

Using E-Waste, Recycled and Local Materials to Build Durable, Low-Cost Flashlights

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Abstract - Access to reliable lighting remains a critical yet unmet need in many off-grid and low-income rural communities across the Global South. Meanwhile, the accelerating growth of electronic waste (e-waste) poses a mounting environmental challenge. Paradoxically, much of this discarded material—such as LEDs, lithium-ion batteries, and robust plastic housings—can be salvaged and repurposed into affordable, energy-efficient lighting devices. This paper examines the potential of transforming e-waste into durable flashlights, addressing both environmental and energy access gaps. The core concept is to address the dual challenges of energy poverty and e-waste accumulation by transforming discarded electronics into affordable, durable lighting solutions. Essential components like lithium-ion batteries, LEDs, and PCBs can be salvaged from common e-waste, including old mobile phones, radios, and broken flashlights. This recovered technology is then combined with readily available and recycled materials—including bamboo, PVC pipes, scrap plastic, and Aluminium foil—to create the flashlight's structure and optical elements, making the production process highly cost-effective and environmentally sustainable. The financial and technical feasibility is demonstrated by case studies from countries such as Kenya and Ghana, where models have been developed to produce flashlights at a fraction of the commercial cost, designed for local reparability. Furthermore, this process is organized into a localized ecosystem covering collection, assembly, sales, and servicing. This approach represents a powerful “waste-to-wealth” strategy that fosters micro-entrepreneurship, provides skill development for women and youth, and enhances community resilience, thereby contributing to global goals for clean energy and responsible consumption.

Keywords: E-Waste Recycling, Upcycling, Low-Cost Lighting, Sustainable Design

I. INTRODUCTION

Access to reliable and affordable lighting remains one of the most pressing challenges in rural and off-grid communities across the globe. According to the International Energy Agency (IEA, 2021), nearly 770 million people still live without access to electricity, the majority of whom reside in sub-Saharan Africa and South Asia. In such areas, flashlights and small portable lamps are often the only sources of artificial light, supporting critical household activities, education, and livelihood practices. However, commercially available flashlights are frequently unaffordable, fragile, or unsustainable in these contexts, creating both social and technological barriers to equitable energy access.

At the same time, the global surge in electronic waste (e-waste) poses a parallel challenge. The Global E-Waste Monitor estimates that more than 53.6 million tonnes of e-waste are generated annually, with only about 17.4% formally recycled [1]. Discarded devices such as mobile phones, radios, chargers, toys, and broken flashlights themselves contribute significantly to this growing environmental burden. These devices, while considered obsolete, often contain functional components, including light-emitting diodes (LEDs), lithium-ion batteries, switches, wires, and plastic or metal casings, that can be recovered and repurposed.

The scale of the e-waste problem can be illustrated by national contributions, as shown in Figure 1. China and the United States are the largest generators of e-waste, producing approximately 10,129 kT and 6,918 kT annually, respectively, while India contributes 3,230 kT. Other significant contributors include Japan, Brazil, Russia, and several European countries [2]. This distribution highlights not only the magnitude of the problem but also the uneven geography of waste generation and potential resource recovery. For countries like India, which simultaneously face high e-waste volumes and large populations without electricity access, the reuse of discarded electronics for grassroots energy solutions is particularly compelling.

This convergence of challenges and opportunities presents a unique pathway: using e-waste and locally available materials to construct low-cost, durable flashlights for rural populations. By recovering electronic components from discarded devices and combining them with indigenous materials such as bamboo, coconut shells, recycled plastics, and scrap metals, communities can create functional, repairable lighting devices. Such an approach not only reduces environmental pollution but also empowers local entrepreneurship, lowers costs, and promotes circular material flows [3–4].

The aim of this review is therefore twofold: (1) to synthesize existing knowledge on the technical and material feasibility of repurposing e-waste for flashlight construction, and (2) to highlight case studies, design considerations, and socio-economic implications of such initiatives. Rather than presenting new experimental findings, this paper compiles and evaluates diverse

academic, institutional, and grassroots reports to assess the potential of “waste-to-wealth” pathways in addressing rural energy challenges [5]. The scope of the review is deliberately interdisciplinary, drawing insights from materials science, engineering design, development studies,

and sustainability research to provide a holistic picture of how small-scale, everyday technologies like flashlights can contribute to broader goals of energy equity and environmental sustainability.

