handled by the facility and staff as well as the machinery used.

Common PPE to be used across most facilities include:

- Chemical resistant and sturdy gloves to protect hands from cuts, harmful dusts and chemicals.
- Safety glasses to prevent dust and debris from entering the eyes during dismantling.
- Coveralls to protect against dust. These should be removed after exiting the facility to avoid transferring dust and chemicals to other areas.
- Work boots to protect against heavy objects falling and sharp punctures from dismantled sections.
- In some cases, a respirator and personal workspace ventilation systems when handling fractions that contain hazardous dust.

Lithium Batteries

It is crucial that lithium batteries are either stored in their original product (i.e. not removed) or in a plastic drum between layers of sand (see below). E-waste management companies sometimes provide plastic bins for the storage in an exchange program (i.e. they loan you six, and, upon collection, replace with another set).



Plastic drum

The main risk of lithium-based batteries at end-of-life is fire. Lithium-Iron-Phosphate batteries (most common in off-grid solar) are the lowest risk in terms of **fire** but should still be treated with care. Fires from lithium batteries are due to uncontrolled "thermal runaways", which are caused by either deep discharging, short circuiting or overcharging. Therefore, lithium batteries should be fully discharged prior to storage. Other key storage protocols include:

- Avoid any damage to the cells, do not try to dismantle battery packs.
- Cover the poles of the batteries with insulated tape.
- Storage area should be sheltered from heat and rain.
- Lithium batteries should always be stored in a separate area of the warehouse, to mitigate the risk of fire spreading in the event of an incident.
- Batteries should be discharged, then stored in plastic containers covered with sand. The sand will absorb any thermal runaway, and create a glass around the battery, stopping the spread of any fire.

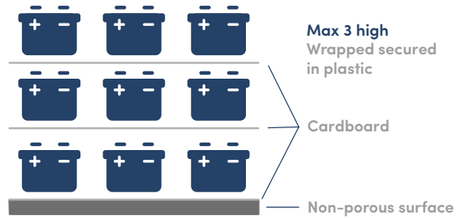
Wear personal protective equipment

Avoid damages to batteries

Change clothes after work

Maintain high personal hygiene standards

Example of poor storage. Phenix Recycling



Lithium-Iron-Phosphate batteries are less prone to thermal runaways (short circuit) than other lithium-based batteries, but they should still be stored within layers of sand and with their terminals taped and covered.

And example of good storage. E- Parisaraa Private Limited

Transportation of Lithium batteries

Similar protection measures should be adhered to when transporting lithium batteries to protect against fire risks during transport . Prior to long-distance or extended transport (such as in the case of transboundary movements), it is recommended to have stored the batteries for a long time, thus making use of lithium batteries self-discharging properties and helping to ensure that the batteries are fully discharged

Lead Acid Batteries (PbAcid)

Lead-acid batteries are hazardous because of their two primary components: Lead and Battery Acid. Most solar batteries are gel or maintenance-free type PbLead batteries. If undamaged, these should be transported whole to the recycler.

Lead-acid batteries should be kept out of direct sunlight. Wet batteries (those that require an addition of distilled water in their lifetime) should be drained, and the acid stored in secure bins. Sealed batteries should not be opened and kept on a non-permeable surface.

Lead-acid Batteries should be stored and transported on pallets (see image below). Similar sized batteries are placed next to each other. Every layer of batteries includes a layer of thick cardboard in between to absorb any leakage of battery acid. The batteries are stacked no further than 3 layers high.

Lead acid Batteries should be stored and transported on pallets (see image below). Similar sized batteries are placed next to each other. Every layer of batteries includes a layer of thick cardboard in between to absorb any leakage of battery acid. The batteries are stacked no further than 3 layers high. Once stacked, the pallets are wrapped and sealed with plastic wrap according to shipping requirements (criss-crossing the plastic for stability of the load) to be ready for transport. After arrangement in this manner, pallets can be stacked maximum 2 high.

