Selected Solutions for the Management of Problematic Fractions of E-Waste

Feasibility study & Roadmap

Final Report, October 2024

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Economic Affairs SECO

Empa
Materials Science and Technology

WORLD RESOURCES FORUM

Authors: Aly El Sherei, Mohamed Youssef , Mohamed Sherif

Publication year: 2024

ISBN: 978-3-906177-50-2

Acknowledgment: This report has been developed by Dcode Consulting, with advice and review from CEDARE and dss+

Dcode Consulting

CEDARE

dss+ Protect. Transform. Sustain.

SRI SUSTAINABLE RECYCLING INDUSTRIES

Turning waste into resources for development

SRI builds capacity for sustainable recycling in developing countries. The programme is funded by the Swiss State Secretariat of Economic Affairs (SECO) and is implemented by the Institute for Materials Science & Technology (Empa) and the World Resources Forum (WRF). It builds on the success of implementing e-waste recycling systems together with various developing countries since more than ten years.

sustainable-recycling.org

sri@wrforum.org

Acronyms

BAT	Best Available Techniques
BFR	Brominated Flame Retardants
CAPEX	Capital Costs
CRT	Cathode Ray Tube
EoL	End-of-Life
EPR	Extended Producer Responsibility
EFF	Extended Fund Facility
FX	Hard currency
GoE	Government of Egypt
IMF	International Monetary Fund
IRR	Internal Rate of Return
Li-Ion	Lithium-Ion Batteries
LIB	Lithium-Ion Batteries
NPV	Net Present Value
OEM	Original Equipment Manufacturers
OPEX	Operational Costs
PCB	Printed Circuit Boards
POP	Persistent Organic Pollutants
POP-BFR	Persistent Organic Pollutants-Brominated Flame Retardants
SCZone	Suez Canal Economic Zone
ToR	Terms of Reference
WEEE	Waste Electrical and Electronic Equipment
WMRA	Waste Management Regulatory Agency

Table of contents

1 Executive summary

1.1 Background

The Sustainable Recycling Industries (SRI) programme is funded by the Swiss State Secretariat of Economic Affairs (SECO) and implemented in Egypt by the Center for Environment and Development for the Arab Region and Europe (CEDARE) and DSS Sustainable Solutions Switzerland (dss$^+$). Key partners also include the Ministry of Communications and Information Technology (MCIT) and the Egyptian Ministry of Environment (MOE).

The overall development objective of the programme is that favourable framework conditions enable the development of a sustainable recycling industry for e-waste and related waste streams. The programme is focusing on governance and technology aspects that allow for an optimal recovery of secondary raw materials and the safe management of hazardous substances. In all its activities, SRI strives for inclusive approaches, aiming at beneficial economic conditions for both the private industry and the informal sector. SRI leverages the concept of a circular economy and contributes to actions on climate change mitigation through a reintegration of secondary raw materials into industrial processes. To maximize and measure the positive impact of the programme, metrics for sustainability and the environmental benefits of implemented changes are developed and applied.

SRI in Egypt was conducted in two phases. Phase 1 took place between 2016 and 2018; Phase 2 started in 2020 and will last until 2025. One of the key objectives of the current phase is to address the issue of problematic fractions and identify locally adapted solutions for their safe treatment. Accordingly, a baseline assessment and an opportunity study were conducted in 2022 which identified some problematic fractions for which Egypt currently lacks environmentally sound solutions for the management of some fractions including: Lithium-ion batteries (LIBs), Plastics containing Persistent Organic Pollutants-Brominated Flame Retardants (POP-BFRs), Capacitors containing PCBs and CRT screens. Based on the findings from that study, several solutions were recommended, and upon which SRI programme commissioned the current study to validate the solutions and test their feasibility within the Egyptian market.

Thus, the stated objective of this current study is to conduct a more **in-depth feasibility assessment for the promising solutions identified and to propose a roadmap for implementation**. The **objectives** of the feasibility study are as follows:

1. To identify the most **cost-effective solutions** for the environmentally sound management of problematic fractions from e-waste in Egypt.
2. To assess the **CAPEX and OPEX of identified solutions** and break down the costs per ton of waste equipment treated so that advanced recycling fees can be added to new equipment purchase prices.
3. To identify **key technical, legal, and economic challenges** related to the implementation of identified solutions.
4. To establish a **roadmap for implementation** of identified solutions, highlighting key responsibilities of relevant stakeholders in the short, medium, and long term.

1.2 Methodology Adopted

To achieve these objectives, Dcode Economic and Financial Consulting (the commissioned firm to conduct the study), has adopted a mixed approach (qualitative and quantitative), and the following steps were undertaken in developing the study:

1. **Literature review, Collection of Data, and Initial Solutions' Selection:** A comprehensive literature review was conducted to gather information and data on the current situation of e-waste in Egypt, focusing on data on the quantities and prices for both inputs and outputs. The secondary research also included collecting information on the costs associated with establishing and operating Best Available Techniques (BAT) for Plastics containing POP-BFRs incineration and LIB recycling facilities, in addition to prices of recycling outputs (Black mass, metallic fractions, plastics and other non-metallic fractions and wastes). Based on the literature review, a selection of initial potential solutions was identified:

    a. **POP-BFR**: Two options were suggested:
        i. **Option1**: to export shredded POP-BFR, and
        ii. **Option 2**: to establish a BAT Incineration facility locally.

    b. **LIB**: Two options were initially suggested:
        i. **Option 1**: to export black mass after conducting semi-processing, and
        ii. **Option 2**: to establish a Pyrometallurgical Processing facility locally.

2. **Stakeholders' Consultations:** Meetings were conducted with several stakeholders (A list of all entities contacted and/or met with the status can be found in Annex 2). To stand on the current solutions/practices in Egypt and gather data on the financials associated with them, to get updates on the legal and regulatory framework and schemes (e.g. Extended Producer Responsibility – EPR), and to gather information and data on the operations, costs and revenues' structures of international known companies that operate incinerators and LIB recycling facilities (A list of all entities contacted and/or met with the status can be found in Annex 2). The findings from the consultations shaped the decision for the selection of the BAT solution(s), which was discussed with the project team, and hence it was agreed to proceed with most suitable solution(s) for the Egyptian context, and within the context of the lack of certain information areas and data.

3. **Identification and Selection of Most Viable Solution(s)**: Based on data and information collected from primary and secondary research, all options were preliminarily analysed and evaluated in terms of legal feasibility, technical feasibility, management and operational feasibility, financial feasibility, and social and stakeholder acceptability. This comprehensive assessment aimed to determine the most valid options for a fully-fledged financial feasibility study.