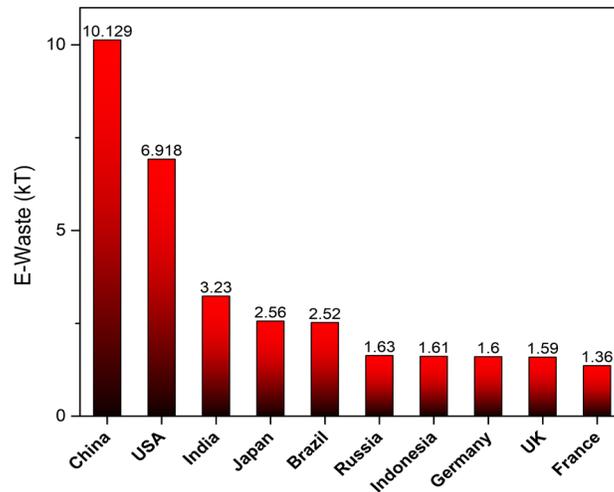


Fig.1 Annual E-Waste Generation by Leading Countries (In Kilotonnes)

II. FUNDAMENTALS OF FLASHLIGHT TECHNOLOGY

A flashlight is a portable lighting device designed to convert stored electrical energy into visible light. Its fundamental components include a light source (usually an LED), a power source (battery), a housing (casing), optical elements (reflectors or lenses), and a control system (switch and wiring), as shown in Figure 2. When the switch is engaged, current flows from the battery through conductive wiring to the light source, where electrical energy is converted into luminous energy. Modern flashlights primarily employ light-emitting diodes (LEDs) due to their efficiency, durability, and long service life, replacing earlier incandescent bulbs [6].

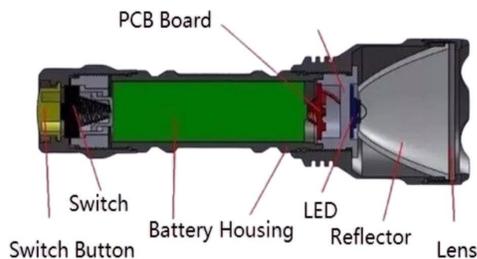


Fig.2 Parts of Flashlight

A. E-Waste as a Resource for Flashlight Construction

Electronic waste, often framed as an environmental liability, is in fact a resource reservoir containing a wealth of components with direct applicability in small-scale lighting systems. Items such as discarded mobile phones, radios, chargers, toys, and broken flashlights frequently contain the essential parts needed to construct durable, low-cost lighting devices.

The three most critical categories of components for flashlights are batteries, light-emitting diodes (LEDs), and printed circuit boards (PCBs). Together, these elements form the energy storage, energy conversion, and energy regulation backbone of flashlight functionality, illustrating how circular economy principles can be embedded at multiple levels of design.

B. Batteries - Energy Storage Backbone

Batteries are central to flashlight performance but also represent the largest environmental and safety concern. According to Tran *et al.*, recycling alkaline and ZnC batteries can recover valuable metals (zinc, manganese, iron), saving up to 90% of mineral resources compared to landfill or incineration pathways [7]. Yet, this process remains energy-intensive.