Phenix Recyling

For more information on handling, storage and the hazards of batteries, please see below:

- GIZ/Sofies: Guide to battery recycling for off-grid solar, https://www.giz.de/de/downloads/giz2018-en-waste-solar-guide.pdf
- Guidance poster on ULAB storage by Oko-institute http://www.econet.international/fileadmin/user_upload/poster_lab_en_A3-A4.jpg
- Lighting Global Eco Notes on Batteries, https://www.lightingglobal.org/resource/eco-design-note-1-battery-toxicity-and-eco-product-design/
- https://batterycouncil.org/page/Battery_Recycling
- http://www.econet.international/index.php?id=10
- The Lead Recycling Africa Project by Econet http://econet.international/index.php?id=3

Storage and handling of other components

In the case of off-grid solar, it is common for e-waste management companies to carry out large collections from logistics hubs a few times a year. This means that companies are required to store their e-waste until it is collected.

In general, the following principles should be upheld when storing items:

- Products should be stored in segregated components (cables, pv panels etc). This assists in tracking how much your e-waste is worth.
- All containers should be clearly labelled and tracked. Refer to local regulation for specific requirements in storing e-waste.

Mobisol, labelled and stored e-waste, separated by component

E- Parisaraa Private Limited. Dismantling of solar lights

Transport

In general, e-waste management companies will undertake all transport of the e-waste, collecting from off-grid solar logistics hubs. However, it is important to understand the hazards and best practice of transport as part of assessing waste management partners.

Domestic Transportation

Good practice for transferring of e-waste is the same as it would be for other hazardous waste; it should be transported in a sealed truck (to contain any leaks), dedicated solely to the transport of hazardous waste. The truck should also be labelled with appropriate signage and have a permit for the transport of hazardous waste. Drivers and other staff accompanying the waste should have appropriate safety gear.

Local regulations often contain specific requirements or outlined responsibilities that companies should be aware of. For example, in Tanzania, provision 135 (3) indicates that the e-waste producer is liable for any damage to human health, living beings and the environment. For this reason, it is important to understand the transportation means and methods of your waste management partner.

Transboundary Movement

When waste crosses international boundaries, it is referred to as Transboundary Movement. It differs from domestic or national transportation and is therefore governed by international conventions (Stockholm, Rotterdam, Basel), along with local regulations. Compliance requirements can include, among others, requirements for specific vehicles and permits like the ones needed for domestic transportation.

When dealing with transboundary movements are, companies should bear the following in mind:

- Components and fractions should be segregated and stored appropriately
- Only verified and licensed transportation methods should be used.
- Transboundary processes and notifications documents should be complied with at all stages.

If e-waste is shipped without adhering to regulations and policies such as the Basel convention, it is possible that the shipment could either be stranded in the destination port or returned to the departure port for re-processing. In these situations, the waste can sometimes be dumped or incinerated causing unknown environmental damage and financial penalties.

Example of domestic transportation requirements:
National Environmental Management Act No. 20, 2004, Tanzania

135.-	1. The Minister shall ensure that, any movement of hazardous waste within and through Tanzania shall be conducted in a manner that prevents or minimizes adverse effects to human health and the environment and shall conform to movement procedures as may be prescribed in the Regulations. 2. Any generator of hazardous waste shall take measures to minimize the generation of such waste. 3. Any generator of hazardous waste shall be responsible for its disposal and shall be liable for any damage to human health, living beings and the environment.	Movement of hazardous waste
136.-	1. Subject to the provisions of subsection (2), disposal of any hazardous waste shall be done in an environmentally sound manner. 2. Environmental Impact Assessment shall be carried out before hazardous waste is disposed of into soil, land, air, or body of water.	Environmental Impact assessment for hazardous waste

