GOGLA

The Voice of the Off-Grid Solar Energy Industry

E-waste Toolkit
Module 2 Briefing Note

Design for Reduction of Waste

Executive summary

The high costs of managing products at end-of-life (take-back, collection and recycling) in the off-grid solar sector create a financial incentive for companies to avoid and reduce waste. Furthermore, strategies to reduce waste can deliver enhanced value for consumers and environmental benefits such as reduced greenhouse gas emissions.

There are two predominant approaches to design for sustainability in the sector: Design for Durability and Design for Ease of Maintenance & Repair. A number of off-grid solar companies have elements of circular products and business models though there is significant scope for optimisation and replication.

There is some low-hanging fruit for the sector to reduce waste – improved labelling of materials, design for disassembly, expanding digital tamper-proofing, reduced plastic packaging – and more complex challenges – improved battery management systems, enhanced interoperability and compatibility, managing different products and generations in parallel, etc. Greater investment in R&D and industry cooperation can help unlock these and make the sector more sustainable.

This Briefing Note identifies strategies and tools to reduce waste in the off-grid solar sector, including:
- Circular business model strategy games & KPIs
- Waste hierarchy
- Off-grid solar scorecard – indicators for recyclability, repairability and spare parts
- Design for sustainability framework

The Briefing Note takes a holistic approach, recognising that it is most effective and efficient, to start by not producing waste. It explores product, services and business models that can reduce waste and includes case studies of four innovative companies.

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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 sector. The Toolkit consists of six modules focused on different themes such as 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 identify tools and strategies to reduce waste in the off-grid solar sector. It takes a holistic approach, recognising that it is most effective and efficient to start by not producing waste. It explores product, services and business models that can reduce waste and includes case studies of four innovative companies. The target audience is staff within strategy and management, product design and engineering.

Off-grid solar products have a positive environmental impact through displacing incumbent lighting and power sources such as kerosene lamps, diesel generators and torches powered by disposable batteries. Quality-verified products have a demonstrably longer life than non-quality-verified competitors and thus produce less waste. However, even good quality products can have a negative impact on the environment and society if they reach end-of-life prematurely and go straight to disposal.

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Off-grid solar technology performance and lifetime

For a SHS kit manufacturer a key technological decision with implications for the waste strategy is the choice of battery – the weakest component in the core system. Proponents of lead-acid batteries point to the positive value of lead and the ubiquity of recyclers (albeit of mixed quality). Whereas lithium batteries are more robust, longer lasting and are not toxic, though can only be recycled in Europe or Asia.

Lithium battery technology continues to improve in terms of performance, longevity and cost; the typical design life for an SHS kit battery is now around 2500 cycles[1] – giving five to seven years' service. As the industry grows and matures, there is opportunity for engaging suppliers of higher quality. Further innovation on battery management systems that control the battery health and performance also offer potential for longer life and improved performance.

The other core components of a system – PV module, PCB, lights – are relatively robust, though common technical problems arise from cables and connectors that are subject to wear and tear. Also vulnerable to rough use cases are TVs, fans and other appliances.

Connected devices and the Internet of Things have introduced powerful possibilities to enhance performance and extend product life, for example battery monitoring can identify if the PV panel needs cleaning and send an automated message to advise the owner. Likewise, it can predict when the battery needs replacement and inform the company's spare parts inventory. At the fleet level, data analytics is helping companies to optimise component and system design.

Individual companies have a reasonable grasp of product and component lifespans (particularly true for devices with remote monitoring), though precise sector-wide data does not exist. Such a study would be valuable to help companies identify common challenges and inform industry metrics on social and environmental performance.

An obvious additional factor on the product performance and lifespan is the consumer and their level of understanding of the product's functionality (and limitations), warranty mechanism, and maintenance and repair options. Though Lighting Global verified products come with a user manual and warranty details, the sales force still has a big role to play. For larger systems it is typical for a trained agent to do the installation and show the customer how the product works, how they can make payments, etc. Consumers typically have a limited understanding of the potential hazards of products at end-of-life or what are the available disposal options. A later Module in the Toolkit will focus on e-waste and the consumer.

