Piloting of treatment solutions and innovative finance models for problematic e-waste fractions

Implementation Report

PREVENT Waste Alliance
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Executive summary

This report describes in detail the mission commissioned by GIZ for the PREVENT Waste Alliance, i.e., delivery of *Piloting of treatment solutions and innovative finance models for problematic e-waste fractions,* that was carried out by the LANDBELL GROUP. The period of the assignment started on 1 July 2020 and ended on 30 November 2021.

The project aimed to find both treatment and financing solutions for fractions of waste electrical and electronic equipment (WEEE, henceforth called e-waste) for which recyclers in low- and middle-income countries have no local solutions, so-called problematic e-waste fractions. At the start, the project looked for opportunities to pilot solutions for 5 problematic fractions of e-waste (e-waste plastics, lithium-ion batteries, PUR insulation foams from refrigerators, mercury containing lamps and screens) in 3 regions (Balkans, South America and East/West Africa. Following a survey completed by 25 recyclers in the target regions and in-depth follow-up discussions in 2020, the focus was narrowed down to potential treatment pilots of e-waste plastics, PUR Foams and lithium-ion batteries with recyclers in Brazil, the Balkans, and East Africa. An additional pilot looking at exporting a mixed shipment of lamps and printer cartridges was explored in Senegal. Together with the selected recyclers, 4 treatment pilots were planned for 2021. These were to be supported with the use of 2 financing mechanisms.

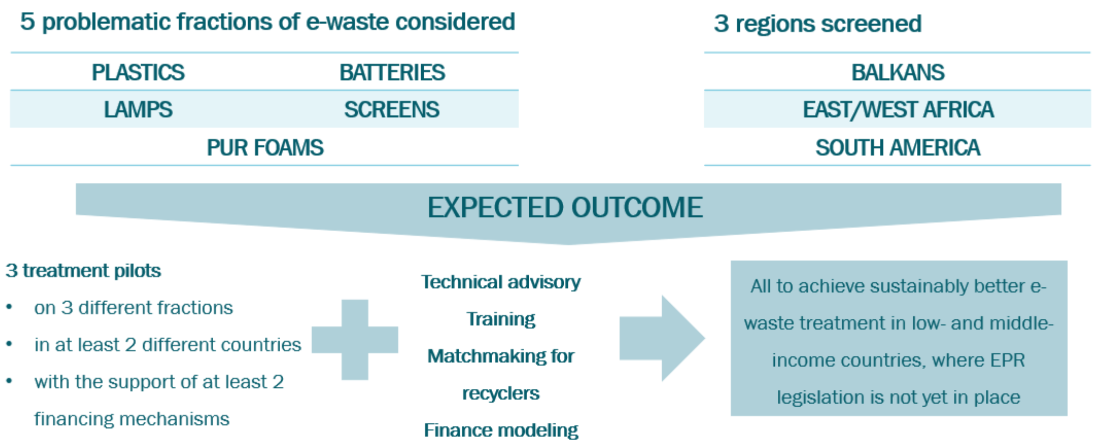

Figure 1. Project objectives

The 18-month project ended with goals partially achieved. As of December 2021, none of the planned treatment pilots has been fully completed or produced final results. 3 pilots are still in the preparation stage, and 1 proved impossible to execute in the selected region. Due to the Covid-19 Pandemic, the project team was not able to conduct site-visits in person to assess local options and build up personal relationships with recyclers in the project. The impacts on recyclers and the shipping industry during the pandemic also made it challenging to move some materials. While much was possible via videoconferencing and pictures, this ultimately slowed down communications. Expectations of recyclers were also not always in line with the project, with some hoping to receive all costs covered or grants for infrastructure. Despite these challenges the project team was able to initiate solutions with recycling partners on several problematic fractions, advance discussions with potential finance partners and elaborate the steps and economic boundaries for piloting of such treatments to take place:

- In East Africa a recycler was identified in Tanzania (Chilambo General Trade) who had collected 60 tons of lithium-ion batteries. The project team supported this recycler to sort and classify these batteries, finding that the vast majority were Lithium Iron Phosphate (LiFePo or LFP) batteries commonly used in solar applications. Local recycling facilities for lithium-ion batteries do not yet exist in Africa, and at the present time, export of LFP batteries is not viable due to high treatment costs (ca. 1000€ per ton) at receiving facilities in Asia or Europe. Due to high recycling cost of LFP batteries, their local repurposing was investigated as an interim solution. The first assessment shows that the process could be economically viable and not only finance the treatment of end-of-life cells but also provide good revenue to the local recycler. Further steps are necessary to turn these battery packs into marketable second-life products on the local market, but discussions with battery re-purposing companies in the region indicate that re-purposed battery packs could have good potential on the local market, even with better performance and price than low quality new imports.
- In Brazil, Circular Brain, a local start-up, aims to bring traceability to the recycling market through consolidating materials produced by recyclers and tracking these from dismantling through to the entry into new products, supporting the circular economy. Due to the potential to collect plastics from recyclers across the whole market, Circular Brain was selected to receive advisory support in order to initiate the market for e-waste plastics recycling in Brazil. The project team supported through technical advice, supporting exchange with suitable compounders and connecting to Electrolux Brazil (an Original Equipment Manufacturer (OEM)) as a possible offtaker who would potentially pay for high quality recycled plastics from e-waste in Brazil. The project team and Circular Brain conducted a hybrid online and in-person training in Sau Paulo at Grupo Reciclo in November 2021 with around 50 participants. The training focused on how to classify, sort and manage e-waste plastics, and it is hoped that the seed has been planted for an e-waste plastics recycling market to develop in Brazil going forwards.
- In the Balkans, discussions were undertaken with recyclers and a carbon credit trading company for a potential shipment of PUR foams containing climate forcing refrigerants (R11) to a certified destruction facility in Greece or Western Europe. The discussions with the recycler broke down when the 28 tons of foams on hand were landfilled, making the pilot unviable within the project timeframe. Despite this, a theoretical model for financing of PUR foams via carbon credits was elaborated. Carbon credits could be applicable for recyclers operating in countries with no R11 and R12 destruction obligation in local legislation. The ultimate profit or loss on this operation depends, among others, on the country of origin, country of destination, logistics cost and current value of CO_2 certificates, meaning any project of a similar nature will have to be assessed case by case. So that these efforts are not in vain, Assessment Guidelines for a future pilot along these lines were developed;
- Of the remaining recyclers surveyed, SetTIC in Senegal was kept as an additional option to support in conducting a shipment of some problematic fractions together with some profitable fractions to enable cross-financing of the overall treatment costs between waste streams. While such cross-financing of a mixed waste shipment is not innovative and has already been undertaken by recyclers, it was felt

that sharing how to approach such an exercise and sharing information on costs could be generally helpful to smaller recyclers looking for solutions to some of their e-waste fractions. In this instance, the problematic fractions with net treatment costs are printer cartridges and several thousand mercury containing lamps, which would be sent together with printed circuit boards and cables for treatment at different sites across Europe. The pathway to this solution has been set up, with an offtaker company in Europe that would be prepared to take the whole mixed shipment and send on to other partners for further processing. The next steps are to start the Basel Notification Process and proceed on the shipment, if no better local solutions are found.

The project team often ran into issues around transboundary shipments and the Basel Convention Notifications process, which must be applied for the transport of hazardous wastes between countries[1]. In particular this had a bearing on the best transport routes to take, but also collaboration options between recyclers in different countries. In East Africa it was not possible to ship a small sample of batteries across the border for testing at a re-purposing facility without undergoing a Basel notification processes, and instead some basic testing equipment was sent to the recycler. Even after testing and determining the cells to be functional, it remains an administrative challenge to send the tested batteries across borders to be transformed into exemplary re-purposed battery packs.

While the number of treatment pilots was originally limited to three options, most of the recyclers approached (surveyed) received support in the form of technical advice as well as matchmaking with state-of-art recyclers operating in industrialised countries. In November 2021, approximately 200 participants profited from online trainings on how to identify, classify, sort and manage end of life batteries (online in *English* and *French*) and e-waste plastics (online in *English* and in a hybrid format in *Portuguese* with local attendance in Sau Paulo; slides in *French* were also developed). Financial models were developed in Excel for the different pilot fractions, which are available together with the training material and recordings on the *PREVENT website*/*PREVENT Youtube*.

This report documents all the main obstacles met, activities undertaken, their outcome (both positive and negative), replicability potential and key lessons learnt. The report starts with introducing the project goals and background, before explaining the methodology behind choosing the different treatment pilots and an overview of finance mechanisms considered. The recycler selection process and technical advisory is then explained. Following this, the treatment options for the different pilots are described in detail, explaining the challenge that the e-waste fraction represents, the approach of the treatment pilot, and potential financing mechanisms. Finally, conclusions for future research are given.

[1] For more information on the challenges see *PREVENT-StEP Discussion Paper on Practical Experiences with the Basel Convention*

List of acronyms

ABS - Acrylonitrile Butadiene Styrene

BFRs – Brominated Flame Retardants

CAPEX – Capital Expenditure

CO_2 – Carbon Dioxide

CFCs - Chlorofluorocarbons

CRT – Cathode Ray Tube

EPR – Extended Producer Responsibility

EU – European Union

E-Waste - Waste from Electrical and Electronic Equipment (WEEE)

EWC – European Waste Code

GHG – Greenhouse Gas

GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH

GWP – Global Warming Potential

HCFCs – Hydrochlorofluorocarbons

HFCs - Hydrofluorocarbons

HIPS – High Impact Polystryrene

ICT - Information and Communication Technology

LCO – Lithium Cobalt Oxide

LFP – Lithium Iron Phosphate

Li-Ion – Lithium-Ion
LIB – Lithium-Ion Battery

MSDS – Material Safety Data Sheet

ODP - Ozone Depletion Potential

ODS – Ozone Depleting Substance

OPEX – Operational Expenditure

PCBs – Printed Circuit Boards

PP – Polypropylene

PRO – Producer Responsibility Organisation

PUR – Polyurethane

TFS – Transfrontier Shipment

VAT – Value Added Tax

WEEE – Waste from Electrical and Electronic Equipment (E-Waste)

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1 Project description and objectives

With membership of over 70 organisations based in more than 25 countries worldwide, the PREVENT Waste Alliance **E-Waste Working Group** focuses on supporting the development of take-back and recycling systems for waste from electrical and electronic equipment (WEEE, generally referred to as e-waste in this report), adapted to local conditions.

Providing support to formal recyclers in low- and middle-income countries can generate local options for the sustainable recycling of e-waste, support the establishment of sustainable local e-waste recycling industry and provide an ecosystem around which policy makers can develop formal recycling legislation. While numerous formal recyclers in low- and middle-income countries treat specific (usually higher value) fractions from e-waste, it is often challenging to scale businesses and maintain profitability if a supporting legal framework is absent. In 2019 the PREVENT E-Waste Working Group contacted recyclers across Africa, South America and the Balkans to determine where the challenges with specific e-waste fractions lie. It was seen that various ***problematic fractions*** pose a challenge to formal recyclers, including: e-waste plastics, PUR refrigerator foams, batteries (lithium and disposable), fluorescent lamps and screens.

Each of these problematic fractions is usually associated with a treatment cost under environmentally sound treatment methods, and often no local treatment infrastructure exists, meaning that recycling is only an option if the fraction is exported to international facilities. Recyclers in low- and middle-income countries can benefit from better understanding their local recycling options and gaining better access to international recycling markets, particularly if they are able to process e-waste fractions to the required quality for further processing and shipment. When correctly sorted and separated, for instance, e-waste plastics may have a value in local manufacturing or international recycling markets. However, the costs for processing and transport may be higher than the material value, which is also subject to price volatility in world markets. Additional finance is necessary to make recycling viable in the long term.

In OECD countries, the costs for managing such fractions are usually covered by Extended Producer Responsibility (EPR) legislation, which makes producers responsible to pay for the treatment costs of recycling. In contexts where no EPR legislation exists and is not likely to come into force in the near future, the treatment of problematic fractions remains an ongoing problem. Even if there are no local EPR financing mechanisms in place, there may still be ways to finance the treatment of problematic fractions through other arrangements. Innovative approaches to meeting these financing needs are urgently needed, however, beyond international project finance the viability of alternative financing mechanisms have been little explored or tried in practice.

To develop new solutions for dealing with these problematic fractions in situations where EPR schemes are not operational, the PREVENT Secretariat (hosted by GIZ and financed by the German Federal Ministry of Economic Cooperation and Development) developed an assignment with the following objectives:

- Develop and pilot solutions for treating problematic fractions and innovative models for the financing of treatment in low- and middle-income countries.
- Improve formal recycling of problematic e-waste fractions in low- and middle-income countries through advisory support and practical trainings.
- Develop a framework through which successful approaches might be scaled and applied in other contexts.

In June 2020 LANDBELL GROUP was awarded the contract for *Piloting of treatment solutions and innovative finance models for problematic e-waste fractions*.