E-Waste stories

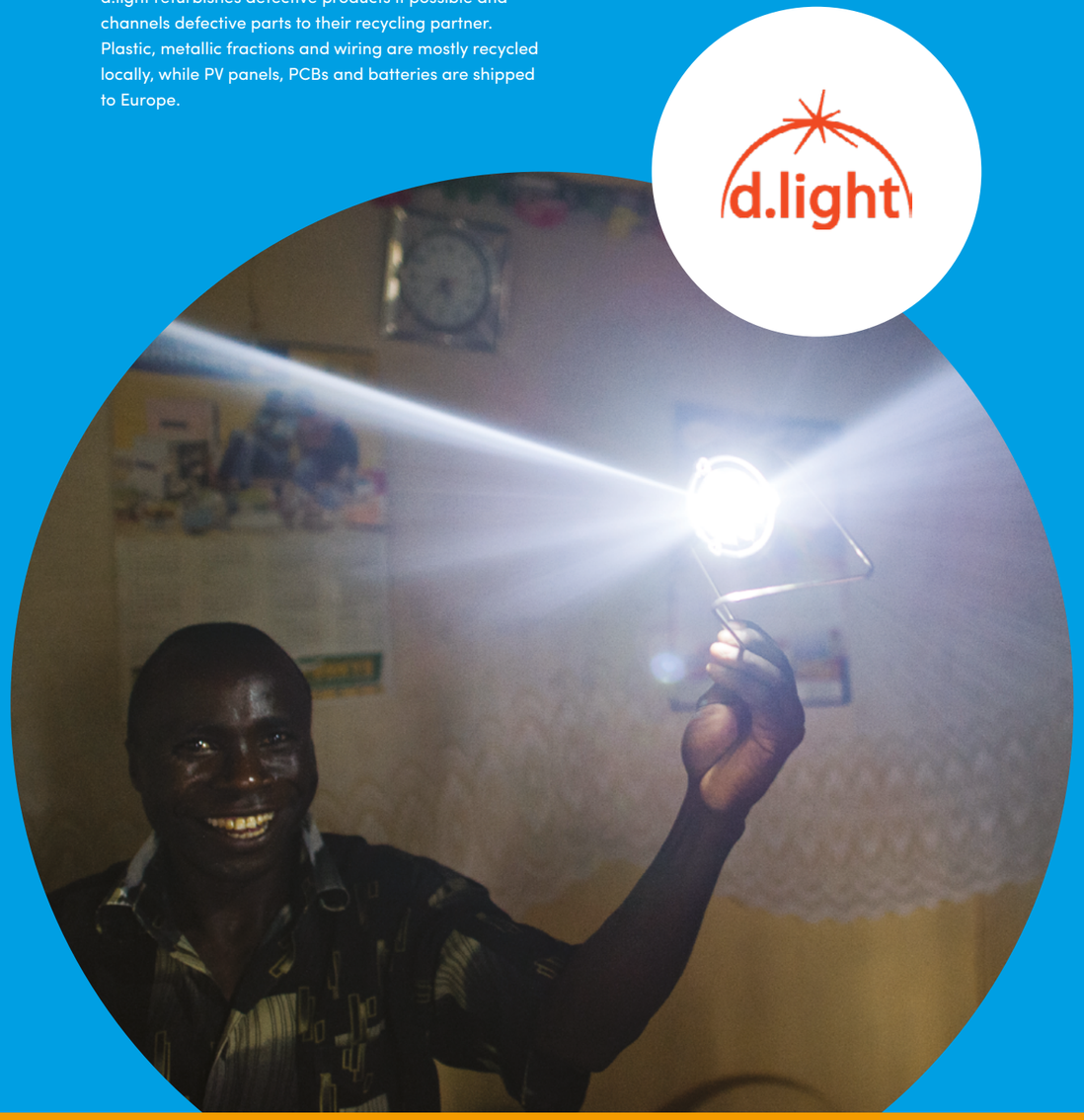
Through four hubs in Africa, China, South Asia and the United States, d.light has sold over 20 million solar light and power products in 65 countries, enabling over 90 million people to have access to clean, safe and reliable energy. A set of well-established policies guide their e-waste strategy and they have various partnerships to assist with e-waste management.

d.light offers a warranty on all products; if a customer has a defective product it can be returned to the point of sale, where an assessment is made, and a replacement offered - the product can then be repaired or sent further down the recycling chain if repair is not an option. The products are then dismantled, and their components inspected to find the root cause of failure.

d.light refurbishes defective products if possible and channels defective parts to their recycling partner. Plastic, metallic fractions and wiring are mostly recycled locally, while PV panels, PCBs and batteries are shipped to Europe.