TABLE I COMPONENTS, FUNCTIONS, AND CONVENTIONAL MATERIALS OF AN LED-BASED LIGHTING SYSTEM

Component	Function	Conventional Materials
Light Source (LED)	Converts electricity into light	Semiconductor-based diodes (GaN, InGaN etc)
Power Source	Stores and supplies energy	Alkaline or Li-ion batteries
Switch	Controls current flow	Plastic toggle/push buttons
Wires & PCB	Conduct electricity, regulate voltage	Copper wires, epoxy resin PCBs
Housing / Casing	Provides structure and insulation	ABS plastic, Aluminium
Reflector / Lens	Focuses and directs light	Aluminium-coated plastic, polycarbonate

TABLE II RECOVERABLE COMPONENTS FROM COMMON E-WASTE SOURCES

E-Waste Item	Recoverable Parts	Application in Flashlight
Mobile phones	Li-ion batteries, LEDs, PCBs	Power source, light source, charging regulation
Radios & toys	Switches, resistors, LEDs, casings	Control systems and housing
Chargers/adapters	Small PCBs, wires	Voltage regulation, connectors
Broken flashlights	LEDs, reflectors, casings	Direct reuse
Desktop computers	Fans, wires, switches, Aluminium heatsinks	Casings, reflectors, switches
Remote controls	Buttons, switches, plastic shells	Switches and small casings
Old CD/DVD players	LEDs, small motors, PCBs	LEDs, PCB circuits for regulation
Household appliances (e.g., torches, toys, emergency lights)	Batteries, LEDs, reflectors, casings	All major flashlight components

The reuse of second-life lithium-ion batteries offer a practical alternative for small devices: few studies show that used mobile batteries still provide adequate capacity for study lamps in off-grid settings [8]. Primary batteries, especially alkaline and zinc-carbon (ZnC) cells, are still among the most widely used energy sources in flashlights, particularly in rural and low-income regions where rechargeable options are less accessible. Their popularity stems from their low upfront cost and availability, but their environmental impact is significant. When discarded into landfills, corroding casings release zinc, manganese, iron, and residual electrolytes, which leach into soils and water systems. This makes primary batteries both a critical resource pool and a serious environmental liability. According to Tran *et al.*, establishing circular systems for these batteries is essential, both to conserve resources and to mitigate their toxic legacy.

The structure of these batteries offers several recoverable materials. In both alkaline and ZnC cells, the zinc anode and manganese dioxide cathode represent the primary active materials. Alkaline batteries typically use potassium hydroxide as the electrolyte, whereas ZnC cells employ ammonium chloride or zinc chloride. In addition to the electrochemically active materials, the iron-steel casings are recoverable as ferromagnetic scrap, and plastic components can be either recycled or used in energy recovery processes. These materials, once recovered, have broad applications: zinc can be reused in galvanization or alloy production, manganese oxides can be reincorporated into dry cell

production or fertilizers, and plastics can be redirected to recycling chains.

Recycling begins with the collection and sorting of waste batteries. Sorting ensures separation by chemistry, as different chemistries require distinct processing methods. This is typically performed through labeling, automated scanning, or X-ray fluorescence (XRF) techniques. Following collection, mechanical pre-treatment is conducted. Batteries are shredded or crushed in enclosed systems, which minimizes the environmental release of harmful substances. This stage yields several fractions: ferromagnetic materials (mainly steel casings), non-ferrous materials, plastics, and a fine powder known as “black mass.” The black mass is especially important because it contains the zinc and manganese oxides, along with carbon and electrolytes, which require further processing to recover.

Two dominant methods are used for extracting materials from black mass: hydrometallurgy and pyrometallurgy. Hydrometallurgical processing uses aqueous solutions, such as sulfuric acid or hydrochloric acid, to leach zinc and manganese ions. These ions are then separated by precipitation, solvent extraction, or electro-winning, producing compounds such as zinc oxide, zinc sulfate, manganese dioxide, or manganese sulfate. This method is widely considered advantageous for its high recovery efficiencies (often above 90%) and the purity of recovered materials [9]. In contrast, pyrometallurgy employs high-

temperature smelting, typically above 1000 °C, to volatilize zinc and reduce manganese oxides. The volatilized zinc can be condensed as metallic zinc, while manganese is recovered in oxide or alloy form. Though effective, pyrometallurgical methods are energy-intensive and rely heavily on fossil fuels, making them less sustainable from an environmental standpoint [10].