The Project team was comprised of 7 consultants (and 3 backstoppers) providing the necessary technical expertise and regional experience. In addition to the consultant team and GIZ, other stakeholders, on an as-needed basis, were engaged to ensure completeness and quality of the deliverables. In particular, the members of the PREVENT Waste Alliance E-Waste Working Group were encouraged to collaborate with the project team through providing their input and ideas both by reviewing the Inception Report as well as by actively participating in teleconferences scheduled to brief interested parties on the project progress.

The project scope is described in detail below.

1.1 Providing technical and methodological support to e-waste recyclers in the Balkans, South America, and West/East Africa

This part of the project included the following steps:

- Providing remote support to individual recyclers already contacted in 2019 by the PREVENT Waste Alliance through a recycler survey and further recyclers surveyed by the project team,
- Developing local or international solutions for different problematic fractions which are not currently handled in an environmentally friendly way, or for which the recycler has no suitable off-takers yet,
- Optimising recycling processes and business models on targeted problematic fractions and carrying out 3 distinct pilots in selected countries,
- Developing training materials and providing trainings for recyclers on how to organize collection, dismantling, storage, sorting, packaging and shipment according to defined procedures.
- Bringing in further expertise following exchange with the PREVENT Secretariat,
- Matchmaking – facilitating contact and exchange between recyclers in Africa, the Balkans and South America and recyclers from technically developed markets.

1.2 Improving the treatment of problematic fractions (treatment pilot)

At the start of the project 5 problematic fractions of e-waste were considered for treatment pilots: plastics, batteries, PUR foams, lamps and CRT screens. Based on exchanges with recyclers through a recycler survey, this was narrowed down to 3 fractions to be targeted in the different regions: e-waste plastics, PUR foams and batteries, and in the course of the project another concept was added for further analysis – transboundary shipment of mixed loads of all stockpiled fractions that cannot be processed locally. For these 3 fractions and the mixed waste load, 4 treatment pathways were attempted. The choice was made based upon analysis of the volume of suitable material available, the recyclers' needs and assessment of the potential for finding treatment and financing solutions. The selection and potential pilots were shared with the PREVENT Waste Alliance members during an online exchange.

1.3 Applying innovative models for the financing of the abovementioned processes

Recyclers in the target regions were not expected to be capable of fully covering the costs of the problematic fractions, both during and after the treatment pilots. Since problematic fractions were targeted, it was expected that treatment solutions would, in the best-case scenario, be a net-cost activity. Therefore, the project team was required to conceptualise several innovative mechanisms to finance these processes in the long term. At least 2 of these models were to be implemented in the pilot projects. While it was not expected that the recyclers bear the full cost of the trials, the willingness of recyclers to engage resources, in kind or in cash in the pilot, was evaluated and considered positively.

2 Methodological approach

2.1 Recycler scoping

In an open survey in 2019, the PREVENT Waste Working Group received responses from 11 recyclers across the Balkans, Africa and Latin America on their problematic fractions. This led to the original focus on the five problematic fractions listed of lamps, screens, batteries, e-waste plastics and PUR foams. At the start of the assignment in mid 2020, the project team set out a more detailed questionnaire, translated into French and Portuguese and sent to further recyclers in their networks, receiving responses from 25 recyclers in total. The aim of the survey was to identify small and medium sized formal recyclers who have already accumulated large volumes of problematic fractions, and are unable to find solutions for these locally. Following general indications from the survey, the project team and GIZ conducted one-on-one discussions with the recyclers, in which technical advice was given, as well as possible matchmaking. These sessions provided the basis to shortlist candidates for treatment pilots, in which 3 recyclers (1 per target region) could be supported for the treatment and financing pilot. The purpose of the pilots was not to help the largest/strongest recyclers but support those who would really benefit from the project, i.e., small to midsize entities.

2.2 Recycler and fraction selection coupled with technical advisory

The project team analysed thoroughly the answers given in the questionnaires and engaged in one-to-one exchanges with company representatives. Analysed were the types and volumes of available problematic fractions, current treatment processes, challenges faced by recyclers, possibilities to improve recycling within their facilities, finding local outlets and/or exporting abroad. Interactions with recyclers confirmed that the 5 fractions selected for this project are a common problem for most interviewees, regardless of the country they operate in. The main findings were:

- Small recyclers (e.g., 100-200 tons of waste treated per annum) have trouble finding outlets for their output fractions because downstream offtakers are not interested in small quantities. Not every recycler can accumulate and store waste until minimum batch size required for recycling is achieved.
- Computer peripherals (keyboards, printers) are problematic across all 3 regions due to low value of extracted materials. A number of recyclers also reported problems finding solutions for toner and ink cartridges, which was out of scope of the current project. All of these fractions require further attention in future projects due to no processing capacities on local markets;
- There is a general lack of funds to invest in technology (shredders, grinders and balers for plastics, presses for metals, display and wire cutters, mercury capture and purification systems for fluorescent lamps).
- Some recyclers are already advanced in finding solutions to problematic fractions (running treatment pilots on their own, trying to develop finance mechanisms in cooperation with a consulting firm, having experience with exporting recyclable fractions under Basel notification procedure);
- There is very little knowledge on how to manage batteries (how to identify their types and chemistries, how to collect, transport, sort, store and extract value) and what is

needed to ship them abroad. A few companies underlined bureaucratic difficulties and lack of know-how on waste exports and Basel notification procedure;

- A challenge in Brazil seems to be development of a good downstream recycling chain for e-waste plastics. There are large companies interested in a stable supply chain of good quality recycled plastics but good plastic processors are hard to find. Access to plastics sorting and processing technology is difficult because Brazil does not have companies manufacturing such equipment locally – expensive technology import is needed;
- The solar energy industry in Africa is thriving and lithium ion batteries (LFP) from off-grid photovoltaic systems and solar lamps constitute a big share of collected waste. Believing that all Li-Ion batteries can generate good revenue, some recyclers not only collect them locally, but also import them additionally. Eventually, batteries are stock-piled without having a local recycling solution in place;

Discussions with recyclers, whether or not pre-selected for the pilot projects, created many opportunities for consultants to share their know-how and provide technical advice where asked and where possible. In the course of the mission the following problems were identified and tackled:

- **Optical fiber cables:** offtakers of this telecom waste were searched for. The networking process was activated by examining many options, such as Shields Environnement located in Africa, MTB Recycling based in France, SIMS Mirec in Belgium (and one more company in the Netherlands that did not provide any feedback). However, the recycling market is not mature for this type of waste with poor value. Another process was identified in the USA but the costs of transportation and treatment, and the feasability of the shipment were eventually not evaluated;
- **Capacitors:** networking was activated with TREDI France for the final disposal of waste;
- **Pyrolisis facility audit process:** a short list of control topics (evaluation questions) was developed to help a recycler evaluate the validity of the proposed process;
- **Separation of funnel and panel glass from CRT tubes in TVs and monitors:** advice on the best available technology and associated costs was given. Technologies in scope are most prominently hot wire, laser cutting and diamond cutting. The recycler was advised that in Europe a simple technique like careful crushing of a tube with a hammer and manual separation of funnel and panel glass is applied, with purity of barium glass exceeding 98 %. Therefore, there is no need for a capital-intensive investment in advanced technologies to separate both glass fractions.

Having analysed the comments made by the approached recyclers, the project team proceeded to select the fractions and pilot candidates. The project aimed to be global in scope, so although recyclers in some countries looked promising, it was decided to focus on one pilot fraction per region. Based on the methodology illustrated by Figure 2, the project team pre-selected the fractions and recyclers as candidates for the pilot projects, as described in chapters 2.2.1 - 2.2.3. The recycler and fraction choices were presented and discussed with the PREVENT E-Waste Working Group in October 2020. While there were numerous promising candidates, some companies were not selected due to having relatively small volumes of the fractions in question, being too advanced, having already recently benefited from development cooperation projects, being part of an international recycling company, which could provide the support, or having EPR legislation either in place, or coming into force in their country (e.g., Nigeria).

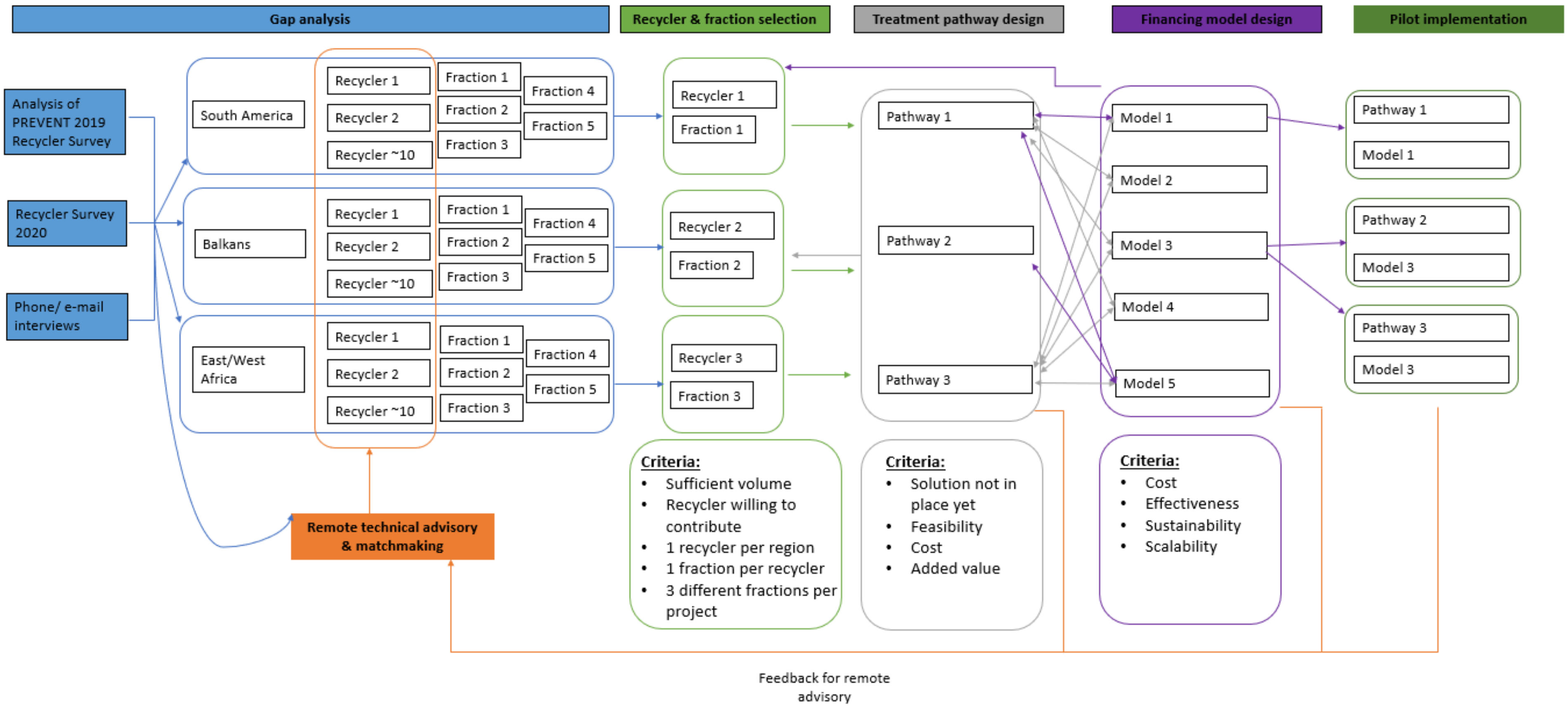

Figure 2. Recycler, region, fraction and finance model selection matrix

2.2.1 Africa

Recyclers based in Africa were very willing to exchange and participate in the project. Responses were received from 11 recyclers in total. Following promising responses on the targeted fractions, discussions were held with recyclers in Kenya, Rwanda, Tanzania, Senegal, Nigeria and Morocco, while surveys were also received from recyclers in Namibia, Niger, Burundi, and Zambia. Having analysed the questionnaires and follow-up interviews, the project team selected two promising pilot candidates in East and West Africa.

In East Africa, Chilambo General Trade based in Tanzania was selected as they had a significant volume of problematic fractions readily available, but specifically due to the fact that they had collected 60 tons of Lithium-ion Batteries at the time of contact, and there is no solution in Tanzania for this waste stream. Discussions with other recyclers across Africa indicated that the lithium-ion battery waste stream was growing, and several recyclers are looking into solutions. Several projects have been implemented on this topic with recyclers in Kenya and in Rwanda in recent years[2], while the ECON project of the PREVENT Waste Alliance has investigated feasibility of recycling solutions in Nigeria[3]. It was therefore felt that attempting a pilot treatment solution in Tanzania could support ongoing activities and provide additional knowledge to other recyclers in the region.

In West Africa, SetTIC based in Senegal had originally been in discussions with the PREVENT E-Waste Working Group in 2019 to develop a solution for mercury containing lamps. These discussions were already quite advanced, so this option was kept open for a treatment pilot. As the project went on, the focus moved towards finding a solution for a mixed shipment due to the presence of CRT screens, printed circuit boards, printer cartridges and lamps.