There is a strong take-back mechanism through the warranty claim process, though this represents a small proportion of total products sold. Customers clearly have a less strong incentive to bring back products outside of warranty claims which represents a major barrier.

d.light operates to the standards defined in its own e-waste policy in all countries of operation (and advises distribution partners to do the same), even though regulation in all countries is not yet established. This includes selecting recycling partners that meet required health and safety and environmental standards.



How and where are fractions recycled?

Glass

Local glass manufacturers or lead smelters Depending on the source of glass (if it is from PV panels or LED screens) then it is either crushed and sold to local glass manufacturers or given to cement and lead smelters.

Mixed

Local Landfills Depending upon the quality of dismantling and segregation, sometimes further fractions (such as capacitors) can be extracted from the Mixed waste. Unless otherwise segregated, mixed waste is sent to landfill.

For further information about specific e-waste management companies and recyclers serving the sector, see the Catalogue of Service Providers on the GOGLA e-waste Hub.

Pb leadings

Kenya, India, China or other transfer internationally After smelting the lead plates of batteries, lead ingots are created and then sold to lead battery manufacturers. Often, this means a shipment internationally. Check with your local lead battery recycler to see where their lead ingots are sold to.

Solporc

Processed at lead smelters Sulfuric Acid should be collected and neutralised in the process of breaking open lead acid batteries.

Plastics

Non-hazardous recyclable plastics These plastics are sorted by colour, chipped and sold to local plastic manufacturers. The plastic chips may be shipped internationally for recycling.
Non-hazardous, non-recyclable plastics These are landfilled locally or sometimes upcycled. Small outfits are attempting to re-use these plastics The quality, effects and side products of this process are currently unknown.
Hazardous plastics (not common in off-grid solar) Hazardous plastics contain additives such as flame retardants (BFRs) and should thus be incinerated at suitable facilities.

Li-Ion batteries

Belgium, Germany, USA All lithium batteries should be transferred to one of five recyclers (see Catalogue of Service Providers), or otherwise disposed in a managed landfill. Lithium-based batteries have a complex anatomy that requires mechanical shredding to recycle. The primary financial driver of recycling is cobalt. The price of most metals when new is cheaper than from secondary sources, which does not incentivise recycling.

Pcb's low quality

Europe and Middle East PCB recyclers are sparsely located around the world due to the large cost and complexity of recycling PCBs. Recyclers classify them into various quality levels; off-grid solar products contain mostly (>90%) "low quality" PCBs, indicating that they have much fewer precious metals such as gold and silver than "high quality" PCBs, such as laptop motherboards. All qualities of PCBs should be segregated from other components, the capacitors manually removed and then transported in-tact to recyclers internationally (most in Europe or Middle East).

Metals

Copper (from cables) – Local recycling Copper is very valuable and easy to recycle. Copper cables are stripped of PVC and the copper is sold to local cable manufactures for use in manufacture of new cables.
Aluminium (from PV Panels) - Local manufacturing Aluminium is expensive to buy new, so local markets for recycled aluminium are common. Most of the time, e-waste distributors will sell their aluminium to metal scrapers who bale it and ship it internationally.

Pv Pannels

Rudimentary recycling – Local manufacture Advanced recycling – Europe The most difficult fraction to recover of PV panels are the crystalline silicon wafers. Therefore, smaller scale and regional waste management companies often treat PV panels like glass. The recycling process starts with the removal of the aluminium frame. When done manually, this often shatters the glass and renders any further separations of components not possible. If the aluminium frame is dismantled properly, then a further mechanical separation of the glass from silicon wafer and back foils can be done. When not separated appropriately, the broken glass panels have small traces of silver and other materials; these are often passed to local cement industries. For full and complete recycling of panels, they require shipping to facilities located internationally.

How to choose an e-waste management provider

In general, there is no "best practice" or "one-size-fits-all" approach to handling your company's e-waste. The choice of which and how many partners to use depends on availability of service providers, which components/ fractions to recycle, operational and financial requirements, and environmental and safety standards.