Overall, the study was conducted in the period 2023-2024. This study faced several limitations impacting the depth and accuracy of the findings. Notably, the proposed solutions have never been implemented in Egypt, resulting in a lack of local experience with the required technology and operational practices. Since this is a budgetary feasibility study without a specific investor or timeline, foreign technology providers were cautious in sharing detailed information, and operators abroad were either unreachable or unwilling to disclose confidential financial data.

1.3 Main findings

The analysis has yielded several key findings regarding the feasibility of various solutions.

1. **POP-BFR Plastics Management**:

   - **Exporting vs. Local Incineration**: The study evaluated two potential solutions for POP-BFR plastics: exporting for incineration and establishing a local incineration facility. While establishing an export hub creates a channel for the collection and environmentally sound treatment of POP-BFR abroad and hence could increase collection rates, high export costs and regulatory compliance issues posed significant challenges.

   - **Local Incineration Facility**: Building a specialized incineration facility incurs substantial costs and operational complexities. The financial feasibility was further undermined by stringent emissions regulations and the high initial investment required.

2. **LIBs**:

   - **Exporting Black Mass After Semi-Processing:**

     - This option emerged as the most promising due to its lower relative initial investment requirements and alignment with existing infrastructure for handling e-waste. The semi-processing method involves the collection, discharging, dismantling, and mechanical processing of LIBs to separate valuable black mass, which is then exported for further refining.

     - **Insufficient Financial Feasibility**: The financial analysis indicated a positive Net Present Value (NPV) of EGP 3.2 million and an Internal Rate of Return (IRR) of 15%. The financial analysis indicates that while the project is technically feasible, as the NPV is positive, the IRR is lower than the cost of capital. This makes the project financially unattractive to private sector investors under current conditions.

     - **The importance of Collection Rates**: The study highlighted that improving collection rates of end-of-life (EoL) lithium-ion batteries is crucial. The current collection rate is estimated at around 15%, which must increase to ensure the viability of the processing facility.

   - **Local Pyrometallurgical Processing Facility:**

     - **High Capital Investment**: Establishing a facility for pyrometallurgical processing, particularly using a Top Blown Rotary Converter (TBRC), involves significant capital expenditure (CAPEX) exceeding EUR 3 million. Given the low volumes of EoL LIBs, this option was deemed unfeasible.

     - **Operational Challenges**: The operational costs and complexities associated with maintaining high environmental standards present additional barriers. The financial analysis showed a negative NPV and IRR for this option, making it unattractive to investors.

Suggested Priority Actions

To overcome the financial, operational, and regulatory challenges associated with the environmentally sound handling of problematic e-waste fractions, specifically End-of-Life (EoL) LIBs and POP-BFR plastics, a collective set of strategic recommendations are outlined below:

1. Addressing High CAPEX Costs

Some of the proposed solutions for both Li-ion batteries and POP-BFR plastics involve high capital expenditure (CAPEX). To mitigate the high upfront investment, the following financial mechanisms are recommended for consideration and deployment:

- Blended Finance: Combining public, private, and philanthropic capital can reduce risks for private investors while securing essential funding for public goods. This approach could leverage concessional funds from international donors or development banks to improve project feasibility.
- Grants and Concessional Loans: Securing grants from environmental funds (such as the Global Environment Facility or Green Climate Fund) and concessional loans from development banks with below-market interest rates can help lower the cost of capital and ease the burden of high CAPEX.
- Public-Private Partnerships (PPPs): Engaging private entities in co-investment opportunities can reduce financial risks by sharing responsibilities and profits. This model can ensure long-term returns through mechanisms like gate fees or extended producer responsibility (EPR) contributions.
- Government Subsidies: Temporary government subsidies, particularly in the early stages of implementation, can be vital in making the collection and processing of e-waste more attractive, with subsidies gradually reduced as financial sustainability is achieved.

2. Improving Collection Rates

Low collection rates present a challenge for both e-waste streams, as alternative disposal methods (e.g., informal recycling or cheap landfilling) reduce the volume of waste reaching formal treatment facilities, eroding their profits and thus financial feasibility. To address this:

- Enforce Regulations: Strict enforcement of regulations to prohibit environmentally unsound informal recycling and improper disposal of e-waste is essential. Monitoring systems should be established to track production and disposal, while penalties for non-compliance must be clearly defined.
- Innovate Collection Systems for Households: Innovative regulations and solutions to increase e-waste collection rates from households such as digital platforms or mobile apps that can allow households to schedule pickups or drop-offs for e-waste, with tracking features ensuring proper disposal. Additionally, providing small incentives for household participation.
- Increase Fees for Alternative Disposal Methods: After the enforcement of regulations, it would be important to increase the current disposal fees (such as for landfilling at Nasreya) to disincentivize this type of disposal. By raising fees, industries would be encouraged to channel waste through formal collection and treatment systems.

3. Leveraging Extended Producer Responsibility (EPR) Schemes

To support the financial viability of the treatment solutions, an EPR fee should be introduced for both LIBs and POP-BFR plastics. This fee should be designed with a built-in buffer to account for market volatility and ensure stability during the initial phases. Additionally, a dynamic adjustment mechanism can allow the fee to be recalibrated annually based on actual market conditions, ensuring sustainability over time.

4. Developing a Self-Sustaining Revenue Model

For both e-waste streams, the viability of treatment solutions can be strengthened by expanding operations beyond the initial scope. For example, the hazardous waste incineration facility for POP-BFR plastics could process other hazardous materials, reaching economies of scale and generating consistent revenue through gate fees.

5. Technology and Strategic Partnerships

To ensure access to the latest technologies, especially for processes like the semi-processing of LIBs (black mass) or smelting (pyrometallurgical processing), strategic partnerships with technology providers should be established. This can include Public-Private Partnerships (PPP) between the state bodies and technology providers, which can ensure the use of state-of-the-art techniques while securing higher collection volumes through a well-implemented EPR scheme.

6. Ownership of Recommendations

It is essential to clearly define who will take ownership of each recommendation to ensure the successful implementation of the proposed solutions. The roles and responsibilities are outlined as follows:

- **Government and Regulatory Bodies:** The government should take the lead on elaborating on and enforcing regulations, raising landfill fees, negotiating concessional loans or grants, and introducing EPR schemes. These bodies will also be responsible for creating and overseeing the monitoring systems needed to track waste production and disposal.
- **Private Sector:** The private sector, including recyclers and technology providers, will need to engage in PPPs and take the initiative to entrepreneur and invest in technology and operational improvements. Their role in financing and operationally processing the e-waste is critical, especially for achieving system efficiency, including through economies of scale.
- **International Organizations and Development Banks:** These institutions, such as the World Bank and environmental funds, will provide technical assistance, concessional loans, and blended finance mechanisms to support the projects. They will play a key role in reducing the financial risk and ensuring the financial viability of these solutions.