The environmental benefits of recycling primary batteries are substantial. Compared to incineration or landfill disposal, recycling can save between seven and nine times more mineral resources. Additionally, the recovered zinc and manganese compounds are directly usable in industrial supply chains, including fertilizer production and new battery manufacturing, thereby reducing reliance on virgin mineral extraction. The recycling of steel casings and plastic components further enhances resource efficiency by reintegrating these fractions into established recycling streams. Despite these benefits, significant challenges remain. Pyrometallurgical approaches consume large amounts of energy, limiting their sustainability. Collection systems are also complex, particularly in developing regions where informal waste handling dominates. Furthermore, the

economic value of recovered zinc and manganese is relatively low, making large-scale recycling financially challenging without policy incentives or subsidies. Toxic residues from electrolytes also demand careful treatment and safe disposal, adding further cost and technical complexity.

For flashlight applications specifically, large-scale industrial recycling of alkaline and ZnC batteries may not always be practical in community-level projects. Instead, the priority at the grassroots level should be on the safe collection and storage of spent primary batteries and their redirection to regional recycling facilities equipped for hydrometallurgical or pyrometallurgical treatment. Local projects should focus more heavily on repurposing second-life lithium-ion batteries from discarded phones or laptops, which offer longer life cycles and easier reuse pathways. However, education on the safe handling of spent alkaline and ZnC batteries remains essential, both to protect communities from environmental exposure and to ensure that these resources eventually enter sustainable recycling streams [10–11].

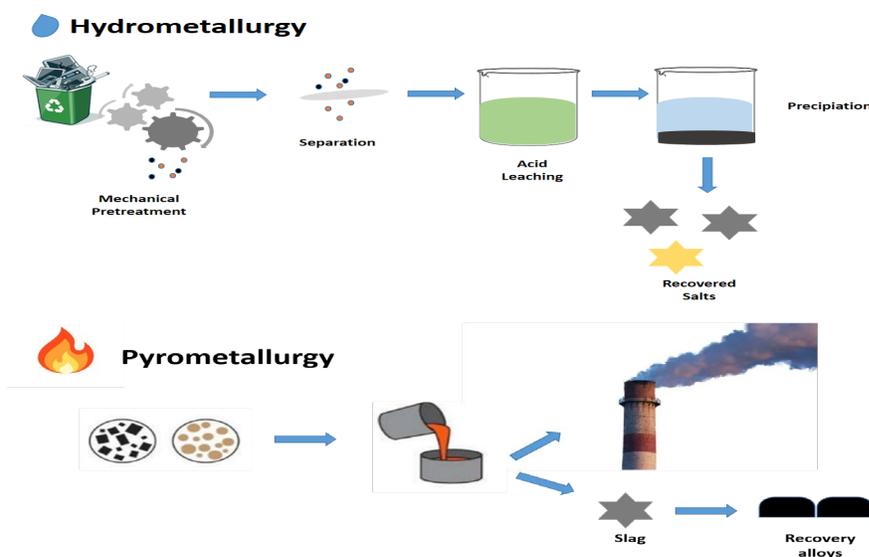


Fig.3 Hydro and Pyro Metallurgy Techniques

C. LEDs - Energy Conversion Core

Light-emitting diodes (LEDs) have become the dominant light source in flashlights due to their exceptional efficiency, durability, and long operational lifetimes. Modern LEDs can last between 20,000 and 50,000 hours, far exceeding the lifespan of traditional incandescent or fluorescent bulbs (Masters & Garski, 2025). Their low power requirements also make them ideal for integration with small batteries, including second-life lithium-ion cells. From a materials science perspective, LEDs are composed of semiconductor junctions (gallium nitride, indium, or Aluminium compounds) mounted on substrates, with encapsulating resins and optical lenses for light direction. Although LEDs themselves are difficult to recycle due to

their complex composition and minute size, they are highly suitable for direct reuse in small-scale circular applications. In the context of e-waste reuse, LEDs can be salvaged from discarded electronic devices such as toys, remote controls, indicator panels, and broken torches. Masters and Garski (2025) demonstrated in their eco-flashlight design project that LEDs recovered from electronic scrap performed nearly as well as new commercial diodes when tested in student-built prototypes [13]. Similarly, other reviews on small electronics stress that reusing LEDs delays their entry into the waste stream and reduces the demand for virgin semiconductor production, which is energy-intensive and geopolitically sensitive [14]. The key to LED reuse lies in functional testing and selection: diodes with intact solder

pads and consistent brightness can be repurposed, while dim or flickering LEDs should be excluded.