2.2.2 The Balkans

The original survey by the PREVENT Working Group had provided answers from Albania, Serbia, Montenegro and North Macedonia. While some of these companies were interested to cooperate in 2019, a year later some had lost interest. Following further research and numerous contact attempts to other recyclers in the region, initially only one company (anonymised here as the pilot did not continue) showed interest and met the criteria for a pilot. The pre-selected company reported to have 28 tons of PUR foams from old refrigerators on stock (i.e., with a high presence of CFC refrigerants), making it a very interesting business case. According to the information shared, the existing treatment process was to landfill these foams. The recycler also expressed a need in the area of batteries, however, as this fraction was pre-selected for further support in Africa, the project team decided to focus in the Balkans on PUR foams.

2.2.3 South America

The PREVENT Waste Working Group and the project team received responses and exchanged with recyclers across Chile, Peru, Ecuador and Brazil. Discussions with recyclers and financial institutions active in the region (e.g, BVRio and Circular Brain) led the project team to narrow down the focus to Brazil and e-waste plastics. All companies contacted in Brazil underlined that e-waste plastics is a very common problem: while there are potential

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[2] INNOVATIONS AND LESSONS IN SOLAR E-WASTE MANAGEMENT *https://storage.googleapis.com/e4a-website-assets/Clasp_EforA-SolarEWaste_5-May.pdf*

[3] *E-waste Compensation as an international financing mechanism in Nigeria (ECON) - PREVENT Waste Alliance (prevent-waste.net)*

offtakers, recyclers can neither deliver to the expected purity level nor supply stable quantities. The knowledge on how to separate different polymers, and especially those contaminated with hazardous substances like brominated flame retardants (BFRs), is missing and most companies use very simple and harmful to human health techniques, i.e., burning and sniffing to identify polymers. Another problem is the size of the country and the very scattered recycling infrastructure, making transport cost very high, thus negatively impacting any reverse logistics undertakings.

A Brazilian recycler, with 160 tons of plastics per annum, was first classified as the most promising candidate for a pilot. They already had a prospective offtaker for the output fraction, however, could not meet the high standards set by this company. As the recycler was relatively large and the aim of the project was not to support the biggest players in the country, it was eventually felt that it would be best to design a pilot that could provide support to the wider market. The project team saw scope for developing such a solution through collaborating with Circular Brain, a new start-up spin-off from the pre-selected recycler that aims to provide solutions to the e-waste market in Brazil by tracing individual components from WEEE dismantling and recycling from recycler to producer. Therefore, Circular Brain was selected as the cooperation partner on e-waste plastics and the recycler declared that they would share the know-how developed in the course of the project, train smaller recyclers and/or integrate them in the process (e.g., suppliers).

2.3 Innovative finance modelling

The project team, in collaboration with selected PREVENT Waste Alliance members and GIZ, explored and designed options for 3 to 5 innovative models to enable a longer-term funding mechanism for the treatment of problematic e-waste fractions independent of local EPR legislation. The intended outcome of developing financing mechanisms was predominantly to enable systemic change with regards to financing e-waste management internationally. The aim was not to finance infrastructure in a one-off payment, but to demonstrate mechanisms in which the treatment costs can be covered during the treatment pilots and enable this to be replicated or scaled. Such an approach could change the framework conditions, highlighting pathways (mid- to long-term) for the establishment of finance mechanisms that could support treatment of e-waste fractions in the transition period until a local EPR system is effectively implemented. Such mechanisms should not replace local financing (through e.g., EPR), but be complementary to and support the set-up of local legislation and systems.

The following models listed in table 1 were initially considered, each having different pros and cons, scalability potential, effectiveness, costs, and sustainability:

Mechanism	Description	Time to implement	Complexity	Cost	Effectiveness	Sustaina-bility	Scalability
Voluntary take-back	Producer(s) committing under a cooperation agreement to support, for a given period or a given waste volume the cost of proper processing of the waste	+	+	+	Direct impact on the stream and operations	+	++
Voluntary PRO	More structured and advanced than voluntary take-back. More commitment needed	++	++	++	Direct impact on the stream and operations	++	++
Recycler label scheme	Certification of recyclers that apply the minimum levels of waste treatment, in combination with a policy of public purchasing mandating equipment sellers to commit to the disposal of used equipment removed as part of the tender to be treated in certified facilities	++	++	+	Indirect through market demand	++	++
Producer label scheme	Certification of producers/ products/brands who financially support recommended e-waste management processes (and related recyclers) in developing economies.	++/+++	+++	++/ +++	Depends on the appeal of the certificate	++	++
Recycling Angel scheme	Private entity adopts and financially supports a designated treatment facility for some time to help it deliver the expected process and results	++	++	++	Can channel funds directly to a specific recipient	++	+++
EU-wide mechanism for used EEE	Exporters of used EEE pay for each kg of equipment exported to the defined geographies. This money is collected by a clearing house and distributed to recyclers operating in countries in scope	+++	+++	+++	Direct financial impact based on the very products that are exported	+++	+++
Carbon credits	Proper recycling of PUR foam prevents release of high GWP gases and could generate tradeable carbon credits	++	++	++	Would generate direct channel funds to the recycler	+++	+++

Table 1. Finance mechanisms considered in the project

2.3.1 Exchanges with financial partners

Exchanges were made with the following potential partners to check if and how the existing financing mechanisms could be applied:

- **TCO Development** – discussion on how *TCO Certified Edge*, e-waste compensation mechanism, could support the project. TCO Development's concept is that commercial customers who procure new ICT equipment can support recycling in developing economies by paying a premium. The mechanism can be offered to both producers and consumers (premium can be equally shared), involving more stakeholders, and thus making the solution cheaper and more acceptable to those who want to use it. The mechanism is one type of producer label scheme (see list above) ready to be applied in practice but had not been in use yet at the time of the exchange.
- **BVRio** – Circular Action Hub developed by BVRio is meant to support circular economy initiatives. The platform gathers projects where financial support is needed and provides

matchmaking with donors looking for initiatives worth financing. The mechanism was launched in August 2020. This type of a Recycling Angel scheme (see list above) could financially support a recycling solution for any kind of problematic fraction, or simply provide a platform for trading the valuable output fractions.

- Closing the Loop – this company operates out of the Netherlands and uses an e-waste compensation mechanism to support waste collection in Africa on behalf of companies having green procurement in their corporate strategies. The solution includes the recycling part and ensures that waste is shipped to legitimate recyclers. The mechanism focuses on ICT, therefore only a limited number of fractions can be supported, however an extension to lithium ion batteries and screens is being explored in the *PREVENT ECON* project. The company cooperates closely with TCO Development already. Closing the Loop could be part of a solution involving TCO Development where TCO Development would collect the funds and Closing the Loop distribute them to the recyclers have implemented the revised processes.
- Circular Brain – the Think Circular software, developed by Circular Brain, aggregates data on streams and volumes treated by Brazilian recyclers. The software enables on one hand, that volumes (including problematic e-waste fractions) treated by different recyclers can be bundled together so that sufficient tonnage is achieved for off-takers (producers interested in particular waste streams for their closed loop projects or foreign recyclers setting minimum quotas to accept the material). On the other hand, the software can act as a clearing house and offer credits (certificates) to producers searching for environmental initiatives, applying the Producer Label or Recycling Angel Scheme mechanisms.
- Tradewater – U.S. company helping to prevent runaway climate change by removing potent gases before their leakage into atmosphere. Refrigerant, carbon credit projects are conducted pursuant to scientifically reviewed protocols, and each project is independently audited to ensure full compliance. Tradewater is a potential partner who could finance extraction, export and treatment of PUR foams, and that could be done together with carbon credit generation.
- Ecosecurities – company based in Switzerland, offering help in carbon credit generation and monetization. The purpose of the discussion was to check whether the company could support the recognition of PUR foams treatment as a source of carbon credits, and compare their approach to the one presented by Tradewater. Ecosecurities declared themselves eager to investigate, however the typical turnaround time of two years exceeded the project duration. Ecosecurities market their services on a time and material basis but can also consider differered remuneration through the carbon credit trading process.
- Cirplus – global marketplace for recycled plastics. Concept similar to Circular Brain, i.e. the platform connects supply with demand, however, the focus is on plastics in general, and not e-waste plastics specifically. No presence in Latin America as of now, however, the startup wants to expand to this region, and wants to translate its offering into Portuguese.

The table below summarizes various options at play as of December 2020:

	Certification Verification	Trading	Market Place	Credit System	Material Focus
Circular Action Hub			X	X	N/A
Circular Brain		X	X		E-Waste
Cirplus			X		Plastics
Closing the Loop				X	ICT
Ecosecurities	X	X		X	PUR Foam
TCO Development	X				ICT
Tradewater	X	X		X	PUR Foam

Table 2. Potential providers of finance mechanisms for treatment of the selected waste fractions

Out of all the above finance mechanisms, the project team eventually decided to focus on carbon credits (two options were explored with Tradewater and Ecosecurities), and the trading and marketplace option (Circular Brain). Project finance via BVRio could still be an option when forces are joined with Circular Brain, however, the project timeline was too short to bring the pilot to the required stage enabling such a combination. It was also decided that e-waste compensation mechanisms would be difficult to apply, given that none of the waste streams in focus constituted pure ICT and complete end-of-life devices. Individual producer responsibility was explored in East Africa for batteries, but ultimately the project pivoted towards creating a new market for refurbished batteries. Another, less innovative approach of cross financing was explored with a mixed shipment of waste to one European site so that revenue generated from recycling high-value fractions would cover the treatment cost of non-value fractions. A few global EEE producers were contacted with the intention of checking their potential interest in supporting the project (e.g. establishing voluntary take-back schemes, voluntary PRO, producer label scheme) in the regions of their influence. Only one company eventually declared interest and support. That option was explored in Brazil where a producer of white goods was willing to engage in the project to get access to secondary material for their production.

2.4 Defining treatment pilots - summary

In December 2020 the General Assembly of the PREVENT Waste Alliance E-Waste Working Group took place. During this event the project team shared the following ideas for pilot projects and their financing:

REGION	BALKANS	EAST AFRICA	SOUTH AMERICA (BRAZIL)	WEST AFRICA
FRACTION	PUR foams	Li-Ion batteries	Plastics	Mixed waste
PROJECT DESCRIPTION	Shipment of PUR foams to a certified recycling facility in Greece	Shipment of complete batteries for recycling to Asia or pre-treatment locally and shipment of powder only. Solution could benefit also neighbouring countries	Creation of consolidation & sorting center(s) for plastics from smaller recyclers to offer offtakers expected volume and quality levels. Disposal of contaminated fractions funded with revenue from offtakers	Shipment of all e-waste fractions collected by the recycler to Europe
POTENTIAL FINANCE PARTNER	Tradewater or equivalent	Producer (tbc) and/or BVRio	Circular Brain & BVRio	n/a
FINANCE MODEL	Carbon credits	Fundraising (Circular Action Hub)	Market place for trading of valuable fractions (Circular Brain) + Fundraising for consolidation centre (Circular Action Hub)	Cross-financing

Table 3. Summary of selected projects for the pilots

The General Assembly did not object to the above ideas, therefore the project team concentrated their efforts on developing the pilot projects, as explained in the next Chapter.

3 Development of solutions to problematic fractions

3.1 PUR foams in the Balkans

3.1.1 Identification of the problem

Refrigerators and freezers are insulated with a layer of rigid polyurethane (PUR) foam that acts as both a structural and an insulating material. The adhesive properties of polyurethane ensure a firm bond between the inner and outer walls, and also help prevent heat exchange between the interior and exterior. To give the foam good insulation properties, it is usually expanded with a foam blowing agent. Numerous gases can be used in the foams and cooling circuit. In the past these contained chlorofluorocarbons (CFCs) which have been regulated since the Montreal Protocol came into force in 1989. These CFCs affect the ozone layer and are so called Ozone Depleting Substances (ODS), as well as having major Global Warming Potentials (GWP) over 100 years of up to 10,900 times higher than carbon dioxide (CO_2) (see table 4 below). In 1994, production of these CFCs in industrialised countries was stopped and manufacturers started to use hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs, such as R134a) as refrigerants and blowing agents which have no ozone depleting potential (ODP) but a high global warming potential – these are also now being slowly phased out of production following the Kigali Amendment to the Montreal Protocol that entered into force in 2019.

Refrigerators and freezers produced before 1995 in industrialised countries and before 2010 in developing countries often contain R12 as refrigerant in the cooling circuit and R11 as foam blowing agent, with PUR foam containing typically about 5% R11. On average about 130 g of R12 and 310 g of R11 is found in refrigerators and freezers produced before 1995 and arriving in European recycling facilities today. Both substances have very high GWP and ODP values. While some producers leapfrogged to the use of natural refrigerants and foam blowing agents, others moved to the HFC R134a and foam blowing agent HCFC 141b as an intermediate solution. Nowadays, state of the art cooling devices have R600a as refrigerant and pentane as foam blowing agent.