For off-grid-solar companies, it is common to only deal with one e-waste management company that plays the role of collector, dismantler and transporter, and selects the recycler/s and manages this relationship. An exception to this is from companies with lead-acid batteries where it is advisable to deal with the recycler directly for this component - this is advantageous from a financial and logistical perspective as well as ensuring the environmental, health and safety standards of the recycler.

Recycling entails material conversion; it is the process of recovering material from waste and turning it into new products. The original product is destroyed in this process, usually through a melting process, but it used to form new products. **Recyclers** are therefore businesses or operations that use thermal and mechanical processes to convert the fraction into a raw material for re-use, such as smelting lead into ingots, or chipping plastic for use in new manufacturing.

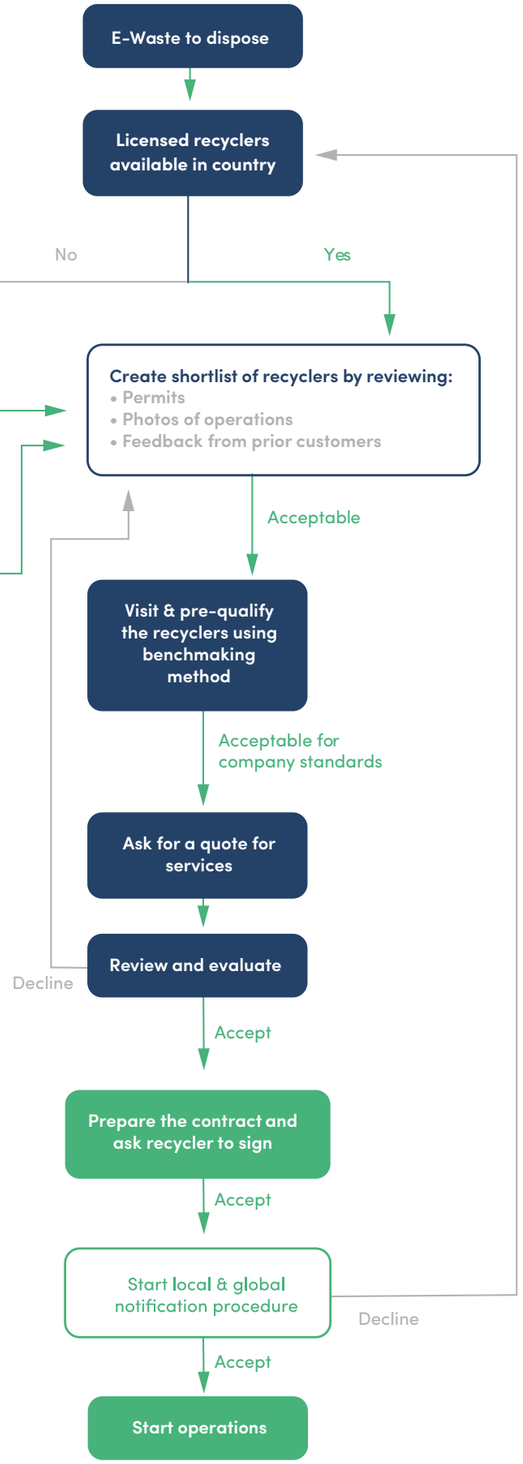
Typology of waste management companies

	Collector	Dismantler	E-Waste Management	Recycler
Brief description	This might be a small shop or freelance street collector who scavenges or purchases small amounts of e-waste from households and small repair shops. The collector transports it to an e-waste management facility to sell.	Dismantlers are often embedded within e-waste management companies. This operation involves workers who mechanically dismantle collected e-waste components into fractions using simple machines. Smaller scale waste management companies who do not shred and separate fractions chemically.	This company provides a full-package service including collection, dismantling and other support.	Otherwise referred to as end-processor, this operation will use mechanical, chemical and thermal processes to reduce fractions into raw materials to be used in manufacturing of new products.
Fractions handled	Only valuable fractions such as mobile phones, laptops and lead acid batteries. Would not collect lithium batteries, Flat Panel Displays or other items that do not have inherent value.	All fractions including lightbulbs, CRT monitors, solar control units, PV panels.		
Location	Local	Regional	Regional and International	Regional and International, depending upon fractions
Pros and Cons	Often informal, and unlicensed, their sole driver for business is financial. For some components (not solar) this can be a good way to collect portions of product. Collectors normally only collect solar if they deem it repairable.	Dismantlers have a fixed and often central location that is easy to visit and assess the standards of their operations. In addition, most dismantlers also handle the collection from your logistics hub, making them the first choice for off-grid solar companies.	Waste management companies do not always directly handle, transport or dismantle e-waste, but rather use a network of service providers to deliver a one-stop-shop. When handling multiple markets, it can be convenient to work with one waste management company rather than lots of dismantlers. Transparency into operations, however, can be much more difficult than when working directly with dismantlers and transporters.	Recyclers specialise in certain fractions and thus it is uncommon to deal directly with them as an off-grid solar distributor (except in the case of lead or lithium batteries). For complex or very hazardous fractions (batteries, PCBs), it is simple to find the recycler and visit their facility. Other more common fractions (glass, plastics) are often spread by waste management companies to many different recyclers and it is therefore difficult to confirm standards of operations.