From a sustainability perspective, LEDs provide one of the most impactful reuse opportunities in flashlight construction. Their efficiency enables smaller battery sizes, lowering overall material demand, while their long service life ensures that reused units can remain functional for years in rural lighting contexts. Furthermore, since LEDs contain minimal toxic metals compared to other lighting technologies, their reuse presents fewer environmental risks. Thus, LEDs represent not only the second most important component of flashlights but also one of the most straightforward pathways to implement circular economy principles at the grassroots level.

The printed circuit board (PCB), which regulates voltage and manages power flow, represents the third most critical component of flashlight design. PCBs in commercial flashlights may be simple, containing only resistors, capacitors, and diodes, or more advanced, integrating charging controllers for solar inputs or USB compatibility. These small boards are typically made from fiberglass-reinforced epoxy (FR-4) laminated with copper traces, along with mounted electronic components such as transistors, resistors, and microcontrollers [15].

From a materials science standpoint, PCBs are challenging to recycle due to their composite nature: they combine polymers, metals, and ceramics in tightly bonded structures. However, in the context of e-waste reuse for flashlights, PCBs can often be directly repurposed with minimal modification [16]. Salvaged boards from discarded radios, toys, and phone chargers often contain usable voltage regulation circuits, which can be adapted to match the power requirements of LEDs.

When considered together, batteries, LEDs, and PCBs form a complete systems architecture for flashlight construction. Batteries provide energy storage, LEDs convert that energy into efficient light, and PCBs regulate the flow to ensure safety and functionality. This integrated approach demonstrates that flashlights can be assembled almost entirely from salvaged parts, supplemented by locally available materials for housings and reflectors.

Beyond technical feasibility, this systems view highlights the broader value of e-waste reuse: it enables circular flows of energy and materials, reduces dependency on virgin resources, and fosters locally repairable, upgradeable designs. By shifting from isolated component reuse to whole-system thinking, communities can transform discarded electronics into reliable tools for energy access and sustainability.

D. Local and Alternative Materials in Flashlight Construction

In resource-constrained contexts such as rural India, where access to formal recycling streams or commercial spare parts is limited, the use of locally available natural and waste-derived materials presents an effective strategy for

flashlight construction. Several indigenous and low-cost alternatives can substitute for conventional industrial components. For example, bamboo is increasingly recognized as a renewable material for housings and casings, given its natural tubular structure and high tensile strength. Similarly, coconut shells and clay can be adapted as insulating enclosures or protective bodies, particularly for stationary lamps. Lightweight PVC pipes, often sourced from construction scrap, serve as robust cylindrical housings suitable for handheld torches [17]. Discarded plastic bottles can also be cut and reshaped to function as protective outer casings or as optical diffusers.

For reflective elements, Aluminium foil, beverage can sheet, and scrap tin metal provide cost-effective alternatives to commercial polished reflectors. These materials can be cut, polished, and shaped into parabolic reflectors, redirecting LED light effectively. Electrical connectivity can be supported by scrap copper wires, while rubber strips, resin, and locally available adhesives provide insulation and vibration resistance. By leveraging these locally sourced inputs, flashlight production becomes more affordable, adaptable, and environmentally responsible, while also promoting grassroots innovation and self-reliance. From a materials science perspective, the suitability of local and recycled materials depends on their mechanical, thermal, electrical, and chemical properties. Metals such as Aluminium and tin exhibit high reflectivity and corrosion resistance, making them ideal for reflectors and heat dissipation. Aluminium foil, despite its thin profile, has excellent optical properties when polished, while tin sheets provide moderate reflectivity with greater mechanical strength.