Refrigerant/ blowing agent	GWP in CO_2 equivalent (IPCC, 4th Assess. 100 yrs.,)	Ozone Depleting Potential	Typically used in refrigerators
R11	4,750	1	Until 1994 (in industrialised countries)
R12	10,900	1	Until 1994 (in industrialised countries)
R134a	1,430	0	This refrigerant has been used in years following CFC phase out, but since the Kigali Ammendment these substances are being withdrawn too
R600a, R290 Propan (isobutane, pentane - natural refrigerants)	3	0	Since 2019 encouraged more

Table 4. Global Warming Potentials and Ozone Depleting Potentials of refrigerants and blowing agents[4]

[4] Greenhouse Gas Protocol, Global Warming Potential Values: *https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf*

While in industrialised countries such as in the EU R11/R12-containing equipment is still found in WEEE entering the waste management system in a share between 30% and 70%[5], this variation is much wider in low- and middle-income economies. The share of equipment containing these refrigerants and blowing agents depends on when the local market phased out these substances and on the number of used imports from industrialised nations. A higher share of R11/R12 equipment in these markets can be due to the fact that appliances tend to have longer lifecycles in developing countries and there is high demand for used appliances from industrialised nations. Other barriers preventing producers in low- and middle-income countries from switching to natural refrigerants earlier were economic, technological and political. A lower share of R11/R12-containing equipment can be observed in countries that have experienced economic growth mostly in the last 20 years e.g., Singapore, Hong Kong, Israel) where refrigerants in most appliances tend to be R600a[6].

In the recycler survey, several recyclers reported challenges or even impossibility to recycle refrigerators according to high treatment standards all-together due to its costs and complexity. In other studies, recyclers have reported no known solution for managing their foams, which are ultimately stockpiled in large, flammable piles next to or on their yard (see Fig. 3). The reason for this is that refrigerator recycling facilities and refrigerant destruction facilities often require high investments and high operational costs. These technologies cost from several hundred thousand to several million Euros depending on the recycling functions and to operate efficiently need a minimum throughput of refrigerators, often in the magnitude of hundreds of thousands per year. On top of this there are usually significant operating costs which cannot be offset by the cost of the valuable metals in the refrigerators alone and are normally subsidised by the local EPR system in industrialised countries. In many low- and middle-income countries the scope for setting up a complete facility is therefore limited: the collectable volumes are often too small and EPR systems either do not exist or are not yet operational, so there are no subsidies available. As a result, there is no investment case for such facilities until financing is available.

Figure 3: Example of PUR foams piled up at a formal recycler. © Daniel Hinchliffe / GIZ

[5] Source: Landbell Group Data

[6] Source: Landbell Group Data, reports from recyclers in the PREVENT working group

Due to inappropriate end-of-life management of refrigerators, their refrigerants and foam blowing agents, ODS and HFCs continue being released to the atmosphere. If not properly dismantled, a typical CFC containing domestic refrigerator will release 0,44 ODP kg and 2,9 tons CO_2 equivalent[7]. In the worst case, foams will be left to the informal recycling sector which likes to use them to sustain a fire and to get high temperatures e.g. for burning cables, releasing numerous other toxic substances to the atmosphere as shown in Fig. 4 below.

Figure 4: burning of cables with PUR foams in the informal sector in Ghana. © Daniel Hinchliffe / GIZ

3.1.2 Technical solutions necessary to handle the fraction properly

Sorting and Treating Refrigerators and Freezers

In general, all newer appliances should have a plate or sticker inside or outside the equipment to indicate the refrigerant and blowing agent used as well as other properties. When the equipment is very old and in poor condition, and such a plate or sticker is unavailable or ineligible, other indicators such as the make/model, age and type of equipment can allow for an approximation to the type of gas in the equipment.

A sorting process is needed to identify and recover appliances containing ODS blowing agents. In order to prevent any leaking to the atmosphere, the foam should be processed in a closed atmosphere, and afterwards the foam blowing agent should be separated from the exhaust gas to ensure recovery of ozone depleting gases. Such a facility may extract refrigerants from the cooling circuit in a first step, then shred the refrigerator in a closed chamber under a nitrogen atmosphere, safely extracting the blowing agent from the foam and separating the further constituents (shredded foam, plastics and metals) for further processing. Typical investment costs here for a complete refrigerant and gas extraction solution are between 2 and 4 million € for machinery plus infrastructure and consumables costs (floor, building, logistics, nitrogen supply). A less environmentally sound option, which is nevertheless often the common practice, is the manual separation of the foam layer

[7] Management and Destruction of Existing Ozone Depleting Substances Banks: Guideline on the Manual Dismantling of Refrigerators and Air Conditioners, GIZ: *https://www.giz.de/en/downloads/giz2017-en-weee.pdf*

from the metal body (see e.g. GIZ Proklima *Dismantling Guideline*). The removed foam needs to be sent to a specialized facility for final treatment (often for an additional treatment cost), e.g., a specialized refrigerator recycling facility with destruction in an incinerator plant or a cement kiln.

3.1.3 Potential finance solutions to handle the fraction correctly

Recyclers in industrialised countries not only recover and recycle metals coming from refrigerators but are also legally obliged to separate R11 from the PUR foams and to destroy refrigerants and blowing agents at high temperature. By doing so, the emission of these gases is avoided, which could otherwise have a global warming potential of nearly 3 tons of CO_2 equivalent per refrigerator or freezer on average, assuming no gases are lost during the life of the equipment (130 g of R12 x 10,900 GWP + 310 g of R11 x 4,750 GWP = 2,89 t CO_2 equivalent). Owing to the fact that these activities are mandatory by law, no monetary incentive is applicable in these cases. However, in low and middle-income countries the legal obligations are more patchy – some have no obligations, while some have specific standards that should be met on refrigerator recycling, but fail to state specific obligations on the treatment or destruction of refrigerants and blowing agents, and these substances are then released to the atmosphere without consequences. Here, CO_2 certificates for adequate gas destruction and therefore mitigation, could potentially be generated since these situations meet the required additionality criteria. The income from the sale of these certificates could provide a transitional finance option to kick-start recycling activities. However, in the meantime policy makers are urged to move to close the gaps in legislation and state clearer obligations on managing ODS wastes.

Avoiding mis-use of Carbon Credits

Carbon credits always need additionality as a criterion. This only exists if there is no legal obligation to destroy ODS in the country, or if it is demonstrated that an existing obligation is not being implemented or enforced. Conversely, this also means that development of national legislation could be slowed down if it is perceived that funding options for recycling of refrigerators are available if no mandatory destruction regulation for ODS is in place. By promoting carbon credits in this case, governments are being let off the hook to take action both on setting up a suitable EPR system for refrigerators and ensuring that ODS are destroyed. Carbon credits should therefore only be seen in this scenario, if at all, as a temporary financing solution for the destruction of ODS and HFCs. At the same time countries must close the regulation gap towards the destruction of ODS and HFCs and ensure strengthening of the capacity to both enforce and implement such regulation.

From a climate protection point of view, some parties argue that offsetting CO_2 pollution rights is the wrong approach and due to the shorter 100-year time frame of the GWPs from CFCs and HFCs compared to CO_2, the climate reducing impact may be shorter lived. Furthermore, care must be taken to ensure that perverse incentives do not arise where refrigerators could be exported as used goods from jurisdictions where their destruction is mandatory to regions where a carbon credits solution would be applied. Nevertheless, solutions for PUR foams are desperately needed and without them the emissions will occur regardless, so it is worth exploring ideas in this space.

3.1.4 Development of a treatment pilot for PUR foams

First choice

Despite wide-ranging research and numerous contact attempts, initially only one company in the Balkans showed interest in the project and hence became the obvious choice. The recycler reported to have 28 tons of PUR foams from old refrigerator units on stock, making it a very interesting business case. The project team engaged in multiple discussions with the recycler and a potential carbon credit finance partner focussed on mitigating climate change by removing potent refrigerant gases before their leakage into atmosphere. This carbon credit partner could potentially finance extraction, export and treatment of PUR foams through carbon credit generation.

Minimum criteria to start the pilot and different treatment routes were explored, as detailed in Section 3.1.5. Due to proximity, Greece was considered as a destination country as shipment of foams would require crossing only 1 border, which would significantly simplify the Basel Convention notification procedure. That, however, would require certifying a new recycling site that the carbon credit partner had not worked with before.

In the course of the discussions, the recycler stated clearly that they cannot incur any costs additional to their current spending. They were also sceptical about transboundary shipment (TFS), arguing that it would be a lengthy, if not impossible process due to Basel Convention procedures[8]. The company did not want to provide any bank guarantees and insurance necessary for the TFS procedure either and expected the finance partner or project team to cover this. The recycler also requested a signed contract with a certified company that would accept the PUR foam as soon as possible, in order to get a notification number in the Ministry of Environment. That was not possible without agreeing all details first and getting some more details on the quality of the foam.

After some time it turned out that the recycler had gone ahead and landfilled the 28 tons of PUR foams at a very low cost in order to renew their waste permit, which would have been a challenge with a pile of foams on site. The very low landfilling charges show the need for a supporting local regulatory environment that makes the recovery of blowing agent from the foams mandatory and attractive compared with landfill fees.

Searching for an alternative, the project team discussed rebuilding up stock. With collection of between 700 – 1,000 fridges annually, it could have been possible to accumulate the necessary volume for the pilot in the project timeframe. However, for this it was crucial to understand what type of refrigerant the fridges contained and how many units were available at that time, i.e., whether or not it made sense to explore this opportunity any further. At the same time, however, the recycler became sceptical about extracting foams and storing them on their site due to space issues. Therefore, shipping complete fridges (that were stored in the open air) to Greece was considered additionally in the analysis but this would deprive the recycler of revenue from steel and metal, which the company could not agree to without having a financial compensation for the raw materials.

Further engagement with the recycler was not fruitful: the refrigerators arriving at the site were constantly disassembled and processed, therefore no exact inventory could be

[8] For an overview on the challenges faced by recyclers in low and middle income countries, see *PREVENT-StEP discussion paper on practical experiences with the Basel Convention*.

shared. The appliances were coming both from households and industry, having different refrigerants. The company was unable to make any estimation with regard to share of fridges containing R11 gases in the foam or R12 gases in the compressors. Eventually, the recycler said that they were still interested in the project but suggested to the project team that maybe they should focus on another company. They also admitted that their expectations from the pilot were different from reality, as they counted on direct financial support from the project team or the project sponsor.

Second choice

Following the unsuccessful outcome of pilot development, the project team was introduced to another Balkan recycler. The company reportedly had 480 tons of PUR foams on stock, which seemed like a very promising opportunity for the pilot. When the project team engaged in discussions with the recycler, the amount of foams collected yearly was confirmed at 700 tons, with an aim of 1,000 tons per year. The current process applied to foams was extraction of gases and production of briquettes which are sold to cement kilns. The gases were liquefied and sent to Germany for destruction, which implied significant cost for the recycler.

The recycler shared chemical analysis of gases extracted at the plant that had been performed for prior shipments. Initially it appeared as though there were 2 tons of gases available for the pilot. However, in the course of qualitative analysis it turned out that CFCs represented less than 1% of the total mass of the effluent, and 99% were substances not eligible for CO_2 offsetting with a very high water concentration. With very low R11 content the project was eventually deemed as not economically viable. In the EU, usually not more than 20% of water in the separated refrigerant is found. The recycler was advised that they could reduce the share of water in the effluent and consequently the total volume of the gases by 90 to 95 %. The project team recommended that the recycler contacts their supplier of separation technology to discuss if the parameters to run the plant (temperature, pressure, circulation rate, etc.) can be changed to reduce the volumes of this hazardous waste stream and improve separation efficiencies.

Additional involvement – India

India was not in the geographical scope of the project, nevertheless, the project team entered into discussions with an Indian recycler of e-waste who expressed urgent demand for support to manage PUR foams. However, according to rough estimates, the proportion of appliances containing pentane were thought to constitute roughly ~85-90% of the processed stock. As any pilot with carbon credits would be dependent on having enough CFC foams and there were no resources available for the recycler to measure the CFC content, this option was also deemed unfeasible for the pilot.

Conclusions

Within the timeframe of the project, none of the candidates eventually met the requirements for a pilot. Still, the Project team believes that if the right conditions are found it would be possible to finance PUR foam treatment with carbon credits, provided that certain conditions are met. Chapter 3.1.5 describes how this could be achieved.