Keywords

POP-BFR Solutions, LIB Recycling Solution, Financial Feasibility, Egypt

2 Identification and Ranking of Potential Solutions for Most Problematic Fractions

2.1 Background - Identification of most problematic fractions

In 2022, a baseline assessment and opportunity study were conducted to evaluate the current state of e-waste management in Egypt (Soliman 2022b). The primary findings from these studies highlight critical concerns regarding hazardous materials found in waste volumes in the country. The assessment identified priority fractions arising from e-waste that require urgent attention:

1. **Plastics Containing Persistent Organic Pollutants (POP)**: This includes plastic casings and circuit boards, which are significant contributors to environmental contamination.
2. **Lead-Containing Glass**: Predominantly found in Cathode Ray Tube (CRT) screens, this material poses serious disposal challenges due to its toxic properties.
3. **Mercury-Containing Backlights**: Commonly used in flat panel displays, these components necessitate careful handling to prevent environmental harm.
4. **Batteries**: Particularly those containing cadmium, lead, and/or lithium, which present significant risks if not managed properly.

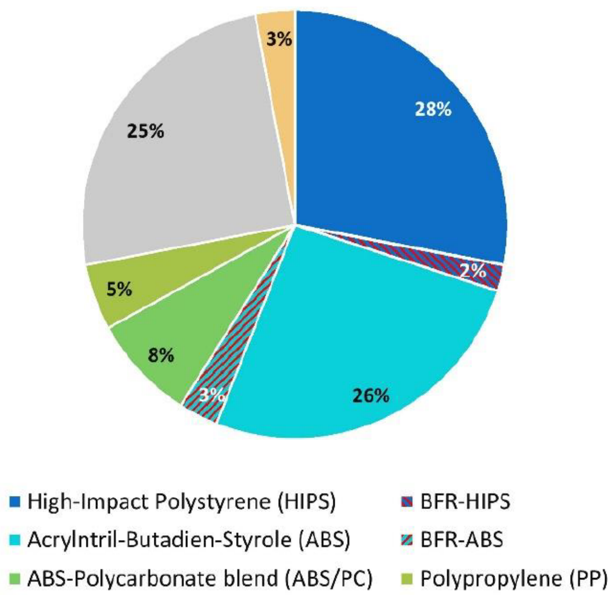
In conjunction with these findings, the opportunity study revealed that there are potential solutions for two main problematic fractions in the formal e-waste recycling sector that currently lack environmentally sound treatment solutions:

- **Lithium-Ion Batteries (LIBs)**: The growing use of lithium-ion batteries across various industries has raised concerns about their safe disposal and treatment. Investigating effective recycling or disposal processes for these batteries is essential to prevent improper handling and potential environmental harm.
- **Plastics Containing Brominated Flame Retardants (BFRs)**: These plastics, which include casings and circuit boards, pose significant challenges regarding disposal and environmental impact. It is crucial to explore appropriate methods for managing and treating these materials to minimize health risks and contamination.

The comprehensive assessment of these problematic fractions underscores the urgent need for immediate and effective solutions in the e-waste recycling sector in Egypt. This current study aims to address these issues by identifying and validating potential treatment methods, thereby mitigating the environmental and health risks associated with hazardous materials.

2.2 Overview on POP-BFR

Plastics containing Brominated Flame Retardants (BFRs) are a significant component of Waste Electrical and Electronic Equipment (WEEE) waste streams. These plastics are commonly used in electronic devices, such as computers, televisions, and mobile phones, to improve their fire resistance properties.



Source: Processing of WEEE plastics, Plastic Handbook, SRI, 2019

BFRs are chemical additives incorporated into plastics to reduce their flammability and meet fire safety regulations. Common BFRs found in WEEE plastics include polybrominated diphenyl ethers (PBDEs) and tetrabromobisphenol A (TBBPA). The levels of BFRs in WEEE plastics can vary depending on the type of plastic and the specific electronic device. Plastics from screens and ICT equipment tends to have higher BFR levels than those from white goods, for instance. Some BFRs used historically (PBDEs, PBBs and HBCD) have been classified as Persistent Organic Pollutants (POP) under the Stockholm Convention due to their toxicity and persistence in the environment. Consequently, the production of these substances is banned, and wastes containing these substances have to be safely disposed of.

2.3 BAT Solutions for POP-BFR

Dealing with plastics containing POP-BFRs involves considering Best Available Techniques/Technologies (BATs), often established at international or country levels. Yet, these BATs may be inaccessible in many regions due to lacking infrastructure, such as hazardous waste incinerators or landfills. Identifying alternative solutions is difficult, given the challenges in evaluating and comparing the long-term impacts of suboptimal methods. Below are the known methods of disposal of POP-BFR.

2.3.1 Hazardous Waste Incineration

Incineration at high temperatures (around 1100°C) is effective in destroying hazardous organic substances like BFRs. State-of-the-art emissions control in hazardous waste incinerators is crucial for removing toxic fumes and heavy metals, making this method a current BAT for plastics containing substances such as BFRs.

2.3.2 Hazardous Waste Landfill

Hazardous waste landfills, equipped with specific control mechanisms, prevent the dispersion of hazardous substances into the environment. These landfills, featuring separate compartments, impermeable liners, and leachate collection systems, offer a viable disposal solution for plastics containing BFRs and heavy metals.

2.3.3 Filler Material in Infrastructure

Using plastics with hazardous substances as fillers in construction materials can be an alternative to incineration or landfilling. However, it is crucial to ensure that hazardous substances are stabilized within the infrastructure to prevent leaching over time (e.g., in road paving).

2.3.4 Recycling and Downcycling

Recycling BFR-containing plastics into flame-retardant products or downcycling hazardous plastic fractions into products stabilizing toxic substances is a viable solution where BAT incineration or landfilling is inaccessible. It is important to restrict the use of recycled or downcycled hazardous plastics to products with prolonged use and minimal human exposure, such as plastic beams in construction.

2.3.5 Non-BAT Incineration

Incinerating BFR-containing plastics or PVC in non-BAT incinerators or as alternative fuels poses challenges. Incomplete combustion due to insufficiently high temperatures can lead to issues, and corrosive acid gases formed during incineration (such as HCl and HBr) may damage the infrastructure. These corrosive effects are especially problematic when halogens are present.