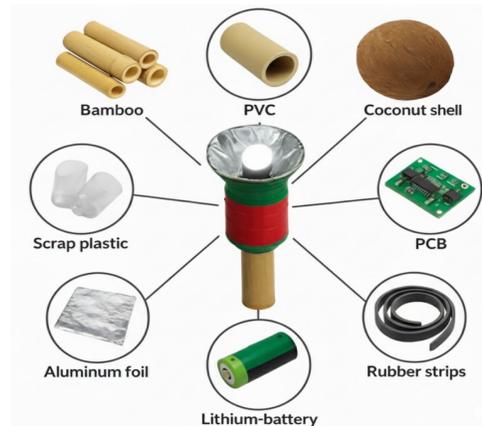


Fig.4 Local Materials as Replacement for Commercially Available

Plastics, such as those recovered from bottles or PVC pipes, are valued for their lightweight nature, electrical insulation, and moldability. They also resist corrosion and can be cut or reshaped with simple tools, though they are less durable under prolonged UV exposure. Natural fibers and bio-based materials, such as bamboo and coconut shells, offer structural robustness due to their high cellulose and lignin content, providing strength-to-weight ratios comparable to some engineering composites. Bamboo, in particular, has

tensile strengths ranging from 100–200 MPa, allowing it to withstand rough handling in rural environments [18]. Coconut shells exhibit high compressive strength and water resistance, making them suitable for protective housings. Clay, while offering excellent thermal insulation and moldability, is brittle and requires reinforcement or protective coatings to ensure durability. In addition, rubber strips and natural adhesives play an important role in providing insulation, shock absorption, and waterproofing. These properties are crucial in rural applications, where devices must withstand high humidity, dust, and frequent drops. Together, these materials provide an accessible and technically viable resource base for flashlight construction when assessed through the lens of materials science.

III. COMPARATIVE ANALYSIS

A. Commercial vs. Local Materials

A comparative analysis highlights the trade-offs between conventional commercial materials and locally sourced alternatives. Commercial flashlights often use ABS or polycarbonate plastics for housings due to their high impact strength and UV resistance, along with precision-molded Aluminium reflectors that maximize optical efficiency. While these materials ensure uniformity and performance, they are costly, non-biodegradable, and contribute significantly to the e-waste burden when discarded.

In contrast, local substitutes offer affordability, accessibility, and sustainability advantages. For example, a PVC pipe or bamboo casing, though less precise in finish, provides sufficient structural stability at a fraction of the cost and with lower environmental impact. Aluminium foil or beverage-can reflectors may not match the optical efficiency of commercial parabolic reflectors, but they can achieve acceptable levels of light concentration for everyday use. Natural materials, such as coconut shells and clay, also introduce biodegradability into the design, further reducing environmental burdens. However, challenges remain in terms of standardization, durability, and long-term performance, as locally sourced materials may degrade faster under repeated stress or harsh weather conditions.

Ultimately, the comparison reveals that while commercial materials ensure optimal performance, local alternatives strike a balance between functionality, cost, and environmental sustainability. In contexts where affordability and repairability outweigh the need for high precision, locally available materials present a practical pathway toward circular design.

B. Building Local Ecosystems and Policy Support for Waste-to-Wealth Flashlights

Beyond environmental sustainability and technical feasibility, the reuse of e-waste and local materials for flashlight construction has the potential to generate profound socioeconomic benefits in rural communities [17]. One of the most promising pathways is the creation of localized ecosystems for the assembly, sales, and servicing of flashlights, supported by community-level training

programs. For community-driven waste-to-wealth flashlight projects to succeed, supportive policies and institutional frameworks are critical. Policies can ensure that efforts are not isolated experiments but become sustainable and replicable models across rural regions.