The Lighting Global product quality standards require a certain level of durability and longevity, as well as a warranty (one year for solar lanterns and two years for SHS kits). It is thought that quality-verified products often have a significantly longer life – and thus generate less waste - than the common non-quality-verified competitors. 17 of the leading non-quality-verified products found on the East African market were tested according to the standard and failed for reasons that would likely lead to a short consumer lifespan[2]. Promoting quality standards and enforcement is a good strategy for stakeholders seeking to reduce waste.

1 Shell Foundation: Energy Storage: Off-Grid Trends in Emerging Markets (2018).
2 Quality Matters. August 2018. Lighting Global (download here).

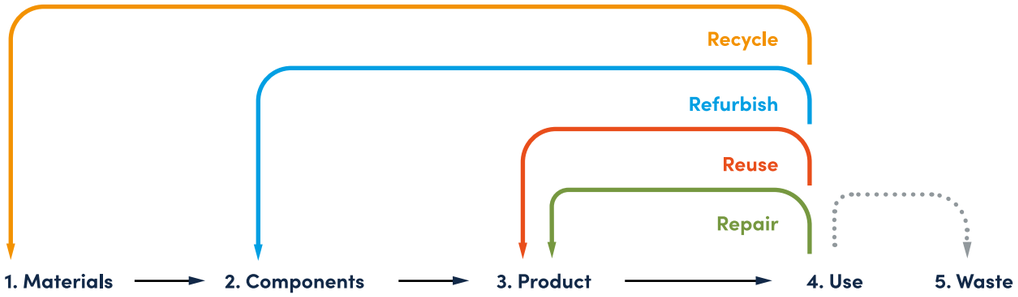
A *"circular economy is a system in which all materials and components are kept at their highest value at all times, and waste is designed out of the system."*[3] This is a stark difference to the predominant linear economy of "use -> make -> dispose". The current state of recycling infrastructure and the actual levels of waste being recycled across all fractions means that the strategy of recycling could still be considered part of the linear economy.

These four principles will resonate with many off-grid solar companies, particularly PAYGo providers with cloud services and leading brands that take a "lifetime customer" up the energy ladder with their range of products[4]:

1. The consumer lifetime of a product is maximised.
2. All products are interconnected and make use of central systems where possible (such as cloud connection for data storage).
3. Customers get fit-for-purpose products that are right for them and can change or swap products as their needs change. Therefore, residual value and utility of products is matched by the appropriate customer needs.
4. Products and components are cascaded to extract maximum benefit from the energy and resources invested in them. This means that products move from high-end consumer electronics to lower-performance applications and that in recycling all materials are recovered and reused.

Below, there are some tools designed to help companies approach circular economy, they can be used to assess a business holistically, or a specific product or process.

Basic principles of circular economy



Name	Description
Circular Design Guide	A raft of circular economy tools and guides for companies to Understand, Define, Make, Release.
Circularity Indicators	This tool provides a methodology and tools to assess how well a product or company perform in the circular economy.
Circulab	A business design game that uses circular economy principles to help companies come up with ideas to be more circular.
ResCoM	ResCoM (Resource Conservative Manufacturing) is developing a systems-led decision-making tool and methodology to support manufacturers in transitioning to closed-loop products that are designed for multiple life cycles.

3 World Economic Forum, "Circular Vision for Electronics" (download here)
4 Ellen MacArthur Foundation

Circular Economy

Designing a circular phone - Fairphone

Fairphone created "the world's first ethical, modular smartphone". Fairphone is a social enterprise on a journey toward fairer electronics with a focus on 1) fair materials, 2) long-lasting design, 3) good working conditions and 4) reuse and recycling.