There are various technologies and methods for managing the non-recyclable fraction of plastic waste, particularly focusing on hazardous additives such as BFRs, heavy metals, and phthalates. Commonly employed treatment technologies include *incineration in municipal or hazardous waste incinerators, co-processing in cement kilns, or utilization as a reducing agent in non-ferrous metal smelters.* Effective destruction or transformation of POP-BFRs is achievable in incineration plants, cement kilns, and smelters, provided a minimum temperature of 850°C is maintained for at least 2 seconds. Regulations, such as those outlined in Article 50 of the Industrial Emissions Directive (2010/75/EU), mandate these conditions for waste incineration plants. While landfilling is not a permitted treatment option for waste containing POP-BFRs above the LPCL (Lowest Practicable Concentration Limit), it may still occur in some countries, posing risks of leaching BFRs and heavy metals into nearby soils and water bodies. Modern landfills mitigate these risks to some extent, but they do not destroy or irreversibly transform POP-BFRs present in the waste (Haarman et al., 2023). However, the main challenge in finding a feasible solution lies in *valorising the plastic fraction*, which requires sorting by type, removal of hazardous additives, and finding specific markets for individual plastics.

2.4 Current Practices/Solutions for POP-BFR in Egypt

In Egypt, the disposal of plastic containing brominated flame retardants (BFR) poses significant challenges due to the lack of clear and widely accepted methods for its proper management. One of the existing challenges is that BFR plastic is not accepted as an alternative fuel (AF) in cement kilns due to its negative impact on the product specifications. This limits the potential for coprocessing BFR plastic in cement kilns, which is a commonly used method in other countries.

Even though Nasreya is designated safe hazardous landfill that accepts BFR plastic in Egypt, the disposal of BFR plastic in Egyptian landfills is not regulated or controlled, leading to potential environmental and health risks. However, it is worth mentioning that some recyclers through our interviews informally use BFR plastic as raw materials for producing certain products such as water hoses and mats, finding alternative ways to repurpose this waste stream, albeit with potentially nefarious consequences (exposure to POPs).

In conclusion, the disposal of BFR plastic in Egypt currently lacks clear methods and designated facilities. However, there are opportunities for research and development, promoting recycling initiatives, and establishing regulations to address this challenge. By implementing proper disposal and recycling practices, Egypt can mitigate the environmental and health risks associated with BFR plastic and move towards a more sustainable approach to plastic waste management.

Box 1: Nasreya Hazardous Waste Landfill

Nasreya Hazardous Waste Landfill stands as the sole facility in Egypt designated for the disposal of hazardous waste. The following provides an overview of this facility.

Nasreya Hazardous Waste Landfill accepts 39 types of hazardous waste from various sources spanning all governorates of Egypt, extending from Alexandria to Aswan. The establishment of this facility commenced under an agreement signed on February 22, 1999, between the Egyptian government and the Finnish government, with funding amounting to 10 million pounds from the latter. The primary project site was designated on a 37-acre area in the Nasreya region, with the main cells covering 14,000 square meters and equipped with insulating lining layers to manage solid inorganic waste. Subsequent phases involved the creation of evaporation basins spanning 5,200 square meters to address liquid waste in compliance with European standards. A chemical laboratory, furnished with necessary equipment for analysis, was also established. The facility-initiated operations on June 29, 2005, following the training of a team responsible for the collection, transportation, and treatment of hazardous industrial waste.

The second phase in 2006 saw the establishment of a physicochemical unit specializing in the treatment of liquids, acids, and hexavalent chromium. A solidification unit was also introduced to treat specific types of hazardous waste before disposal into the burial cell. The third phase in 2009 involved the installation and operation of two incinerators for the thermal treatment of organic waste. Additionally, a waste management unit targeting mercury, specifically fluorescent lamps, was established through cooperation between the Egyptian government and South Korea. The unit, officially completed on September 19, 2011, operates at a capacity of 750 kilograms per hour, utilizing hydraulic presses to compress iron drums post-washing, ensuring they are free from hazardous waste.

The fourth phase, initiated in 2020, led to the establishment of Egypt's largest burial cell, covering 15 thousand square meters at a total cost of 17 million pounds. Four lakes, each measuring 40 meters by 40 meters with a depth of 1 meter, were also constructed (Soliman 2022b).

2.5 Selection of Solutions for the POP-BFR

To address the challenges associated with BFR plastic disposal in Egypt, this section outlines two potential solutions: Option 1: exporting shredded plastic to incinerators abroad and Option 2: establishing a specialized incineration facility locally. Through primary and secondary research, and to determine if the solutions are initially viable, each option was first evaluated based on legal, technical, management, operational, financial (preliminary analysis), and social feasibility considerations.

1. **Option 1: Exporting** focuses on creating a hub for collecting and shipping POP-BFR plastics to foreign incinerators. While establishing an export hub creates a channel for the collection and environmentally sound treatment of POP-BFR abroad and hence could increase collection rates, it poses significant financial challenges due to high export costs and lacks revenue generation.

2. **Option 2: Establish a Specialized Incineration Facility** involves building a local facility to incinerate POP-BFRs. This option offers a localized solution with the potential for energy recovery but comes with high capital costs and operational complexities.

The table below summarizes the key aspects of each option, allowing for easy comparison and tracking of feasibility aspects.

Criteria	Option 1: Exporting	Option 2: Establish a Specialized Incineration Facility
Process	▪ Creation of a collection hub for POP-BFR plastics. ▪ Collection of waste plastics from various sources. ▪ Sorting and preparing the plastics for shipment, including shredding. ▪ Shipping the collected plastics to foreign incinerators for treatment.	▪ Construction of a local facility dedicated to the incineration of POP-BFRs. ▪ Collection and transport of POP-BFR plastics to the facility. ▪ Incineration of collected plastics in specialized equipment. ▪ Emission control processes to manage pollutants during incineration.
Legal Feasibility	Alignment is necessary with 1) Local Laws, 2) International obligations: Basel Convention and Prior Informed Consent (PIC), 3) Health & Safety regulations. Adhering to the requirements will incur additional costs.	Compliance with stringent environmental regulations and waste management policies regarding the incineration of Plastic containing BFR while ensuring operational efficiency is crucial yet challenging.
Technical Feasibility	The absence of processing (Hence valorisation) in the export hub model results in no revenue generation. This technological limitation hinders the financial sustainability of the solution	Energy Generation Efficiency: Optimizing energy generation processes within the incineration facility poses technological challenges. Enhancing the efficiency of energy production while balancing costs is crucial for financial sustainability.
Management & Operational Feasibility	Requires developing adequate facilities for the collection, sorting, and storage of POP-BFR plastics. The hub must be equipped with the necessary infrastructure to handle hazardous materials safely and efficiently. Operational costs related to running the hub, including labour, maintenance, transportation, and compliance costs not aligned with a revenue stream.	High operational complexity: technical know-how and training for staff is needed. Thus, long-term management and operational strategies needed.
Financial Feasibility	The absence of revenues, high export costs and costs of adhering to international requirements outweigh potential financial benefits, rendering the option economically unfeasible.	The initial investment required to establish an incineration facility with a capacity of 5000 tons per year presents a significant financial burden, amounting to EUR 3 million excluding the cost of establishment.
Social & Stakeholder Acceptability	Potential resistance from recyclers to utilize the hub due to costs and logistics, and with no clear incentive scheme. Support from government is needed for legitimacy.	Support from government is needed for legitimacy.