3.1.5 Development of a finance solution for PUR foams

The rules to generate CO_2 certificates from the destruction of refrigerants and blowing agents are laid down in two standards:

- *VCS Version 1.1.* published in November 2017 by Energy Changes Projekt Entwicklung GmbH and USG Umweltservice GmbH, quantifying GHG emission reductions from activities that recover and destroy ODS from products where a partial or total atmospheric release of ODS occurs in the baseline scenario; and
- *ACR Version 1.1*., published in September 2017 by American Carbon Registry, defining a set of activities designed to reduce GHG emissions by the destruction of eligible ODS, high-GWP foam blowing agents or insulation foams

The destruction both of R11 and R12 can be documented as CO_2 reductions and justify the issuance of CO_2 certificates in countries **where no legal obligation exists to destroy them.** At the time of writing this report, the value of the issued certificates varies between 3€/ton of CO_2 and 10 €/ton of CO_2, depending on supply and demand as well as the appeal of the certificate to potential buyers. For simplicity an average price of 8 €/ton (0,008 €/kg) of CO_2 was assumed in this analysis. Based on this assumption, the proper destruction of R11 and R12 can generate the following value:

Waste stream	Potential value of a CO_2 certificate
R11	38 €/kg (€ 0,008/kg x 4,750 CO_2 equivalent)
PUR foam with R11	1,9 €/kg (€ 0,008/kg x 4,750 CO_2 equivalent x 5%)
R12	87,2 €/kg (€ 0,008/kg x 10,900 CO_2 equivalent)
Entire refrigerator	~ 23 €/unit (0,31 kg R11 x 38 €/kg + 0,13 kg R12 x 87,2 €/kg)

Table 5. Waste from refrigerators and its expected value in terms of CO_2 certificates[9]

Today in Europe the share of R11/R12 is decreasing continuously, but in some countries it is still around 70 % of all refrigerants and blowing agents found in recycling of old appliance (the other 30 % is mostly R600a and pentane). It can be assumed that in low and middle income countries with a high proportion of used equipment imports, the share of R11/R12 in post-consumer cooling equipment is higher. Those devices can be relatively easily identified because new models are clearly marked with information, i.e., “Pentane” as a foam blowing agent, or “R600a”as refrigerant on the backside or at the compressor.

In low- and middle-income countries where no local recycling is possible, the revenue from destroying R11/R12 gases properly and linking to carbon credits can be realized by:

- **OPTION A**: separating only the refrigerant from the cooling circuit and then shipping the gases to a destruction facility (mostly available in central Europe)

[9] Source: Landbell Group, estimated values. For explanation of values used, please see Chapter 3.1.1 (Table **4** and above)

- **OPTION B**: separating (manually) the PUR foam from refrigerators and sending it either directly to an incineration facility or to a refrigerator recycling plant (mostly available in Europe), where the R11 foam blowing agent is separated from the foam and then sent to a destruction facility
- **OPTION C**: shipping the entire refrigerators to a fridge recycling plant where they will be accordingly dismantled and the R11 refrigerant in the cooling circuit plus R12 foam blowing agent is captured.

Option A has already been successfully implemented in several countries by carbon credit offset companies, whereas B and C have not yet been pursued.[10]

Assuming that the refrigerators have already been collected, from the potential income the following costs have to be subtracted:

- Shipping costs of the material
- Loss of raw material value to the recycler if entire refrigerators are shipped (steel, copper, aluminium). This effect is neutralized by assuming a kick-back in the recycling costs
- Separation costs for R11 from the foam
- Treatment costs for PUR Foam
- Destruction costs for R11 and R12
- Certification set-up costs
- Running certification costs

Since the above costs vary with distance between collection and treatment points, average values were assumed for in mid 2021 for shipment between the Balkans and Greece. For each case, the assumptions were carefully verified and justified (for more details see finance model excel spreadsheet).

- OPTION B: The breakeven point for PUR foam is achieved with 17 t of PUR foam, which represents the foam from 3,000 refrigerators.
- OPTION C: The breakeven point for entire refrigerators is achieved at 450 t, which represents about 9,000 refrigerators.

The above calculations assume that certification of the project in the form of Option B and C (i.e. 1 accumulated batch/shipment) costs € 20,000. For Option A there are no specific certification costs foreseen because the process has already been certified.

Conclusions

A significant volume of refrigerators is necessary to make the project financially viable. According to the assumptions made, the destruction of only PUR foams could have a break-even point at 3,000 units with R11, and when entire refrigerators are shipped, the break-even point is at 9,000 appliances containing R11/R12 per treatment batch. In the course of developing the pilots, sources of waste containing adequate amount of R11/R12 could not be identified.

[10] Towards the end of implementing this project, the Fairreccyling Foundation joined the PREVENT Waste Alliance. They have set up a full refrigerator recycling facility handling all fractions in Brazil with operations financed by voluntary carbon credits.

Shipment of already captured R12 gases in gas canisters together with foams could be a more economically appealing option but it requires a know-how and technique to efficiently extract and capture these gases.

3.1.6 Can recycling of PUR foams and CFC containing devices in countries which do not ban the release of these substances be a viable strategy?

In countries where caputure and destruction of ODS is not legally mandatory, the treatment of these substances, including PUR foams, might be financed by issuing CO_2 reduction certificates. To assess viability of this finance mechanism for a future pilot and to start a closer investigation on the potential business case, two main questions have to be answered first:

1) Do the appliances contain ozone depleting substance with a very high GWP?

- Were refrigerators collected from private households and is it likely that they were produced before 2000?
- Is the cooling circuit still intact or is the compressor completely missing?
- Is the refrigerant R12 (not 134a or 600a) mentioned on the compressor?
- On the backside of the appliance there is no indication that Pentane was used because these gases have a very low GWP:

Figure 5: Refrigerator nameplate on a compressor

Figure 6: Refrigerators containing pentane will not be relevant for carbon credits. Here the backside indicates pentane

2) Are sufficient volumes available to cover the cost for the certification of the process of CO_2 certificate issuance?

The minimum quantity depends very much on the location and transportation costs to the next treatment facility that can capture and destroy the ozone depleting substances. However, based on the analysis in this report the following minimum quantity can be indicated:

- PUR foam from minimum 3,000 refrigerator units, or
- Minimum 9,000 complete cooling appliances, or
- If these volumes are not available, there is still the possibility to capture only the R12 refrigerant. Here, generally no minimum volumes are required, however, some 100 kg of R11 should be available to justify the project set-up costs.

3.2 Lithium-Ion batteries in East Africa

3.2.1 Identification of the problem

Thanks to high efficiency in converting chemical energy into electrical current, which also allows to make them light and small, Lithium-Ion batteries are considered the best technology for powering portable devices. Hence, they have seen enormous growth during the last years, becoming the main battery type used across portable consumer electronics. A growing importance of Li-Ion batteries can also be observed in electric vehicles and off-grid solar applications. The World Economic Forum estimates a 14-fold growth between 2018 and 2030 in the demand for Li-Ion batteries[11].

Research and commercial application of Lithium-Ion battery recycling has gained increasing interest during the last years as recyclers and other companies try to capture potential revenue opportunities. Whether or not batteries are attractive for recycling depends on their chemistry. There are numerous different chemistries being applied and these are constantly changing, but in general it can be said that lithium-ion batteries from consumer electronics (laptops, smartphones) and current electric vehicles tend to use Lithium Cobalt Oxide (LCO) chemistry and have value from recycling due to the cobalt and nickel content. Due to the high prices of cobalt and the limited reserves, primarily dependent on countries subject to potential supply chain risks, manufacturers are trying to reduce cobalt content in their batteries. Lithium Iron Phosphate (LFP) batteries are lower cost, have no cobalt and are suitable for stationary power in off-grid solar applications. The absence of cobalt and other valuable raw materials in this chemistry makes these kinds of batteries less attractive for recycling.

Due to the high electrical energy density and high reactivity of lithium as well as the risk of thermal runaway, there is an appreciable risk of self-ignition attached to Lithium-Ion batteries. Hence, across the world, recyclers face the problem of these batteries entering their facilities and causing fires. This may be when batteries inside equipment enter a shredder, or when they are critically damaged and not transported or stored properly or simply when equipment awaiting treatment catches fire in the recycling yard. In Europe fires are reported on a regular basis requiring a careful management of waste batteries to avoid risk fire[12].

The number of lithium-ion battery treatment facilities are on the rise with many focusing on raw material rich lithium-ion battery types. The LFP batteries on the other hand, are mostly incinerated at a significantly high cost. Li-Ion recycling facilities exist in North America, Europe and Asia (with South Korea and China representing some of the major hubs) but there are none on the African continent. As a result, export may be necessary, however recyclers in this part of the world face the following problems:

1. Battery classification: Very often, batteries are classified as hazardous waste in many countries and thus need to be exported according to the Basel Convention rules.

[11] World Economic Forum, *A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation*

[12] European recycling organisations have developed *Recommendations for tackling fires caused by lithium ion batteries in WEEE*

2. Shipping companies increasingly refuse to carry this potentially explosive waste on their vessels due to insurance and fire risk reasons.

While in the past batteries have been exported to international facilities from several countries, current difficulties are forcing recyclers to look at local pre-processing solutions.

E-waste recyclers worldwide are confronted with increasing quantities of Li-Ion batteries in their day-to-day operations and need solutions for these. Unlike lead acid batteries which command a high value in both informal and formal markets, Li-Ion batteries do not have an obvious local value other than for potential re-purposing and resale in informal local repair markets. Having heard about the positive value that can be recovered from Li-Ion batteries abroad, some formal recyclers have intensified collection of Li –ion batteries, storing large volumes in the hope of a positive value return through future recycling solutions. However, the value if Li-Ion batteries is dependent on their actual chemistry, as explained above.

3.2.2 Development of technical solution

Following the recycler survey, the project team selected Chilambo General Trade in Tanzania to develop a potential local solution for Li-Ion batteries. The recycler had collected (both locally and from imports) approximately 60 tons of li-Ion batteries of all kinds, primarily from waste solar applications. The goal was to find an economic and ecological solution which can be readily replicated in other countries with similar challenges.

Figure 6. Different types of waste LIB in the project's consignment[13]

Steps taken and challenges

To identify suitable treatment solutions, as a first step it was necessary to understand the chemistries of the batteries in the collection plus the share of Li-Ion batteries in the total volume. For manual sorting, if the chemistry is not directly stated on the label, the most basic parameter which can be used to elementarily differentiate between Lithium-Iron-Phosphate (LFP) and Lithium-Cobalt-Oxide (LCO) batteries is the nominal voltages typically marked on the casing as below:

[13] Source: east African recycler

Figure 8. Li-Ion batteries with nominal voltage[14]

The rule of thumb using sorting by nominal voltage mostly follows the below principle:

1. LFP cells conventionally have a nominal voltage of 3.2 V and a pack will have multiple of this, depending on the number of cells (6.4 V, 9.6 V, 12.8 V, 25.6 V). These are very common in off-grid solar equipment.
2. LCO cells tend to have a nominal voltage of ~ 3.6 V and the battery pack is a multiple of this (7.2 V,10.8 V,14.4 V,18 V) these are common in notebooks, mobile phones.

By using this separation method, the recycler came up with a split of approximately 2 t LCO and 58 t LFP batteries. This separation is crucial because the treatment solution and the corresponding cost depend on chemistry. Waste LCO batteries generally have a positive treatment value pivoted around the cobalt price. This is not the case with LFP batteries which generate a net treatment cost in the recycling process, relying on incineration (or adding to smelting processes).

The first idea of the project team was to ship the 60t consignment to a treatment facility in Singapore. However, based on the obtained quotations, it became clear that such a solution would not be financially viable: logistics was estimated at about € 3,500 for a 20ft container (~15t of batteries plus packaging) and treatment at € 1,200€/t[15]. Also, as Li-Ion batteries are classified as hazardous waste in the country of origin, this pathway would require a Basel notification procedure for Transfrontier Shipment (TFS). The biggest share of costs of this operation are presented in Table 6 below:

	Parameters	Values	
1.	Total volume of waste LIB	60 tons	
2.	Output fractions	**LFP**	**LCO**
2a.	% Of output fractions	~97%	~3%
2b.	Volume	58 t	2t
3.	Shipping Costs	175 €/t	
4.	Treatment Costs	1.200€/t	3.000 €/t
5.	Cobalt price (LME 28.10.21)[16]	0	48.000 €/t
6.	Cobalt content (estimated!)	0%	10%
7.	Income from cobalt extraction	0 €/t	4.800 €/t
8.	Cost (-) or income(+)/t [-3-4+7]	- 1.375 €/t	1.625 €/t
9.	Total cost (-) or income (+) per chemistry [8x2b]	- 79.750 €	3.250 €
10.	**Total cost per consignment**	**- 76.500 €**	

Table 6. Recycling Cost simulation for the 60t waste LIB consignment from East Africa to Singapore

[14] Source: east African recycler

[15] Source: supplier quotes sourced by Landbell Group in 2021

[16] Nickel price is ignored in the calculations because it is currently negligible

It should be noted that in the above cost calculation, the shipment cost is per container (20 ft container has approx. 20 t payload capacity). LIB are typically shipped in drums with sand or vermiculate. Both serve as packaging material for the LIB and significantly contribute to the logistics cost since they add the weight of shipment while reducing true volume of the material per container. Although sand might be readily available and cheaper than vermiculate, the latter is lighter in weight. Furthermore, LIB should be shipped in accordance with Material Safety Data Sheet (MSDS) which is a guideline from the manufacturer on material handling or transportation.

The revenue generated from LCO (rated at 10% in the above calculation) is a negotiation element between the recycler and the treatmemt site. The catalyst here is the cobalt content (high, medium or low) of the battery.