The Fairphone 2 has a modular architecture and is designed for ease of repair and upgrade - an innovative approach in an industry that has often been questioned about its efforts to encourage repairs and device longevity. It has a modular design for the parts and components that most often wear down (e.g. the battery or a USB charging port) or are more exposed (e.g. the screen). Users can replace these parts themselves with standard tools and run diagnostics via a maintenance tool embedded in the phone. This serves a dual purpose: after-sales services are improved, and customers increase their knowledge about the product they hold in their hands. The architecture also enables software upgrades - since its launch in 2015, it has received two major software upgrades, a core function update (the cameras' specs were improved with two upgraded modules for rear and front camera), and other look and feel enhancements. These upgrades ensure that the intrinsic value of the phone stays as high as possible for longer.

To improve collection and take-back Fairphone has implemented: 1) A free shipping label is provided to users who wish to return their phones (any smartphone brand in the EU). 2) Data security guarantees are important: transparency in data erasing processes has proven to be a key topic for some users. 3) Financial incentives: providing a discount on the purchase of a Fairphone 2. 4) Reduction of e-waste KPIs at governance level.

FAIRPHONE

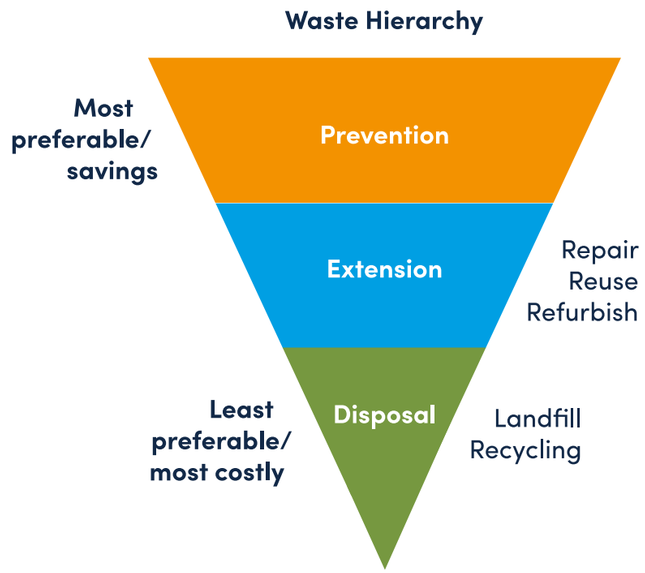
© Fairphone

Waste Hierarchy

The waste hierarchy is a tool used for the holistic evaluation of a company – products, services and processes – with the aim of maximising the benefits of the product and minimising the generation of waste. It is recommended that companies use the tool to assess and identify strategies to reduce waste that encompasses product design and the business model.

The hierarchy captures the progression of products and components through the life cycle and directs priority action to reduce or manage waste. From a resource efficiency and environmental perspective, the priority is to prevent the generation of waste through design and manufacturing changes – for example, a highly durable product with easily replaceable batteries. The next level priority is extending the lifetime of the products and components with design for repairability and refurbishment alongside on-the-ground operations to achieve this.

The high costs of managing products at end-of-life (take-back, collection and recycling) in the off-grid solar sector create a strong incentive for e-waste prevention and product lifetime extension. Furthermore, these approaches can deliver enhanced value and experience for consumers, and environmental benefits such as reduced emission of greenhouse gases and/or pollutants.