Criteria	Option 1: Exporting	Option 2: Establish a Specialized Incineration Facility
Conclusion on Feasibility	Deemed currently unfeasible due to high export costs and lack of revenue, coupled with complex logistics and regulatory challenges.	Deemed currently unfeasible due to high capital and operational costs, as well as uncertainty in revenue generation and potential community concerns about emissions. Based on a study from the Medical and Electronic Waste Management Project[1], a 10,000 ton/year capacity incinerator would be suitable for the initial 10-year phase of operation, addressing the estimated generation of 264,603 tons of e-waste plastics in Egypt (with a 10% collection rate). **However, high initial and operational costs coupled with limited expected revenues make it financially unfeasible.**

Both solutions—exporting POP-BFR plastics to incinerators abroad and establishing a specialized incineration facility in Egypt—are currently deemed unfeasible. **Option 1: Exporting** faces significant challenges due to high export costs and a lack of revenue generation potential, compounded by the complex logistics and regulatory requirements involved in compliance with international waste management conventions. **Option 2: Establish a Specialized Incineration Facility** presents a high capital investment requirement and ongoing operational costs, along with uncertainty regarding revenue generation and community acceptance. While a 10,000 ton/year incinerator could effectively handle the estimated e-waste generated, the financial viability remains questionable due to the significant initial and operational expenses.

In response to the identified challenges the following actions are recommended addressing each challenge while providing practical and feasible solutions.

Challenge 1: High CAPEX Costs (EUR 3.5 million)

For Option 2, the initial investment required to establish an incineration facility with a capacity of 5000 tons per year presents a significant financial burden, amounting to EUR 3 million excluding the cost of establishment.

Solution:

[1] Baseline assessment on persistence organic pollutants (POPs), unintentionally produced persistent organic pollutants (UPOPs), and associated hazardous releases (mercury, lead, cadmium) from electronic waste (E-waste) processing, Module 2, MEWM, UNDP,2019.

- To mitigate the high capital expenditure (CAPEX), a mix of financing mechanisms should be explored to make the project more financially feasible:
- Blended Finance: Combining public, private, and philanthropic capital, blended finance can lower the risk for private investors while providing essential funding for public goods. This approach could attract private sector participation while leveraging concessional funds from international donors or development banks.
- Grants and Concessional Loans: Grants from international environmental funds, such as the Global Environment Facility (GEF) or Green Climate Fund (GCF), can be pursued to offset some of the initial investment. Concessional loans with below-market interest rates from multilateral development banks (e.g., the World Bank or AfDB) can also help finance the CAPEX.
- Public-Private Partnerships (PPPs): Engage private entities to co-invest in the project, sharing both risks and rewards. A PPP model can incentivize private investors to participate, for example by ensuring a long-term return through gate fees.
- Environmental Bonds: Issuing Green Bonds targeted at investors interested in sustainable projects could also help secure additional capital for establishing the incineration facility.

Additionally, if the turbo generator is chosen to be included for power generation, it would require a separate investment of EUR 3 million. This investment should be evaluated carefully based on projected energy revenues and agreements for energy sales (PPA) with the national grid or industrial users.

Challenge 2: Extremely Low Collection Rates

The availability of alternative disposal methods, such as informal recycling (for profit) or landfilling at Nasreya for a small fee, significantly reduces the potential collection rates for POP-BFR plastics. Currently, Nasreya accepts shredded mixed plastics containing BFR for a gate fee of EGP 800 (EUR 15) per ton. The market also provides an incentive for recyclers to sell these plastics, which presents additional competition to the formal collection system.

Solution:

- **Enforce Regulatory Measures:** The government must introduce and strictly enforce legislation that prohibits informal recycling and improper disposal of POP-BFR plastics. Enforcement should be supported by:
  - Monitoring Systems: Develop a monitoring framework to track the production and disposal of POP-BFR plastics across the value chain. This system should involve digital reporting mechanisms for industries producing BFR plastics, as well as regular inspections and audits to ensure compliance.
  - Penalties for Non-Compliance: Set up clear penalties for industries that do not adhere to proper disposal methods, deterring illegal sales to the informal sector and informal recycling. Collaborate with the Waste Management Regulatory Authority (WMRA) to increase awareness and compliance.

- **Increase Fees for Nasreya Landfill**: Once enforcement of regulations is effectively monitored, the next step is to raise disposal fees at the Nasreya landfill to make it a less attractive alternative. The current gate fee is EGP 800 (EUR 15) per ton, which is very low. A proposed increase in this fee, combined with strict monitoring and penalties for improper disposal, should create an economic disincentive for industries to use this option and push them towards utilizing the formal collection and export/incineration solutions.

Challenge 3: Low Returns Due to Negative Intrinsic Value

In Egypt currently, the mixed plastics with Brominated Flame Retardants (BFR) have a negative intrinsic value of EUR 107 per ton. This intrinsic value applies only when the recyclers cannot sell the plastics to the market and have to pay instead for its treatment. If they are able to sell these plastics to the informal sector, the costs associated with waste collection would increase by at least the revenue they generate from these sales. This, combined with limited revenue from incineration, presents a significant challenge for the financial feasibility of Option 1 and Option 2 for POP-BFR plastics.

Solution:

- Gate Fees Supported by EPR Schemes:
  - Introduce gate fees that can cover the cost of collection, packing, export, or incineration. To make the system for appropriately treating POP-BFR plastics financially viable, an additional injection of around EUR 150-200 per ton is required. These fees can be supplemented or fully covered by contributions from the Extended Producer Responsibility (EPR) scheme, where producers of BFR plastics are obligated to cover part of or the total of the disposal cost.
  - The total system cost of managing POP-BFR plastics should be assessed, and gate fees should be designed to cover these expenses. To avoid imposing high gate fees, a burden that might deter recyclers of plastic from disposing the POP-BFR in an environmentally sound manner, the EPR scheme can be partially used to subsidize the cost of treatment/ exporting and hence reducing the gate fees to be paid by plastics recyclers.