Additional expenditure would be the Basel notification and the associated administrative costs estimated at about 1500€/EWC plus export and transit paperwork cost estimated at soon 2000€/EWC. Without factoring in these extra costs into the cost calculation, the above simulation shows that, with prices and available technology options in 2021, the economic value of LCO could not finance the shipment and treatment of the entire battery mix that is composed mostly of LFP. Therefore, an alternative to recycling was to extend the LFP battery lifetime through local repurposing.

Before eventually going for the repurposing solution, local shredding of Li-Ion batteries and sending black mass to a chemicals processor in India was discussed. The main conclusions were:

- Batteries need to be fully discharged before crushing and yet, the shredding process may still result in fire because there is always still some minimal electric charge inside the “discharged” battery.
- The Indian recycler was concerned that black mass may generate florine acid (electrolyte) that damages machines and is a disposal challenge. The concern is not justified because during the crushing process, the electrolytes are heated and should evaporate after friction heating reaction, and then will be collected by the negative pressure fan to the spray tower treatment

For a full analysis of recycling options and technologies for lithium ion batteries in the African context, see the report *Management of End-of-life Li-ion Batteries through E-waste Compensation in Nigeria: Collection, storage, pre-treatment and downstream options*, developed in the PREVENT ECON pilot.[17]

3.2.3 Refurbishing process

There are a few players specializing in developing reuse solutions for batteries (among others, Aceleron Energy, Powervault, Brill Energy), The project team partnered with one of them, a European company with a growing presence in East Africa.

The aim of refurbishing is to generate second life battery packs from the waste LIB. To do this, testing of each cell in the pack is necessary to determine the technical health of the cells. The good cells are recharged and wired together again in new battery packs which

[17]Available here from end of May 2022: *E-waste Compensation Nigeria - PREVENT Waste Alliance (prevent-waste.net)*

are marketable following quality checks. According to the refurbishing partner, the refurbished packs from their process have good performance and even outperform some of the brand-new packs available in the local market.

The starting point in this process was testing of the cells. The refurbishing partner has an own facility in another African country where testing, charging, and making of the packs takes place. Since all the 58t LFP in the scope of the project could not be shipped there, a pilot shipping and testing of 300 randomly selected cells was envisaged. The pilot load would be a random selection of 100 cells each from the 3 main types of LiFePo4 cells in the consignment, which included: 26650 LiFePO4, 18650 Li-ion and 18650 LiFePO4.

Given that both countries (recycler and refurbisher) are signatories of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, transboundary moving of waste batteries can only happen in compliance with the Convention and a prior informed consent notification procedure is mandatory. The lengthy nature of the notification process and administrative burden would have been out of proportion to the number of batteries being sent for testing, so it was instead decided to test the 300 cells directly at the recycler's site. For this purpose, the refurbisher sent to the recycler 3 handheld, basic testing devices (SkyRC MC3000). There are many other manufacturers of similar equipment, for example, Ansmann, Elzfan and Voltcraft.

This testing technique is very elementary and has its limitations, nevertheless it is easy to use and transport, widely available and relatively inexpensive (approx. 100 USD), and data connectivity via Bluetooth to mobile phones is possible.

Figure 9. SkyRC MC3000 devices used to test batteries in the pilot project[18]

Compared with full-scale testing rigs developed by repurposing companies, the disadvantage of this instrument is that the testing and charging capacity is extremely low (approx. 15-20 cells per day). Following a training on how to use the device, it took the recycler around two weeks to complete testing with the use of two SkyRC units. The test results derived from the testing equipment is the average of the 100 cells per the 3 cell types:

[18] Source: SkyRC Techonology Co., Ltd

Cell chemistry	Nominal voltage	Electrical charge	Standard charge	Charge rate [mA]	Voltage on testing [V]	Target voltage [V]	Voltage attained after charging [V]
LiFePO4 18650	3,2	1500	1	1500	3,1	3,6	3,4
LiFePO4 26650	3,2	3200	1	3200	3,3	3,9	3,8
Li Ion 18650	3,7	2200	0,5	1100	3,6	4,2	4,2

Table 7. Indicative, average results achieved from testing 300 cells by SkyRC devices

Initial tests showed that the voltage met thresholds for refurbishment, i.e., it was possible to charge them to their nominal voltage and in some cases the voltage attained exceeded the nominal values. To further determine the viability of these cells it was advised that a more thorough testing and charging should be performed at the site of the refurbisher. This would provide a more robust and detailed assessment of the cells, as well as produce sample of refurbished LIB packs.

The challenge here is again the transboundary movement of hazardous waste and notification procedure. Although the 300 cells are tested, recharged, and proven to still be in a technically healthy state, they cannot be transported as secondhand goods. Some countries accept such material as used or secondhand goods if the technical state is satisfactory and certified. In this case the receiving country, however, did not allow imports of hazardous waste except under very strict circumstances with lengthy red tape. The local project partners are currently exploring solutions to this option.

3.2.4 Finance model

Provided that the 300 cells are successfully shipped to the refurbisher and that their testing brings positive results, the project could be further developed in the recycler's country as the volume of LFP batteries on stock is significant and justifies local investment. The full-scale operation entails the following estimated CAPEX, OPEX and income:

Input	Parameter	Assumptions
Weight of single cell	75g	
Number of cells per pack	128 LIB cells	
Fixed cost		
Single Cell testing Equipment	$ 7 000	Can test up to 1,5t of LIB per month (~20k units of cells)
Pack testing Equipment	$ 12 000	Enables the production of LIB packs approx. 160 packs/month
Management cost	$ 10 000	Includes licensing, IT equipment, label printer, IT support
Total fixed cost	$ 29 000	
Variable cost		
Parameter	**Per cell or pack**	
Fees per tested cell	0,10 $/cell	
Fees per produced pack	10 $/pack	
Pack parts (excl. VAT and possible import duties)	195 $/pack	
Total variable cost per pack of LIB	$ 217,80 /pack	
Total Average cost of producing LIB packs (variable + fixed cost)	$ 234,33/pack	(assuming that 60% of the 58 t can be converted into 3,625 LIB packs)
Market value of LIB packs (134 cells)		
Market value of Refurbished LIB pack (134 cells)	$ 520/pack	
Market value of a Brand-new LIB pack (134 cells)	$ 800/ pack	

Table 8. Cost and income evaluation for refurbishment of waste LFP

In the above cost simulation, it is assumed that a pack of batteries is made of 128 cells of 26650 LiFeP04 as per the local market need. To determine the technical viability of the individual cells, all cells within the 58t consignment would have to be tested. With reference to the 300 tested units in the pilot, it is assumed that 60% of the cells would be eligible for repurposing. Therefore, from the 58t of LIB, an estimated 3625 LIB packs of 128 cells can be produced.

The market for repurposed batteries is strong in East Africa, and it is believed that a refurbished cell could have a market value of $ 1-$4 compared to new cells value of $2-$6, depending on chemistry and manufacturer. The fees in the cost calculation exclude operation cost of tooling, facility, personnel and temperature control unit which are all relevant for the operation. This cost mostly makes up an additional 7-10% of the total cost. The main driver of the refurbishing cost is the pack parts (80%), which is already included in the calculations.

An average cost ~USD 234 is generated to produce a marketable pack of LIB. The pack parts are imported and therefore VAT and import duties might further inflate the cost. Some of the same pack parts could potentially also be retrieved from the old battery parts. The current market value of first life LIB batteries in the region is approx. USD 800 compared to USD 520 for refurbished LIB batteries (size of 128 cells). The refurbisher partner was willing to provide the software and training to the local recycler who would then ultimately refurbish and market the LIB at his facility in East Africa. Assuming constant inflow of waste LFP batteries to the recycler, the income generated by this refurbishing process could be multiplied, providing a sustainable business to the company.

3.2.5 Conclusions

- Refurbishing of LFP batteries could provide an interim economic solution for recyclers, given that the current alternative is export to a thermal treatment/incineration process with high treatment costs of approx. € 1,200/t. The refurbishment solution can be replicated elsewhere. Driving factors would be an appreciable volumes of waste LFP batteries and the market value of second life units. It needs to be noted, however, that after the refurbished units reach their end of life, they will still need to be recycled. Part of the revenue generated from refurbishing should thus be earmarked for future treatment. It should also cover the treatment of those units that cannot be repurposed.
- Providing that a shipping company can be found to take the batteries, LCO batteries can be shipped abroad for treatment since they customarily return a positive value. While exporting, the same difficulties will apply as with LFP batteries, i.e., Basel notification will be required, but the effort and cost can be compensated with revenue from cobalt. For this project, the volume of 2 tons of LCO was too low for shipment. Therefore, the local recycler is encouraged to intensify collection of such batteries to build up the volume. A likely minimum of 10t would be needed for a full load container and packaging. However, as the overall volume of LIB collected by this recycler is growing this may also present a stock-piling problem in the near future.
- The prices in the cost simulation are only indicative figures adapted from a similar model project currently being implemented by the refurbisher. Any replication would require discussions with similar repurposers or development of own repurposing solutions. While treatment cost of € 1,200/t comes from a specialized battery recycler the

testing equipment cost ($ 7,000 and $ 12,000) is quoted by the technology provider. Both fees are around the market average and should not vary too much. Some of the remaining parameters (OPEX, market value of refurbished packs, etc.) will be very closely linked to local conditions and will impact the final profit and loss calculations. Since most of the equipment is produced and imported from China, the lead time is in the order of 8 weeks. VAT and custom clearance would vary per receiving country and should be factored in.

- The next step in this pilot would be securing a notification to move the 300 already tested units to the refurbishing partner for further testing, charging, and making of refurbished LIB packs. Transboundary shipments according to Basel Convention procedures pose a major challenge; attracting a direct investment (technology transfer) from a repurposing partner could be a more feasible option.

For any recycler collecting Li-Ion batteries, it is important to understand the chemistry of the batteries they collect as that has a great impact on the recycling process, destination and cost. Therefore, a proper sorting into common categories of LCO and LFP batteries is required. Not all waste Li-Ion batteries have a positive value. In the absence of EPR legislation, which could finance treatment, based on the chemistry, the recyclers can accordingly bill their clients to better manage the economics of profit and loss. To support the identification, sorting and management of batteries more generally, the project team developed a training on managing alkaline, lithium ion and lead acid batteries, which covers the basics in more detail, available online.[19]

3.3 Plastics in Brazil

3.3.1 Identification of the problem

Nowadays, plastics are found and used everywhere, from packaging, to pencils, from toys to cars, from phones to refrigerators. They are cheap, easy to form and solid. Unfortunately, plastics are also ubiquitously found landfilled or dumped in nature due to the lack of necessary know-how and recycling infrastructure, lack of adequate collection systems, poor segregation and sorting, loss of quality during the recycling process, no offtakers of recyclate (or its low value) and bad habits of consumers.

WEEE plastics represent, on average, 25 % of all WEEE generated annually by weight[20] and consist of a complex mixture of different polymers containing a wide range of additives. In fact, 15 different types of polymers, often mixed together, can be found in WEEE. Identifying them, sorting, removing hazardous additives and recycling means that virgin materials can be saved, less CO_2 emissions are produced and less plastic waste is landfilled or lost in nature.

The problem faced by many recyclers is the large number of types of plastics with very different properties. These properties depend on the content of chemical resins and the presence of additives that are incorporated to improve specific properties:

- Flame retardants (more than 45 types)

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[19] Training slides on Management of Waste Batteries: English, French

[20] Source: Study on the Impacts of Brominated Flame Retardants on RECYCLING WEEE Plastics in Europe by Arthur Haarman, Federico Magalini, Joséphine Courtois for SOFIES, November 2020

- Fillers
- Pigments
- Stabilizers

Manufacturers of goods, provided that they accept recyclate, wish to receive clean and sorted plastic loads, as this ensures better quality and purity of the final products they produce. Such recycled e-waste plastics can command a good market price, as shown in table 9 below. Thus, well-sorted, decontaminated plastics can ensure products with reliable characteristics in terms of durability, hardness, flexibility and visual aspects.

	December[6] 21	November 21	Oct. 21	Sept. 21	Aug. 21	Nov. 20
HDPE regrind[1]	600	580	570	620	630	490
HDPE regranulates[5]	880	960	880	830	920	670
LDPE bale goods[2]	350*	370*	170*	290*	270*	200*
LDPE regrind[1]	470*	430*	340*	380	420	470
LDPE regranulates[5]	840	890	740	690	700	540
PP bale goods[3]	260*	380*	570*	0*	0*	170*
PP regrind[1]	620	730*	650	620	570	480
PP regranulates[5]	1380	1530	970	930	880	690
PS regrind[4]	740*	760*	700	700*	650*	540
PS regranulates[5]	1140	990	920	890	850*	700*
PVC_P regrind[1]	490*	0*	360*	270*	400*	350*
PVC_U regrind[1]	480*	0*	0*	50*	540*	430
PET bale goods	70*	90*	290*	180*	160*	180*
PET regrind mixed colours	460	520	520	420	440	300

Table 9. Standard plastics price according to plasticker; listed in €/t[21]

At the same time, separating clean plastics from contaminated ones increases costs and reduces the volume of tradable plastics. This can be a vicious circle for smaller recyclers: on one hand they have trouble delivering up to purity standards set by offtakers, and on the other hand when separating plastics properly, they may effectively diminish their income by not having a critical mass to engage offtakers who need sustained supply for their production.