Waste is leakage

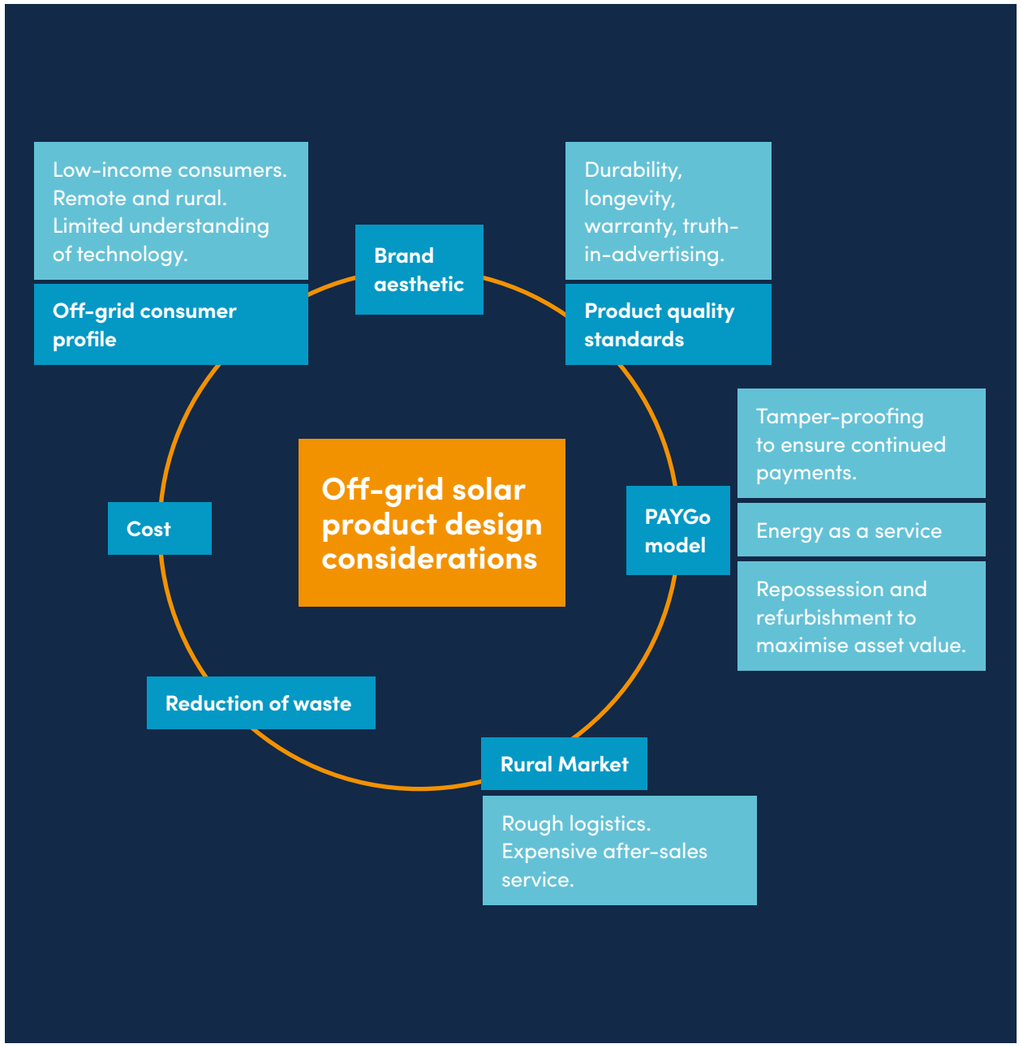
Every component of a solar system or other electronic product has an embedded value that consists of all efforts to create the product and get it to the customer including design, manufacturing, assembly, transportation and distribution. If a product breaks early or is not extended through repair or refurbishment, it means that it is prematurely classified as "waste". Thus, the resources that have been invested in that product - **the residual value** - have not been fully realised. Therefore, anything that is disposed of (even through recycling) is essentially a leakage of materials and resources.

> Product design determines to a large extent the longevity, repairability, recyclability, proportion of recycled and renewable material in the product, and its suitability for refurbishment or remanufacture. Product design therefore determines the circularity potential of a product.[5]"