- Designing a Self-Sustaining Revenue Model:
  - Develop a business model where hazardous waste incineration services are expanded beyond POP-BFR plastics. By processing other hazardous materials, the incineration facility can reach economies of scale and utilize its full capacity, generating more consistent revenue through gate fees.

- Government Subsidies:
  - The government may consider providing temporary subsidies to make the collection and incineration of POP-BFR plastics more attractive in the early stages of the program. These subsidies can gradually be reduced as the system becomes financially sustainable.

Conclusion

In summary, overcoming the financial, operational, and regulatory challenges for the disposal of POP-BFR plastics in Egypt requires a combination of enforced regulations, innovative financing, and strategic adjustments in fee structures. Implementing these solutions can pave the way for a financially viable and environmentally sound waste management system. Additionally, a phased approach can ensure that each challenge is systematically addressed, and long-term sustainability is achieved.

2.6 Overview on End-of-Life Li-Ion Batteries (EoL-LIB)

Li-ion batteries can be classified into various chemistries, with the following being particularly pertinent in today's economic landscape:

- LNMC (lithium-nickel-manganese-cobalt-oxide)
- LCO (lithium-cobalt-oxide)
- LNCA (lithium-cobalt-aluminum-oxide)
- LMO (lithium-manganese-oxide)
- LFP (lithium-iron-phosphate)
- LTO (lithium-titanate)

The chemistries containing cobalt (LNMC, LCO, and LNCA) exhibit higher energy densities compared to other Li-ion batteries but are also more costly. Consequently, they find predominant use in mobile applications such as smartphones and electric vehicles, where weight and energy density are critical factors. On the other hand, stationary applications generally opt for the more cost-effective LMO or LFP batteries. Despite LTO batteries offering distinct advantages in terms of fire safety, they are not extensively manufactured and used due to their lower energy densities and relatively higher costs (Manhart et al., 2018).

The components of LIBs can pose various hazards, including fire and explosion risks due to highly calorific and self-igniting carbonate electrolytes, human toxic effects from gaseous decomposition products, and potential carcinogenic effects through the release of inhalable particles from battery components. Proper handling of waste Li-ion batteries should consider these potential hazards. Moreover, certain circumstances, such as overcharging or short circuits, can trigger 'thermal runaway,' resulting in rapid heat release and toxic gas emissions, posing technical hazards and health risks (Sojka et al. 2020).

Currently, with the increasing prevalence of e-mobility, a substantial number of lithium-ion batteries (LIB) are entering the waste stream. Thus, it is crucial to develop and implement disposal and recycling strategies. There is an urgent worldwide demand for safe, environmentally friendly, and economically viable routes for the EoL LIBs. These batteries contain strategically important elements and critical materials, emphasizing the need to ensure their reuse or recycling to support future battery manufacturing industries, reducing both costs and waste (Sommerville et al. 2021).

2.7 BAT Solutions for EoL LIBs

Upon examining existing LIB recycling technologies in the industrial sector, they can be categorized into four distinct process stages: Preparation, Pre-treatment (involving both thermal and mechanical pre-treatment), Pyrometallurgy, and Hydrometallurgy. A shared characteristic among all these approaches is the imperative requirement for the material to undergo the essential final hydrometallurgical refining, ultimately resulting in the production of marketable products (Sojka et al. 2020). As the demand for diverse and high-quality output products increases, the number of treatment stages also rises proportionally. Conversely, employing a simple and undifferentiated treatment method, such as direct melting, would yield an equally undifferentiated, mixed product with numerous elements at a low level of distinction. Below is a description for the different stages of LIB treatment:

2.7.1 Preparation

Preparatory processes upstream are not directly linked to the recycling procedure, as they do not actively contribute to ingredient recovery and do not alter the state or composition of the LIB cell. Traditionally, this involves activities like disassembling large stationary or automotive battery packs into cell or module sizes, subtype sorting, separation of plastic housings (common household power packs) and discharging.

2.7.2 Pretreatment

the Pretreatment of Li-ion cells involve chemical and/or physical alterations to the components. Its sole purpose is to separate or modify battery ingredients to a degree that allows integration into existing large-scale industrial processes. Pretreatment methods can be purely mechanical, thermal, or a combination of both. If LIBs are untreated, they could lead to operational disruptions, such as fire and explosion events in feeding systems, impurities due to incorrect sorting, and gas explosions in smelters.

2.7.3 Main Treatment: Pyrometallurgy

Following pretreatment, battery residues undergo a pyrometallurgical intermediate purification before entering a hydrometallurgical final refining process. Pyrometallurgy aims to eliminate unwanted or process-disturbing components and convert target components into a consistent intermediate product. It compensates for fluctuations in feedstock composition, crucial for the sensitivity of hydrometallurgical processes. Components like fluorine, chlorine, graphite, and phosphorus, which pose technical challenges in hydrometallurgy, can be addressed through slagging or utilization in the pyrometallurgical step. Economically, it makes sense to slag low-value non-precious metals, reducing material and energy costs that would otherwise be incurred in hydrometallurgy through dissolving, precipitation, and filtering.

2.7.4 Main Treatment: Hydrometallurgy

The intricate hydrometallurgical refining step involves an autoclave, (chlorine) acid leaching of the intermediate product from pyrometallurgical treatment, precipitation and filtering of non-noble metals or undesirable elements, followed by solvent extraction, nickel electrowinning, ion exchange, and cobalt electrowinning. Parallel and sequential processes include roasting, dissolving, precipitation, filtering, and electro-extraction to extract copper and other by-metals such as lead and precious metals. Achieving an economically viable recovery of the most crucial LIB valuable components, focusing on Co/Ni/Cu, requires detailed pretreatment and pyrometallurgical intermediate purification before reintegrating them into the economic cycle as products.

LIBs recyclers along with their applied techniques can be categorized as follows:

- Optional preparation before recycling, involving activities such as sorting, disassembly, discharging, etc.
- Multi-step pretreatment in specialized battery recycling plants, typically medium-sized companies focusing on battery pretreatment.

- Multi-step main processing in mostly non-specialized battery recycling plants (Sojka et al. 2020).