Several key policy areas are relevant:

1. *E-Waste Collection and Extended Producer Responsibility (EPR)*: Governments can strengthen e-waste collection at the village and municipal levels, requiring manufacturers to support take-back schemes. Collected devices can then be channelled into community recycling and assembly workshops rather than centralized disposal.
2. *Skill Development and Training Programs*: National initiatives like Skill India and Digital India could integrate green electronics training modules specifically designed for women and youth. Training in the safe handling of e-waste, basic electronics assembly, and repair would empower rural populations to build and maintain flashlights.
3. *Microenterprise and Financial Support*: Policies promoting microfinance, subsidies, and cooperatives can help rural entrepreneurs set up small-scale flashlight assembly units. Linking this to rural livelihood schemes (e.g., India's National Rural Livelihood Mission) ensures economic viability for communities below the poverty line.
4. *Circular Economy and Eco-Design Standards*: Policymakers should encourage eco-design principles by mandating that flashlights and similar devices be modular and repairable, making it easier to reuse parts. Integration with India's Circular Economy Action Plan or global frameworks, such as the Basel Convention, would strengthen sustainability goals.
5. *Renewable Energy and Rural Electrification Policies*: Many countries, including India, run rural solar energy programs. By integrating solar charging for flashlights into these policies, governments can promote hybrid lighting solutions that reduce dependency on disposable batteries.
6. *Public-Private-Community Partnerships*: Partnerships between governments, NGOs, and private firms could support scaling production. For example, NGOs can provide training, local governments can facilitate infrastructure, and companies can donate e-waste or provide supply-chain support.

This ecosystemic approach can be visually summarized in Figure 5, which illustrates how the collection of discarded materials feeds into community assembly workshops, leading to sales and ongoing servicing within villages. By localizing the entire cycle, from resource recovery to distribution and maintenance, the model ensures that both economic and social value remain within the community. Women and youth trained in assembly and repair not only gain employment opportunities but also acquire technical skills that can be applied across other domains of sustainable development.



Fig.5 Ecosystem Model for Waste-to-Wealth Flashlight Production in Rural Communities

In this way, the waste-to-wealth flashlight initiative becomes more than a technological intervention; it evolves into a community-driven ecosystem for livelihood creation, empowerment, and long-term resilience. In essence, implementing waste-to-wealth flashlight projects in rural areas can transform discarded electronics into not only affordable lighting solutions but also pathways for poverty reduction and gender empowerment. By embedding assembly, servicing, and sales within villages, communities can build resilience, self-reliance, and sustainable livelihoods around the simple but transformative technology of the flashlight.

IV. CASE STUDY

A. Repurposing E-Waste for Rural Lighting

Repurposing e-waste for rural lighting has been explored across diverse contexts, demonstrating both the technical feasibility of such solutions and their community development potential. These case studies provide evidence that discarded electronic components, when paired with local innovation and training, can deliver affordable, sustainable, and socially empowering lighting systems.

One of the most widely cited examples comes from Kenya, where Mills *et al.* reported on community workshops that assembled solar-powered flashlights using discarded materials. In these projects, LEDs were salvaged from broken appliances, while plastic casings were repurposed from bottles and electronic housings. The total production cost of these devices was under \$2, compared to \$5–\$10 for commercial equivalents. Beyond affordability, the projects also emphasized local reparability, allowing communities to extend the lifespan of their devices without reliance on external supply chains. This underscores the importance of combining technical reuse strategies with educational training, ensuring that communities gain not just products but also the skills to maintain them [19].

In Ghana, Rogers and Henderson (2010) described the “Twig Light,” a low-cost flashlight constructed using repurposed radio components, scrap plastic, and simple

wiring. The project was notable for its explicit focus on the empowerment of women and youth, who were trained in electronics assembly. By integrating waste reuse with skill-building, the Twig Light project illustrates how grassroots lighting initiatives can deliver both environmental benefits and livelihood opportunities. This reflects the principle of “learning by making,” where participatory design fosters ownership and resilience within marginalized communities [EJ1269886].

Another important case comes from Bangladesh, where Islam *et al.* reported the development of solar study lamps built using recycled mobile phone batteries and small solar panels [20]. Costing less than \$3 per unit, these lamps were distributed to off-grid students, significantly improving their ability to study after dark. The reuse of lithium-ion batteries in this context illustrates the practical potential of second-life energy storage systems, a theme also emphasized by Tran *et al.*, who argued that reusing discarded cells for low-voltage applications reduces environmental burdens associated with primary battery production and disposal.