5 Circular by Design https://www.eea.europa.eu/publications/circular-by-design

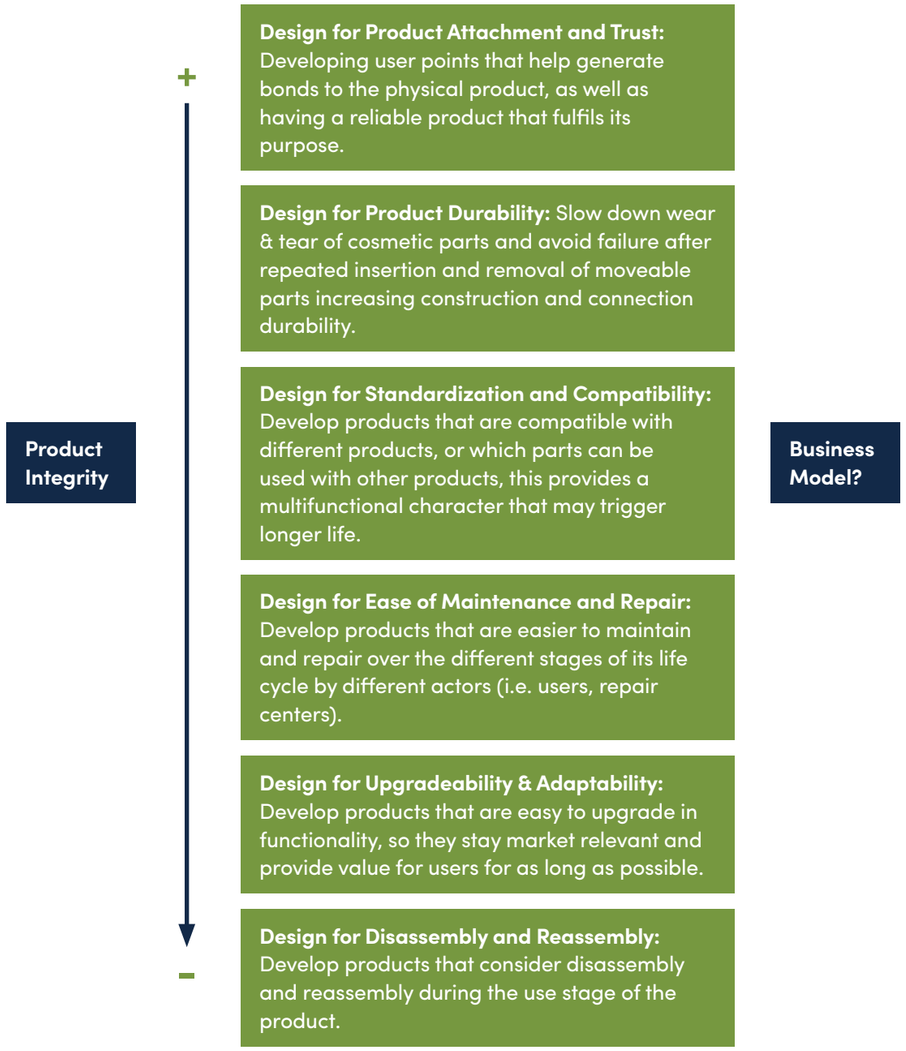
Design strategies for reduction of waste

There is an array of product design considerations for manufacturers; reduction of waste is one among many overlapping and sometimes competing priorities. Seen as an independent and discrete element, design for reduction of waste is likely to be low on the list of priorities for a commercial enterprise. However, embedding design for reduction of waste in the wider business model can add value to customers, strengthen brands and reduce the cost of refurbishment and recycling.



Design strategies for reduction of waste

The dominant strategies in the off-grid solar sector are **Design for Durability** and **Design for ease of maintenance & repair**. There are smaller companies and initiatives exploring other strategies. While it may be possible to achieve elements of various strategies, it is suggested to opt for a single approach and optimise around this. Whichever strategy companies decide to place their focus on, it is increasingly important to know where products are, how they're being used (e.g tracking battery performance in the field) and being able to manage different product versions and generations in parallel[6].



SOURCE Products that Last. Bakker et. al. (2014)

6 Design principles for multiple lifecycles to enable the Circular Economy.

Design for Product Durability

Design for durability aims to extend the consumer lifespan of a product as much as possible. It prioritises slowing down wear-and-tear of cosmetic parts, avoiding failure after repeated usage of movable parts and increase construction and connection durability.