Box 2: Example of Umicore

"The Umicore process is mainly composed of smelting (in shaft furnace) and subsequent hydrometallurgical treatment steps. Li-ion and NiMH batteries and production scraps are fed directly without significant preparation treatment into the smelter. Preparation is limited to large sized industrial batteries, which are first dismantled to small size (e.g. cell level). Besides batteries, additives such as coke, sand and limestone (slag formers) are fed into the smelting furnace. The smelter generates following output fractions:

- Metal alloy: Containing Co, Ni, Cu, Fe, which can be forwarded to the downstream hydro-metallurgical process for recovery of Co, Ni and Cu. It is noted that since hydrometallurgical process requires fine particle as input material (especially in leaching step), the alloy shall be granulated before forwarding them into leaching step in hydrometallurgical process.
- Slag: Containing Al, Li, Mn, which can be used in the construction industry or further processed for metal recovery. The slag from Li-ion batteries is said to be integrated in Li-recovery flowsheets through a cooperation with external partners.
- Cleaned gas: Off-gas is cleaned by UHT technology. The flue dust resulting from cleaning system, which contains the halogens (mainly F), is landfilled" (Sojka et al. 2020).

Looking into the different recyclers and their techniques, currently, only two combinations, both incorporating thermal pre-treatment and pyrometallurgy, have demonstrated technical feasibility and reached industrial maturity. Thus, based on the analysis and literature review, it can be affirmed that Pyrometallurgy (smelting) stands out as the predominant recycling method for EoL LIBs. This method involves operations at elevated temperatures where redox reactions are initiated to smelt and purify valuable metals like nickel, cobalt, and copper. Meanwhile, metals with high oxygen affinity, such as lithium, manganese, and aluminum, are lost in the slag.

In contrast, Hydrometallurgical recycling employs aqueous solutions to recover and extract valuable metals from minerals or inorganic compounds. It also breaks down components into molecular compounds, with the process typically divided into three general stages: leaching, solution concentration and purification, and metal recovery. Some facilities adopt an integrated approach, combining pyro- and hydrometallurgical process steps in sequence to capitalize on the advantages of both methods, thereby increasing the range of metals recovered (Magalini et al. 2021).

In comparing the two processes: Smelting/pyrometallurgy, is a somewhat capital-intensive method that generates notable greenhouse gas (GHG) emissions. While it effectively extracts and recycles certain critical materials (e.g. cobalt, nickel, and copper), it falls short, particularly from an economic standpoint, in recovering other essential elements such as lithium or aluminum. On the other hand, hydrometallurgy, involving chemical leaching, is a less energy-intensive process that can recover a broader range of recyclable materials compared to smelting. However, the effective management of the caustic reagents required for leaching poses technical challenges (ESMAP 2020).

From the analysis made by (Sojka et al. 2020), the economic efficiency of recycling processes is gauged by their cost composition—comprising capital, general operating, and personnel costs—contrasted with revenue composition based on the quantity and quality of recovered metals. The required investments, and hence capital costs, for the two pretreatment and two main treatment steps escalate exponentially in the following order: mechanical treatment, pyrolysis, pyrometallurgy, and hydrometallurgy.

One important other factor that should be included in studying options for the recycling of LIBs, is economies of scale play. Essentially, the larger the recycling plant, the greater the return on investment, and the more effective the process design can be. This holds particularly true for the hydrometallurgical process, which, as the final step in nearly every recycling process to recover metals, is intricate and demands access to robust management options for a variety of chemicals. Such a process is most feasible on a large scale. Thus, what is suggested as a potential feasible option for Egypt is to have partial treatment and export.

2.8 Current practice/solution for LIBs in Egypt

Currently, there is no definitive data available regarding the collection rate of lithium batteries in Egypt. However, based on previous studies conducted for E-waste assessment in the country, it has been estimated that approximately 2500 tons of small electronic equipment, including lithium batteries, are generated annually. Furthermore, these studies indicate an annual increase in the generation rate of around 4%. The legally-compliant practice in Egypt is to dispose this type of batteries in hazardous landfill at Al-Nasreya hazardous waste landfill, and the following steps describes the disposal process there:

1. Discharging: The batteries are firstly discharged. The main purpose of discharging the batteries is to reduce the reactivity of the batteries so that it is close to being inert. Afterwards, the discharged batteries are directly landfilled.
2. Transportation: Batteries are transported to Al-Nasreya hazardous waste landfill. The other route which described through interviews with local e-waste recyclers that *it is a common practice to collect a certain amount of batteries that are then exported "informally" to recycling facilities outside the country.*

Based on the interviews conducted with recyclers, it was found that the **prevailing operational practice involves storing lithium batteries until a significant amount is accumulated for export**. Additionally, some recyclers collaborate with other recycling facilities to gather a substantial quantity of batteries within a short period, specifically for the purpose of **exporting them informally to foreign facilities for recycling**. The estimated cost for exporting such batteries ranges from 1500 to 2000 USD per ton. *In an interview with the Waste Management Regulatory Authority (WMRA), it was revealed that they are currently in the process of drafting a decree for hazardous waste, which includes circuit boards and batteries. This decree aims to enable the exporting of such waste through annual permits issued by the WMRA.*

2.9 Selection for Solutions for LIBs

Through the literature review, there are different business models that exist within the battery recycling space. These range from companies covering individual value-chain steps (for example, shredding) to integrated companies covering all value-chain steps from end-of-life battery reverse logistics to battery material refining. In identifying the best suited solution/s, potential paths were further studied utilizing primary resources (included getting offers from OEMs), and the two options that were selected initially as potential to be implemented in Egypt are as follows:

1. **Option 1: Export black mass after conducting semi-processing:** The process begins with the collection of lithium-ion batteries from small electronics, which are then discharged and dismantled to ensure safe handling. Following this, mechanical processing involves crushing and shredding the batteries, allowing for the separation of the black mass from other components. This black mass, primarily consisting of lithium, cobalt, nickel, manganese, and graphite, is then prepared for export. The final step involves packaging and shipping the processed black mass to specialized facilities abroad for further refining and recycling.

2. **Option 2: Establishing a pyrometallurgical processing facility locally:** The establishment of a pyrometallurgical processing facility utilizes a Top Blown Rotary Converter (TBRC) to smelt lithium-ion batteries, aimed at recovering valuable metals. During this smelting process, two main products are generated: ingot alloys and slag. The ingot alloy typically contains cobalt (1-3%), nickel (10-20%), manganese (3-7%), and copper (60-80%), representing approximately 35% of the input end-of-life lithium-ion batteries. The remaining materials consist of slag, which contains lithium and cobalt-nickel-copper at concentrations of less than 1%. This process not only efficiently recovers valuable metals but also culminates in the exporting of the produced alloy to further processing facilities or markets.

The table below summarizes the key aspects of each option, allowing for easy comparison and tracking of feasibility aspects.