Hence, the two main challenges tackled in Brazil by the project team were:

- How to cover the cost of separating clean plastics and disposing of contaminated plastics?
- How to offer market access to smaller recyclers?

3.3.2 Development of technical and finance solution

The challenges listed in the previous section could be solved by the creation of consolidation and sorting center(s) for plastics from smaller recyclers to offer the expected volume and quality levels to offtakers. Disposal of contaminated fractions could be funded with revenue cashed in from offtakers. This section describes how the technical and finance solution was developed.

[21] Source: Market Report Plastics (plasticker.de), December 2021

As described in chapter 2.2.3, a recycler processing 160 tons of plastics per annum was selected for the pilot project. The recycler found an interested compounder selling packaging to the cosmetic industry. However, during that project it became clear that the requirements could not be fulfilled: any packaging containing products entering into contact with skin needs to be contamination-free. Recyclate coming from WEEE with unknown history cannot fulfil this specification.

Instead, the project team introduced the recycler to Electrolux, a producer of white goods. Electrolux has a global strategy to achieve a 50 % share of recycled plastics in its products by 2030. The strategy has to be implemented in Brazil, too, regardless of the immaturity of the recycling market and the fact that the Brazilian subsidiary currently achieves only a 5 % share of recyclate as of today. The advantage of working with an EEE producer instead of cosmetic packaging compounder is that the former one has quality requirements very similar to the one the WEEE plastic had to fulfil in its first life. Products having contact with food (e.g., fridges and freezers) are still challenging in terms of recyclate usage, the producer was also concerned about the colour of the recyclate (fridges and freezers tend to be white), nevertheless it was agreed that the cooperation could start with less demanding products, like vacuum cleaners.

Electrolux has developed technical specifications which determine the minimum requirements for the supply of material such as polypropylene (PP) compounds, acrylonitrile butadiene styrene (ABS) and high impact polystyrene (HIPS) that are used in injection molding processes to manufacture their products. The specification was shared with the selected recycler who confirmed that they could meet the requirements.

In order to ensure adequate mass and quality of plastics for the needs of the Electrolux Brazil, more recyclers were invited to join the project. This was enabled through Think Circular, a software/ tradeable online platform developed by Circular Brain. Think Circular aggregates data on streams and volumes treated by Brazilian recyclers. Volumes treated by different recyclers can be bundled together so that sufficient tonnages for offtakers are achieved. The software offers credits (certificates) to producers searching for environmental initiatives.

3.3.3 Next steps and conclusions

The current mission expired before the pilot project could be completed. In the next step, Circular Brain will further work with Brazilian recyclers, Electrolux Brazil and the selected compounder to deliver the first batch of recyclate. Provided that the expected quality and purity is achieved, the engaged parties should be able to continue the project on their own. Part of the revenue generated from sales to Electrolux Brazil should be allocated to creating consolidation and sorting centres throughout the country so that plastics are not transported long distances. Alternatively, investment in infrastructure could be made by a third party who sees a good business case, i.e., is aware of the existence of sufficient supply of pretreated e-waste plastics and demand for them. In November 2021, Circular Brain hosted a hybrid workshop with consultants from the Project Team and support from the

PREVENT Secretariat to initate the next steps of this project. The training materials cover main aspects around classifying, sorting and managing e-waste plastics.[22]

The concept could be replicated in other countries, provided that suitable plastic compounders (or manufacturers willing to feed recyclate into their production lines) are found. The aggregating software/ tradeable platform could either be delivered by Circular Brain, who is expanding into other geographies, or by any other software developer active in circular economy. Should the revenue generated from sales to offtakers be insufficient to finance CAPEX investments in consolidation and sorting, application of measures offered by other finance partners (e.g., BVRio, Closing the Loop) could be explored. Due to timeline of the current project and many delays faced on the way, the latter options were not pursued in Brazil.

3.4 Shipment of mixed e-waste fractions

3.4.1 Identification of the problem

SetTIC in Senegal collects and treats many WEEE-related waste streams. At the time of contact they had stockpiled around 20t of different WEEE fractions plus 6000 units of different types of lamps which are jointly regarded as mixed waste and could be shpped as a mixed shipment. The fractions included the following waste streams of weights ranging from several kg to almost 14,5 tons with no immediate local solution:

Waste fractions	
CRT screens	Cables (VGA)
Cartridges	Cables (HDMI)
Computer PCB (with iron processor)	Cables (copper)
Computer PCB (with plastic processor)	Lamps (forecast)
PCB (Low grade)	Lithium-ion Batteries
PCB (Telecommunication - High grade)	Alkaline batteries
PCB (Telecommunication - back panels)	Saline batteries
PCB (Medium grade	Button cell batteries
Total volume: ~ 20,000 kg	

Table 10. Recycler's inventory as of May 2021

The main challenge presented by this is in finding a specialized downstream partner for such a wide range of fractions.

3.4.2 Development of technical solution

In search for a solution the project team supported by advising on the waste categorization, classification, shipment process and treatment of the waste adhering to the highest recycling standards and in compliance with local environment and health protection requirements.

Shipping waste from West Africa (as well as any other region) to Europe is challenging and costly through transport and administrative expenses such as Basel notification, VAT and customs clearance charges. To optimize these costs, a mixed shipment of waste was

[22] Training slides on Management of E-Waste Plastics: English, French, Portuguese

considered, i.e., one 40 ft container including all waste without local solutions stockpiled by the African recycler was to be shipped to a single recycler based in Europe.

3.4.3 Finance model

The waste fractions in the inventory received from the recycler comprised of both revenue generating and non-revenue (cost) generating ones. Having analysed the waste on stock, the project team reached out to a number of European recyclers in their network. The most competitive quotation came from a German recycler not specialising in all of the waste fractions but willing to accept and process them (and ship to further recyclers if not able to treat themself). Based on this quotation as well as offers received from other European recyclers, the treatment prices can be generalized as the following:

Fraction	Revenue (+)/Cost (-) (Indication range only)
CRT Screens	0-80€/t
Computer PCB (with iron processor)	3,500-4,000€/t
Computer PCB (with plastic processor)	3,400-4,000€/t
PCB (Low grade)	400-650€/t
PCB (Telecommunication - High grade)	2,500-3,500€/t
PCB (Telecommunication – back panels)	1,500-2,200€/t
PCB (Medium grade)	500-900€/t
Cables (VGA)	600-1,100€/t
Cables (HDMI)	600-1,200€/t
Cables (copper)	500-1,200€/t
Cartridges	-370-540€/t
Lamps	-1,000-1,200€/t

Table 11. Revenue and cost calculation based on the existing inventory

The expected transport and administrative costs have to be added to the table to calculate the total profit/loss on the mixed shipment to Germany. A typical paperwork cost for notification would average 1,500€/EWC (European Waste Code). Some countries do charge transit fees for waste shipment and there may be other documentation paperwork costs in the exporting, transiting and importing country projected at 3,500€/EWC. The exact amounts are hard to estimate as depends on volume and case by case. Therefore, a total notifcation and administrative cost surrounding waste shipment can be estimated at ~5,000€/EWC.

3.4.4 Viable business model

The waste consignment is a mixed waste stream with both hazardous (in EU waste shipment regulation: Amber listed) and non-hazardous waste fractions (in the EU: Green listed) whereby the hazardous parts (e.g., lamps and cartridges) represented about 85 % of the total stockpile and a general cost to the entire project because they are non-revenue generating fractions. A lesser composition of the Amber listed waste fractions and a higher composition of Green listed fractions would return a positive value and a higher economic offset in terms of treatment cost. The presence of batteries, especially Lithium-Ion, in the consignment increases the logistics difficulties because of the fire and short circuit risks. The consignment could be split into the following Amber and Green listed fractions:

Amber list

Stream	EWC	Basel Waste code	Notification
Cartridges	160216/ 080317*	A1180/ B1110	Required
Lamps	20 01 21*	A1010	Required
CRT screens	16 02 13*	A1180	Required
Lithium-ion Batteries	16 06 05	A1170	Not required (in Germany)

Table 12. Waste fractions collected by the West African recycler that can be sent on an Amber list

Hazardous waste fractions increase the shipment cost and require a Basel notification which add additional time and administrative cost.

Cartridges: Toner cartridges are not automatically classified as hazardous. Some manufacturers of toner cartridges provide this advice in the product specification for reference. Therefore, with some degree of traceability to the manufacturer of the cartridges, the Material Safety Data Sheet (MSDS) could be used to investigate whether or not the specific cartridges are classified as hazardous by the manufacturer. In the case of SetTIC the large volume and diverse collection source made traceability impossible. More so, the collection is a mix of liquid and powder toners which potentially can generate a hazardous solvent and hence must be classified as hazardous waste fraction. It is important to preserve collected toners in such a way so as to prevent the flow or release of liquid or powder material of the toner. This mixed collection makes reuse of the toner difficult.

Figure 10 Toners in the cartridge mix[23]

Lamps: The recycler has collected different types of lamps:

Figure 11. Lamps in the mixed waste load[23]

[23] Source: west African recycler

To create more space in the warehouse and potentially reduce shipment cost, lamps are shredded with a crusher (“bulb eater”). The problem with this preliminary step is that, through shredding, the glass from the lamps and the mercury vapor come in contact making the mix highly hazardous. The treatment cost for lamps is in the range of about 1,000€/t. If the bulbs are removed prior to shredding and the good sortable metals sidelined for immediate selling, the remaining material (plastics, electronics and fiberglass) has no material value. The treatment cost here would be in the orders of about 200€/t.

Figure 12: Bulb eater[23]

Batteries: The quantity of batteries in the consignment was limited, representing several hundred kilos. The mixture contains LIB, alkaline, saline and button batteries.

SetTIC has a mixture of both LCO and LFP batteries from which a positive value could not be calculated given the limited quantity of the stockpiled LIB in the consignment. The project team provided a sorting guideline how to differentiate between LCO and LFP batteries and advised on the associated cost related to treating those batteries. The cost of LFP recycling is in the range of 1,000-1,200€/t and mixed batteries can cost up to 2000€/t. There is a general reluctance from downstream recyclers to accept LFP batteries. A special offer submitted to the project team by a treatment facility contacted for this pilot project foresees a standard handling fee of 20€/t for the battery fractions due to the limited amounts in the consignment which is leveraged by the historic business relationship between the suppliers and the project consulting firm. Lithium-Ion batteries (LIB) are a grey zone waste in Germany. According to the European Battery Recycler Association (EBRA) LIB are non-hazardous except for two Federal States in Germany. However, the Baden-Württemberg Ministry of Environment states that both hazardous and non-hazardous waste codes can be used when classifying LIB. For LIB to be considered non-hazardous, it must be retrieved from the equipment on which it was mounted and separated from other batteries. The West African recycler would therefore need to verify from the exporting authorities in its home country if a notification from the exporting side is needed in this case. Nevertheless, LIB remain dangerous and present a risk of fire. This risk, when factored in the logistics, further inflates the transportation cost.

Amber listed waste does not have to be shipped together with Green listed fractions. Given that the often-lengthy Basel notification procedure is needed for the Amber listed waste streams, it could be recommended that the Green listed streams are shipped first and in parallel, the notification process would be started. The plausible revenue generated from Green listed waste stream could be used as a partial funding source of the hazardous waste shipment and administrative costs.

Green List

Stream	EWC	Notification
Non-hazardous IT components	16 02 16	Not required
Alkaline batteries	16 06 04	Not required

Table 13. Waste fractions collected and stockpiled by the west African recycler that can be sent on a green list

Alkaline batteries are non-hazardous and typically have a treatment fee of about 260€/t in a typical European recycling facility.

Mixed IT Components: This is composed of Printed Circuit Boards (PCB) and cables.

This mix is of high revenue generating and green listed fractions which can be shipped immediately without a notification process.[24] The potential economic gains herein could be used to partially finance the operations of the Amber listed fractions. The assumption here is that the PCBs are removed from the equipment prior to shipment. Shipping PCBs within the device requires notification.

3.4.5 Challenges

The cartridges are a mixture of different types and represented a large proportion of the total weight of the entire consignment, getting shipment and treatment quotation without specifics in terms of origin and nature of the material was a primary challenge. There are hardly any treatment facilities which would accept the whole mixed shipment at once, especially as the bulk of inventory is low value material. In Germany, most cartridges of this nature are typically sent for energy recovery. This would also be mentioned in the notification document, and it is necessary to consider how this would affect the notification process itself or whether the authorities in the exporting country would approve it.

The presence of LIB in the consignment presents an appreciable risk which generally can impact the overall transportation cost. It was not possible to differentiate the various types or chemistries of LIB. This is a general problem that many local recyclers face, in which case they are unable to assess and compare the cost and the potential revenue of the LIB in their keeping.

The value of the cables is mostly driven by the copper portion in the cables. The nature, type and quality of the cables couldn’t be well determined.

As of the time of writing this report, the notification process has not yet started. This process will definitely be a significant hurdle which must be dealt with from both the exporter and importer sides.