Identifying a waste management partner

Selecting a waste management partner is a unique process for each company -the service provider must meet local regulations and operate at a standard that satisfies the company. Below is a decision tree to assist companies is the iterative steps required to assess and select suitable partners in each of their markets of operation.

NOTE
- If a licensed facility exists in a country, it is better to try to work with them to simplify compliance and to minimise costs.
- Many technical assistance programs exist to improve the environmental and safety standards of waste management operations, solar companies can leverage with them to improve their selected waste management partner.
- After choosing a waste management partner, a notification procedure exists where you must inform local and national regulatory bodies of your intention to recycle your waste with a specific provider. See local regulation for more information.



The benchmarking method

Before visiting and pre-qualifying a recycler you can map the various local regulations and standards required by your company into a scale of good-practice to bad practice. This can be put into benchmarking tool such as the one show below. Using this list of requirements can help the assessor understand the areas where a waste management company is not meeting required standards. This tool can be used when conducting due diligence of service providers and help assess the current standards against those required legally and by the company.

A **benchmarking method** for lead-acid battery recyclers, was developed by the International Lead Association though can be used to assess the environmental, health and safety standards of any recycling operation and develop a roadmap to improvement. E-waste management companies may use benchmarking tools to identify recyclers.

To pre-qualify an e-waste management facility, it is recommended to visit and assess the operations. Good practice in an e-waste treatment facility could be described as below (and included in a benchmarking tool):

- A waterproof covering or roof
- Impermeable surfaces on the floor with suitable drainage angles
- Drains and spillage collection facilities where the liquid effluent can be collected and treated.
- Adequate lighting and ventilation
- Ventilation system with particulate matter retention and dust control

In addition, it should have basic safety standards such as:

- Clear safety labelling and working instructions posted
- Marked traffic lines for pedestrians and vehicles
- And emergency evacuation plan
- Fire-detecting and extinguishing system
- Other safety standards as determined by respective licensing and legislation.

For more info on good practice and international e-waste recycling standards, see below:

- ILA Benchmarking of Environmentally Sound Recycling of ULABs
- WEELABEX standards www.weeelabex.org
- GIZ and STeP Webinars for e-waste recyclers: https://www.youtube.com/playlist?list=PLE-AQTsQB0uMOrJadvRbCKpwvdAquE__e
- Recycled Plastics http://www.recycledplastic.com
- Oeko Institute safety equipment
- Life Infocycle Youtube channel, https://www.youtube.com/channel/UCFr-0F6Z0GkNS1vlQP7HGLw. A series of training videos regarding safe e-waste recycling

Extract from Phenix Recycling benchmarking tool for e-waste recyclers

	Poor Practice			Good Practice
Where is the facility located?	Residential Area	Near community centres (schools, religious centres etc	>1km from general population	Industrial Zone
How are cables treated?	Open burning	Cables are put into incinerator to remove insulation	Cables stripped by hand, metals are segregated	Cable Stripper, PVC and metals segregated

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