Moreover, the project highlights the role of education-focused deployment: by targeting schoolchildren, the initiative maximized social impact while extending the lifespan of discarded electronic components. In India, several grassroots initiatives have experimented with repairable torch projects built from e-waste and local materials. These devices were designed for easy disassembly, allowing microentrepreneurs to repair and resell them within their villages. Such modularity reflects circular economy design principles, which advocate durability, reparability, and adaptability in small devices. Moreover, these projects created local repair networks, reducing reliance on disposable imports and enhancing the economic resilience of rural households [21].

Taken together, these case studies demonstrate that the reuse of e-waste for flashlight production is not only technically viable but also socially transformative. They show that simple, low-cost interventions can turn discarded materials into vital tools for education, safety, and livelihood. At the same time, the diversity of approaches, ranging from solar-powered lamps in Bangladesh to repairable torches in India, illustrates the adaptability of e-waste reuse strategies to local cultural and material contexts. As Masters and Garski (2025) argue in their eco-flashlight design project, small-scale innovations in lighting can also serve as educational platforms, embedding sustainability principles in both formal learning environments and community workshops. These case studies highlight a broader theme: when e-waste reuse is combined with local training, community engagement, and circular design principles, it offers a pathway not only to affordable lighting but also to socio-technical empowerment. By reframing waste as a resource, rural communities can actively participate in the creation of sustainable technologies rather than remain passive consumers of imported, disposable goods.

TABLE III SOCIOECONOMIC IMPACTS OF CIRCULAR FLASHLIGHT PROJECTS

Impact Dimension	Benefits	Example Case Study
Environment	Reduced e-waste, reuse of hazardous components	Battery reuse in Bangladesh study lamps
Economy	Job creation, micro-entrepreneurship	Ghana “Twig Light” project
Education	DIY workshops, skill training	Eco-flashlight school projects
Energy Access	Affordable, durable lighting for rural poor	Kenya solar flashlight workshops

V. CONCLUSION

The review demonstrates that e-waste, when re-imagined as a reservoir of usable components, provides a powerful opportunity to address the dual crises of energy poverty and electronic waste accumulation. By reclaiming batteries, LEDs, switches, and circuit boards from discarded devices and combining them with locally available materials such as bamboo, coconut shells, PVC pipes, and scrap metals, communities can construct low-cost, durable, and repairable flashlights that directly respond to rural energy needs. Case studies from Kenya, Ghana, Bangladesh, and India highlight that these solutions are not only technically feasible but also socially transformative, creating opportunities for education, skill development, and micro-entrepreneurship. From a materials science perspective, the analysis shows that alternative materials can effectively substitute for conventional plastics and metals, offering adequate strength, insulation, and optical properties while lowering environmental impact. On the technological front, reused lithium-ion batteries and salvaged LEDs represent particularly high-value components, enabling efficient, long-lasting devices that outperform disposable alternatives. While challenges remain—including safety risks in handling batteries, lack of standardized collection systems, and limited awareness of reuse practices—emerging frameworks in circular economy and appropriate technology provide promising pathways to overcome these barriers. Crucially, the reuse of e-waste for flashlight construction should not be seen merely as a stopgap solution but as part of a broader paradigm shift. When integrated into repair networks, school workshops, and grassroots enterprises, such initiatives foster community resilience, environmental stewardship, and energy equity. They demonstrate how simple technologies, when redesigned through circular principles, can contribute to global goals such as SDG 7 (Affordable and Clean Energy) and SDG 12 (Responsible Consumption and Production). In conclusion, e-waste-based flashlights embody the essence of “waste-to-wealth” innovation. They reduce environmental burdens, extend the life of valuable materials, and deliver affordable lighting to those most in need. The next steps lie in scaling these practices through policy support, technical training, and cross-sector collaboration, ensuring that the humble flashlight becomes not just a source of light, but a beacon of sustainable development.

Declaration of Conflicting

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