3.4.6 Next steps and what can be done

Given the large scale and profound operational network of recyclers across Europe, this model can be replicated by any recycler wishing to access qualified, modern and compliant recycling facilities for waste streams which cannot be treated locally. The selection and operation of the treatment facility should be based on the logistical proximity between the waste site and the destination to minimize logistics cost and to reduce the carbon footprint during waste transportation.

While the total cost from the Amber shipment has not yet been determined, pending notification related cost, the green listed shipment can potentially generate a revenue of approx. 8500€ excluding shipment cost. To minimize the transportation cost, a single shipment of the two waste fractions is envisaged using a 40ft sea container. The African recycler would initiate the notification process as exporter of the waste while the project team would

[24] At the Basel Convention COP in 2022 a Ghana and Switzerland proposal will be discussed by parties which aims to make all e-waste fractions notifiable.

coordinate with the logistics carrier from the collection port in Dakar to the compliant treatment facility in Germany.

The African recycler shall prepare the waste loads for shipment according to compliant specifications of the Basel convention. For this model to work and be self-sufficient, the positive value or revenue must be greater than the total sum of logistics and treatment costs for the entire consignment. With that, the model can be easily replicated without any form of financial burden to the local recycler. If the revenues generated are lower than the operating costs, the exporter of the waste would have to finance the operation. In countries where EPR is absent, it is important that the local recycler charges a management fee to the local waste generator in order to cover logistics and treatment cost in this scenario.

After the treatment of each shipment, a certificate of treatment would be issued to the exporter by the treatment facility.

4 Final conclusions and further research suggestions

PUR foams

A functional model for financing of PUR foam recycling has been elaborated. Recyclers in countries with no R11 and R12 destruction obligation can check, by entering data applicable to their business, whether the treatment of PUR foam presenr in their warehouse (or to be collected) can be financed with CO_2 certificates and whether this activity would be profitable for the recycler. The ultimate profit or loss on this operation is only an estimation and will depend on, among others, the country of origin, country of destination, logistics cost and current value of CO_2 certificates. All these factors have to be assessed on a case by case basis.

For such an operation to be viable it has to be checked first if sufficient volumes are available and if PUR foams contain R11 refrigerant. Therefore, questions were developed to help to assess, if any PUR foam and/ or complete freezers and refrigerators are eligible for the carbon credit. If yes, the authors of the study can guide any interested party to the business partners to test such an opportunity.

Lithium-Ion batteries

Several recyclers approached were not aware of the chemical composition of the various types of LIB technologies, therefore the project team developed sorting guidelines helping to identify portable batteries and LIB. Using these guidelines, the recycler selected for the pilot project sorted about 60 tons of LIB batteries, more than 90 % of which were based on LiFePO technogy and did not contain any cobalt or nickel.

The economics for recycling of LiFePO are currently poor. In order to circumvent this, a LiFePO refurbishing solution was found and proposed. The financial simulation that was developed around this model shows that LiFePO battery repurposing, at least in East Africa, is a profitable activity that can generate revenue to waste owners and potentially also provide some finance for the ultimate recycling of the end-of-life cells. This could not be proven within this study due to the limited timeframe, hence this opportunity should be followed up in further research.

Plastics

The project team supported local recyclers in Brazil who were trying to find offtakers from industriy whose technical requirements could not be met by the e-waste processors. The project found a new offtaker form the EEE industry capable of consuming regranulates from WEEE recyclers. The implementation of such a project usually takes several years and could not be carried out as part of the pilot study.

While the potential partners in Brazil will try to materialize the above concept within the next years, other offtakers from the EEE industry should be identified with similar material specifications.

Mixed waste shipment

African recyclers may generate revenue or breakeven for various problematic e-waste fractions if they send a mixed waste shipment directly to European recyclers. It was concluded that the shipment of green listed wastes would be ecomically viable, but shipment could not take place within the project timeframe as the inventory of the selected recycler was constantly changing, resulting in the change of the potential recycler in Europe that could process all the fractions. A transboundary shipment notification process could not be initiated before the end of the project.

Other key takeaways

EEE producers approached by the project team to financially support the treatment pilots in the absence of EPR legislation in target countries declined their participation in such an initiative. They were either involved in other initiatives or preferred to wait a few more years for EPR obligation to come rather than do something voluntarily. The only exemption was an EEE producer in Brazil who had a vested interest in getting involved due to their corporate strategy of achieving a 50 % share of plastic recyclate in their production by 2030. This could be a lead for similar projects in the future.

Aside from Li-Ion batteries, PUR foams, CRT screens, lamps and e-waste plastics, recyclers in the target regions frequently mentioned having trouble with managing toner and ink cartridges. Perhaps this fraction could be further examined in similar projects.

Recyclers in some low- and middle-income countries have started collecting Li-Ion batteries believing that all of them generate income from processing. While this is true for cobalt-rich batteries, other chemistries bring only cost. In order to change that, recyclers could seek for repurposing options, which, as the attempted pilot project show, could be profitable in case of LFP batteries. Should that not be possible, recyclers should charge waste generators higher fees for collecting LFP batteries so that they can finance their treatment.

Basel Convention notification procedure not only slows down waste exports, but in some cases prevents them. This leaves recyclers in low- and middle-income countries with fractions they cannot process locally. It is necessary to speed up the TFS notification procedure to support recyclers in developing countries with exporting problematic e-waste fractions to countries where the necessary recycling infrastructure already exists. This would require a multistakeholder dialogue between Basel Convention Competent authorities in the target regions (Balkans, Africa, South America) and some European countries where there are recycling facilities for problematic fraction (e.g. Belgium, Spain, France, Finland and Germany for Li-Ion batteries and R11/R12, Belgium, Spain and Germany for cartridges, etc.). The involvement of recyclers on both sides is also necessary:

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6 Annex: Finance Models

An overview of the cost models with exemplary starting values is given here. Values can be changed in the excel spreadsheet accompanying this report on the PREVENT Waste Alliance website.

Profit and loss calculation for treatment of PUR foams

Disclaimer: this finance model aims to provide initial inidications of costs, assumptions should be verified in other contexts

Income and cost per scenario		OPTION A (shipment of R12 refrigerant):		OPTION B (shipment of PUR foams):		OPTION C (entire refrigerator):	
	Parameters:	**Assumptions:**	**Calculations:**	**Assumptions:**	**Calculations:**	**Assumptions:**	**Calculations:**
Income	Fraction	Refrigerant only		PUR Foam only		Fridges	
	Available weight	0.10 t		17.00 t		450.00 t	
	R12 refrigerant content	100%				0.30%	
	CO_2 Equivalent	10,900				10,900	
	R11 refrigerant content			5%		0.60%	
	CO_2 Equivalent			4,750		4,750	
	Conversion factor	1		1		1	
	Value of certificates	8 €/ t CO2 EQ		8 €/ t CO2 EQ		8 €/ t CO2 EQ	
	Total value		**8,720 €**		**32,300 €**		**220,320 €**
Cost	Bottles/ cylinders	200 €/t	20 €				
	Shipping	1000 € per shipment	10 €	1000 € per shipment	3,778 €	1000 € per shipment	60,000 €
	Treatment in a Cold recycling plant	2,500 €/t	250 €	100% 400 €/t	6,800 €	300 €/t	135,000 €
	Treatment in a cement kiln*			0% 50 €/t	0 €		
	Cerification costs one-off*	€ 0	€ 0	20,000 €	20,000 €	20,000 €	20,000 €
	Cerification costs continuous*	100 €/t	10 €	100 €/t	1,700 €	10 €/t	4,500 €
	Total cost		270 €		32,278 €		**219,500 €**
Total income (+) or cost (-)			**8,450 €**		**22 €**		**820 €**

Legend

(white)	Data to be entered by waste stream owner
(blue)	To be confirmed by site or downstream vendor, expected average costs indicated
(yellow)	Varies over time and depends on the route, to be confirmed before shipment, expected average values indicated
Treatment costs cement kiln*	It is unlikely that the cenemnt kiln can be certified
Certification Costs*	To be confirmed by Tradewater or other finance partner

Profit and loss calculation for treatment of Li-Ion batteries

Disclaimer: this finance model aims to provide initial inidications of costs, assumptions should be verified in other contexts

Input		60.00 t						Total Income
Battery Sorting		150 €/t						
Output fractions		Pb	Alkaline	Li-Ion with Co	Li-Ion w/o Cobalt	Ni-Cd	Others	
				3%	97%		0%	
		0.00 t	0.00 t	2.00 t	58.00 t	0.00 t	0.00 t	
Shipping Costs	3500 € per shipment	175 €/t	175 €/t	175 €/t	175 €/t	175 €/t	175 €/t	
Treatment Costs		200 €/t	250 €/t	3,000 €/t	1,200 €/t	3,000 €/t	600 €/t	
Raw Material		Pb		Co	Li	Ni		
Raw material Price		1,600 €/t	0	48,000 €/t	0 €/t	18,000 €/t		
Raw material content		50%	0%	10%	0%	11%	0%	
Raw material income		800 €/t	0 €/t	4,800 €/t	0 €/t	1,980 €/t	0 €/t	
Income per ton		425 €/t	-425 €/t	1,625 €/t	-1,375 €/t	-1,195 €/t	-775 €/t	
Total Income		0 €	0 €	3,250 €	-79,750 €	0 €	0 €	**-76,500 €**
					Repurposing*			

Legend

(white)	to be entered by waste stream owner
(blue)	to be confirmed by site or downstream vendor, expected average costs indicated
(yellow)	Varies over time, to be confirmed later, expected average values indicated
Repurposing*	The major treatment costs meant that instead of treatment, repurpusing was pursued in the pilot. The revenues here depend on dismantling costs, testing costs, health rate of individual cells, assembly costs and sales revenue. See accompanying report for potential revenues from repurposing.
Noficiation Cost*	For hazardous waste fractions notification is mandatory. This cost approx. 1500€/EWC plus other export,transit and import authority paperwork. This depending on route, volume and nature of waste can amount to additional 3500€/EWC

Profit & loss calculation for treatment of e-waste plastics

Disclaimer: this finance model aims to provide initial inidications of costs, assumptions should be verified in other contexts

Input	200 t					Total
Platics Sorting	200 €/t					40,000 €/t
Output fractions	ABS	PS	PC/PC&ABS	PP	Other	
	60%	30%			10%	
	120.00 t	60.00 t	0.00 t	0.00 t	20.00 t	
Shipping Costs	50 €/t	50 €/t	50 €/t	50 €/t	50 €/t	
Refinement and Compounding incl waste disposal	400 €/t	400 €/t	400 €/t	400 €/t	100 €/t	
Yield	80%	80%	80%	80%	80%	
Sales price Compound	1,000 €/t	700 €/t				
Revenue per ton input	350 €/t	110 €/t	-450 €/t	-450 €/t	-150 €/t	
Revenue per stream	42,000 €	6,600 €	0 €	0 €	-3,000 €	**45,600 €**
Total revenue						**5,600 €**

Legend

(white)	to be entered by waste stream owner
(blue)	to be confirmed by site or downstream vendor, expected average costs indicated
(yellow)	Varies over time, to be confirmed later, expected average values indicated

Profit and loss calculation for treatment of mixed fractions

Disclaimer: this finance model aims to provide initial inidications of costs, assumptions should be verified in other contexts

Container shipment cost		2,100 €	20 ft container	
Notification Cost*		5,000 €		
	Weight	**Revenue (+)/ Costs**	**Secondary shipment**	**Total value**
Mixed batteries	2.00 t	-2,000 €/t	500 €	-4,500 €
Computer PCB (with iron processor)	1.00 t	4,200 €/t	167 €	4,033 €
PCB high grade	1.00 t	3,300 €/t	167 €	3,133 €
PCB low grade	2.00 t	2,400 €/t	167 €	4,633 €
PCB (Medium grade)	2.00 t	1,000 €/t	167 €	1,833 €
Cables	2.00 t	1,200 €/t	167 €	2,233 €
Lamps	3.00 t	-1,000 €/t	500 €	-3,500 €
CRT Glass	2.00 t	80 €/t	500 €	-340 €
Cartridges	3.00 t	-370 €/t	150 €	-1,260 €
Sub-Total Treatment Costs	18.00 t			6,266 €
Container Shipment Cost		2,100 €/t		
Notification Cost		5,000 €/t		
Total income (+/-)				-834 €

Legend

(white)	to be entered by waste stream owner
(blue)	to be confirmed by site or downstream vendor, expected average costs indicated
(yellow)	Varies over time, to be confirmed later, expected average values indicated
Secondary Shipment	Refers to the shipping costs over land to the recycling facility
Notification Cost*	For transboundary movement of hazardous waste fractions, the Basel Convention notification procedure must be followed. The cost associated with the process varies and is estimated at 1500€/EWC (European Waste Code). To this, extra export, transit and import authority paperwork is surcharged depending on the carrier's route. This can also amount to an additional 3500€/EWC. Both costs must be factored in to the final P&L model for shipment abroad.

This represents the costs for one mixed waste container shipment