In general, products designed for durability have higher costs of manufacturing (and quality control testing), but reduced costs for servicing and honouring the warranty.

Key characteristics of a product designed for durability include:

- Components are selected for robustness, longevity and lower maintenance requirements.
- Materials are selected based upon their resistance to wear-and-tear or ability to be refurbished (e.g. polished) to high aesthetic standards.
- Greater product integrity to discourage disassembly and tinkering by non-trained individuals.

PAYGo and tamper-proofing

Solar Home System Kits sold on PAYGo are typically made tamper-proof to protect against the consumer opening the control unit and bypassing the remote lock-out function. This is considered necessary to protect the company's assets whilst the consumer is making payments under contract. Physical tamper-proofing such as encapsulation of batteries, or special screws inhibit the repairability (particularly from third parties) and recyclability of the product. Digital tamper-proofing methods are now on the market, with in-built sensors and lock-out function, that can achieve the dual aims of securing assets and enabling disassembly.

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Design strategies for reduction of waste

Robust design for a longer lifetime - Azuri Technologies

Azuri Technologies is a leading commercial provider of pay-as-you-go (PAYGo) solar home systems for rural off-grid homes. Across sub-Saharan Africa more than 750,000 people (150,000 households) now enjoy affordable, clean energy access as a result of Azuri solar products.

Azuri has always been a PAYGo company since its foundation in 2011, and this has had a significant impact on the way they approach the lifecycle of their products, from material and design choices, relationships with suppliers and distributors, through to after-sales strategies.

Although the starting point is to deliver robust products with good lifetime characteristics, Azuri believes it is essential for a PAYGo solar business to extend the useful life of its products both from a resource efficiency and a financial point of view. To help achieve this goal, Azuri has taken several steps to ensure easy repairs and refurbishment.

One area has been the careful selection of plastics used for the product housings. Azuri has adopted a surface finish which minimises the impact of marks and blemishes and the simple application of a damp cloth restores the look and feel to "as good as new". Screen printing, particularly on handheld products, has also been eliminated as it can be rubbed off as a result of daily use and handling. Instead, product information is molded into the plastic housing or laser etched.

Greater attention to product reliability and robustness has also meant the need for repair can be reduced to a low level. If a problem does occur, upfront design can minimise repair time and cost. For instance, PV module cables can be damaged in use on the sharp edges of tin roofs or during component removal. To make them easier to repair, Azuri has worked with its supplier to modify the design of the junction box to maintain a high level of environmental resistance but at the same allow quick and easy cable replacement. It is worth noting that physical and technological anti-tampering measures taken by Azuri and other PayGo companies to protect their products have traditionally been considered to impede repairability, but Azuri believes that in their case this is offset by the desire to extend lifetime and "keep the asset working." Consequently, Azuri and their distribution partners are fully trained and equipped to undertake repairs in-house.

Overall, Azuri is committed to, and focused on designs that are robust and fit for purpose, striving to improve durability and lifetime with every product iteration.

© Azuri

Design for ease of maintenance and repair

Design for ease of maintenance and repair recognises that components will fail and emphasises the role of consumers in extending the product lifespan. It also creates opportunities for the informal sector to repair and reuse products and may make recycling easier and cheaper.

The Off-Grid Solar Scorecard includes a set of indicators that measures the repairability, access to spare parts and recyclability of products. They have defined the following factors as important for repairability:

- The ease at which a battery can be replaced or upgraded or if it is even possible.
- The construction of circuit boards (soldered vs. surface mounted) and the availability of replacement circuit boards.
- Non-destructive disassembly and reassembly. Key to repair is being able to access the components needing repair without damaging the product.
- The use of glue, welding or non-reversible screws to assemble components.
- The tools required to disassemble and reassemble and if they are available to most small-scale, independent technicians.
- The time and complexity for disassembly.
- Access to information about how to disassemble or repair a device.

Going beyond product design, there are other aspects where the manufacturer plays a critical role to enable the repair[7]: 1) ensuring the availability of spare parts and components (either through aligning with spares commonly available on the market or a proprietary supply chain), and 2) making available technical designs and specifications of the product and components (either with the product, online[8] or in training materials).

There are different models for provision of after-sales and repair services, including these three general categories:

- In-house and proprietary: Exclusively provided by the original manufacturer (or distribution partner or service provider), thus products must be returned to distributor to be repaired by trained technicians.
- Collaboration with competitors: Use of a third-party repair centre with verified standards that services a category of products rather than specific brands. This would mean that it may be shared with competitors.
- Open and informal: Replacement components and repair guides are made available publicly.

In Europe, the **right to repair electronics** movement[9] is advocating for legislation on consumers' ability to repair and modify their own consumer electronic devices without voiding warranties. It is thought this will not feature in the policy landscape of off-grid solar markets in the foreseeable future.

7 Lighting Global Eco-notes: Product Repair Best Practices (Part 1 & 2).
8 E.g. such as iFixit, a global community with repair guides to enable and promote repair of electronic products.
9 European Environmental Bureau: Europe paves way for right to repair (2019).

Design strategies for reduction of waste

SolarWhat?! Design for repairability and compatibility.

SolarWhat?! is a modular and repairable product developed by the Social Anthropology, International Development Studies and Design faculties at the University of Edinburgh. It consists of a portable torch and an adaptor unit that is Lighting Global certified. The portable torch has two brightness settings and a battery life of around 20 hours. The adaptor unit is designed to be mounted in multiple ways and can be connected to any solar panel between 5 and 30W; it is shipped without a panel so it can be connected to existing panels in circulation.

SolarWhat?! aims to extend the lifecycle of solar products by addressing repairability and compatibility challenges through design. Recognizing that people adapt technologies to contexts of use, there are no additional features –like stands or straps– and both devices are easy to take apart and allow for different levels of access, they are comprised of three sections, held together by easily removable screws. The screws, that can be replaced with standard tools, would make it easy to repair should the device need, for example, a battery replacement.

SolarWhat?! was built to demonstrate a way to reduce waste from off-grid solar devices, at the same time as promoting local economies of repair. The torch and adapter demonstrate that fully repairable products can match existing products on quality and functionality, and that new kinds of product innovation can extend the life of solar modules that are already in circulation.

© SolarWhat?!

Design for standardization and compatibility

"Compatibility" is a concept that can refer to the state of two (or more) products or pieces of equipment (e.g. systems, devices, etc.) working together satisfactorily without needing to be altered or modified. "Standardization" – synonymous with "In¬teroperability" - is a concept that refers to the ability of two separate systems (e.g. solar home systems) to work with and/or use the parts of another system (e.g. a SHS using another SHS' TV)[10]. These approaches can expand and extend the useful life of products, reducing waste and creating value for consumers.

Compatibility also entails modular systems that can be adapted or supplemented to meet the consumer's needs, for example a consumer may start with a single battery, PV module and lights, then later add a second (third or fourth) battery, PV module and appliance.

In the off-grid sector there is currently limited appliance compatibility – PAYGo providers often use proprietary plugs and digital handshakes to avoid customers using expensive appliances with alternative systems and ceasing to make payments. This allows manufacturers to ensure the system and appliance is sized appropriately and protects their revenue stream, but arguably reduces consumer choice and dampens the reuse / second-hand market.

Some companies are looking at interconnection of multiple SHS kits into a "mesh-grid"[11], to share surplus power and give greater availability of power to users, though introducing questions on such as tariffs and complex community dynamics. Interconnection with mini-grids and the national grid are further complicated by the need for power conversion electronics and licensing requirements.

Greater standardization and labelling of spare parts (batteries, electrical components, etc) and electrical connections (plugs, ports and connectors) would ease maintenance and repair and help open the appliance market. The LEIA Interoperability Working Group is developing a Technology Roadmap that will define priorities and a process to make progress on this agenda.

SolarWorx. A modular SHS kit

Solarworx is a SHS manufacturer based in Berlin, with distribution partners in Zambia, Zimbabwe, Cameroon, Uganda and Senegal. Founded in 2018, the focus on designing a product that is easier for the consumer to use and has the potential to reduce e-waste and the environmental impact of disposal.

They have three products: the SoLEGO Home (80Wh or 160Wh), the SoLEGO Water, and SoLEGO Entrepreneur, that consist of three modules: 1) casing, 2) PCB and 3) lithium-ion phosphate battery. The modularity allows the customer to upgrade the capacity of the system, enables easy maintenance, repair and refurbishment. They have a close relationship with their distributors who are trained to handle repair and maintenance.

They currently sell appliances with their SHS, however, they plan to make the main modules compatible with as many appliance brands as possible so that customers can use what they might already have (and avoid these turning into waste prematurely).

The casing uses Arboform (a wood-based alternative to plastic) that can be safely disposed of without it needing to be sent to specialized recyclers.

10 Low-Energy Inclusive Appliances Technology Summaries. Efficiency 4 Access Coalition. September 2017.
11 E.g. SolShare in Bangladesh and Okra in Cambodia.

Design strategies for reduction of waste

Design for Recyclability

Improving recyclability of a product can be simple and has profound effects on reducing the end-of-life impact of products. Key characteristics of a product designed for recyclability include:

- All components / fractions are labelled for efficient segregation and increased value of waste. Labelling of different plastics is particularly important.
- Information about recycling and take-back is easily available on the product packaging and user manual.
- Minimise the selection of plastic, e.g. only one or two types of plastic.
- The product can be easily disassembled with standard tools (e.g. hammer and screwdriver) without being destroyed. Avoid use of glues and encapsulation of components. This simplifies dismantling and increases the value of the fractions.
- Design sub-units in products that can be easily removed and match with the final recycling options to improve sorting and segregation (e.g. the PCB and connectors are located together, whereas the battery pack is separate).
- Avoid or minimise the use of materials that contaminate waste streams due to their characteristics or behaviour in sorting (such as toxicity).

The Off Grid Solar Scorecard has defined a list of indicators for recyclability and evaluated a number of products accordingly.

Packaging

Most considerations in the design strategies section can also apply to packaging design. Reducing packaging waste can often be a "quick win" and there are several best practices identified both within and outside the off-grid solar sector[12]:

Print

- Minimize the use of printing ink, coating and plastics
- No volatile organic compounds (VOCs)
- No cadmium, lead, mercury, chromium or other metallic components, as well as mineral oil.
- No use of suspected CMR substances or organohalogens in offset inks.
- Use solvent-free adhesive

Filling and casing

- Reduce plastics and eliminate polystyrene/ polyethylene.
- Replace plastic bags with paper bags (or eliminate bags altogether)
- No plastic foils glued on top of items.

Alternatives to plastic for packaging design

Name	Description
ArboformR	A wood-based alternative to plastic, Arboform is an easily formable biodegradable polymer. Made combining recovered lignin with natural fibers – flax, hemp or other fibre plants – to create a composite. Disposal of Arboform is the same as for naturally grown wood (i.e. decay or incineration)
PaperFoamTM	Made from industrial starch, natural fibers and water. Lightweight, recyclable with paper, compostable and biodegradable. Generally used for packaging interior.
Stone Paper	Paper-like material made of calcium carbonate and a mix of non-toxic resin. It is a Cradle to Cradle (Silver) certified product. Since no water or bleach is used during production, environmental impact is considerably reduced. Its disposal is the same as Arboform, by decay (with sunlight) or incineration.
Honeycomb	Use as a replacement for PUF, MDF, bubble wrap, EPE, EP foam, mineral wool and particle boards.

12 Adapted from Mobisol internal guidance document.

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