Criteria	Option 1: Export Black Mass After Semi-Processing	Option 2: Establishing a Pyrometallurgical Processing Facility
Process	▪ Collection of lithium-ion batteries ▪ Discharging, dismantling, ▪ Storage of battery packs ▪ Mechanical processing (crushing, shredding) ▪ Separation techniques (Various separation techniques such as sieving, magnetic separation, and density separation), and exporting black mass.	Utilizing a Top Blown Rotary Converter (TBRC) to smelt lithium-ion batteries for metal recovery.
Main Products	▪ Black Mass (35%): lithium, cobalt, nickel, manganese, graphite. ▪ Metallic Fractions (25%): copper and aluminium. ▪ Plastic and other non-metallic materials (25%).	▪ Ingots Alloy: Co 1-3%, Ni 10-20%, Mn 3-7%, Cu 60-80%. Slag with Li, Co-Ni-Cu content < 1%.
Legal Feasibility	Compliance with export regulations and environmental laws is manageable and comparatively less complex compared to exporting full batteries.	Requires adherence to stringent environmental regulations for emissions control, which may complicate operations.
Technical Feasibility	Established semi-processing techniques are available and proven effective for lithium-ion battery recycling.	High technical requirements for smelting and an advanced environmental control system increase complexity.[2]
Management & Operational Feasibility	Low-capacity plants are suitable; processes are easier to control and manage from an environmental perspective.	High operational complexity and significant management resources are required to ensure compliance with environmental standards[3].

---

[2] Pyrometallurgical processes involve the melting of materials at high temperatures, which can release pollutants and emissions. To ensure compliance with environmental regulations and minimize the impact on air quality, an advanced environmental control system would be necessary. The installation and maintenance of such a system would require additional financial resources and expertise, adding to the overall costs of the facility.

[3] In addition to the significant initial investment, the operation costs associated with a pyrometallurgical processing facility were also found to be high. These costs include expenses related to energy consumption, maintenance, labour, and other operational aspects. The projected ongoing expenses were deemed to be economically burdensome and outweighed the potential benefits of the option (see next section).

Criteria	Option 1: Export Black Mass After Semi-Processing	Option 2: Establishing a Pyrometallurgical Processing Facility
Financial Feasibility	Relatively low investment compared to other alternatives; however, revenue generation is uncertain as it requires finding downstream buyers/outlets.	High initial capital investment (> $3 million)[4] and ongoing operational costs are economically burdensome and may not justify potential benefits, especially in the short term.
Social & Stakeholder Acceptability	Generally positive public perception if managed properly; aligns with sustainability goals.	Community concerns regarding emissions and the environmental impact of operations may affect stakeholder acceptance.
Conclusion on Feasibility	Viable for conducting full feasibility study (Presented in next Chapter)	Deemed currently unfeasible primarily due to high capital and operational costs, along with uncertain revenue generation and community acceptance, however further analysis to the option was made and presented in next Chapter.

2.9.1 Conclusion on Feasibility

Both options for lithium-ion battery management face significant feasibility challenges. **Option 1: Export Black Mass After Semi-Processing** presents a relatively cost-effective solution with lower investment needs and potential for alignment with environmental controls. However, logistical and regulatory complexities may hinder its implementation. **Option 2: Establish a Pyrometallurgical Processing Facility** is deemed unfeasible primarily due to high capital and operational costs, along with uncertain revenue generation and community acceptance, however further analysis to the option was made and presented in next chapter.

[4] The received offers indicated that the capital cost for setting up a plant with a capacity of 1000 tons per year would exceed 3 million USD. This high investment requirement surpassed the available budget or financial resources allocated for the project. The substantial capital cost made this option financially unviable (see next section).

3 Business Model & Financial Feasibility Analysis (LIB recycling)

Based on the analysis conducted, two options for LIBs were studied in terms of their financial feasibility, using the same general key assumptions:

Option 1: Export black mass after conducting semi-processing locally - *Full financial feasibility with sensitivity analysis*

Option 2: Establishing a pyrometallurgical processing facility locally - *Rapid financial feasibility, given the lack of data*

3.1 Option 1: General Key Assumptions

3.1.1 Key Project Scope Assumptions

The financial feasibility analysis focuses on the semi-processing facility for Li-ion batteries from small electronics (Mobile phones, Laptops, etc). Access to waste, collection, sorting activities, and hence the volumes and prices follow the current market dynamics in Egypt.

The process includes:

1. Discharging and Dismantling
2. Mechanical Processing: The dismantled batteries undergo crushing and shredding, which helps in separating the black mass from other components.
3. Separation Techniques: Various separation techniques such as sieving, magnetic separation, and density separation.

Main Products are:

1. **Black Mass** (35%): This is a mixture of various materials extracted from the electrodes of the batteries, primarily consisting of lithium, cobalt, nickel, manganese, and graphite.
2. **Metallic Fractions** (25%): Copper and aluminum are typically recovered from the current collectors in the batteries.
3. Plastic and Other Non-Metallic Fractions & waste (25%): The battery casing and separators are often made of plastic and other non-metallic materials.

- Conservatively, the project is assumed to be established in a separate dedicated facility and not in an existing recycling facility.
- The construction & finishing costs are fluctuating and highly volatile in Egypt due to the economic conditions, accordingly the processing facility is assumed to be established in a rented and constructed facility, for the project duration.

Collected Volumes and targeted Capacity:

Equipment	EoL in Years	Average Weight in KG	Avg Battery Weight (Kg)	Battery Relative Weight
Mobile	4	0.1	0.03	30%
Laptop	6	3.5	0.331	9%

Year	2025	2026	2027	2028	2029
Growth rate in collected volumes	4%	4%	4%	4%	4%
Estimated EoL Li-ion Batteries (ton/year)	3,034	3,166	3,303	3,447	3,597
Collection Rate	15%	15%	15%	20%	20%
Average Volume per facility (ton/yr)	455	475	495	689	719

- Weight estimates and waste volumes are based on previous studies*:
  - UNDP, Assessment of WEEE Management in Egypt, 2017
  - SRI, Assessment of the Problematic Fractions, 2022
  - Dcode forecast using the average growth rates
- Waste generated by Enterprise (58%) and governmental sector (19%) can be collected relatively easier than Household (23%)
- Following the current market practices, without the introduction of a specific mechanism to ensure that a high percentage of the EoL batteries are collected for recycling at the new facility, a collection rate limited to 15% is assumed in the first three years and increases to reach 20% in 28/29
- The low collection rate leads to less than 50% utilization of the installed capacity of small production lines, it hence presents a significant challenge for the financial viability of the facility.

Note: For the purpose of the study, investment, installation and commissioning to be done in year 0 (2024) & ramp-up to be completed within year 1 (assuming year 2025). In case of delay in starting the project, the volumes may slightly change without significant implication on the financial feasibility.

*The Li-ion volume estimates were based on the previous studies for consistency and comprehensiveness of data. The actual figures especially for years 2020 and 2021 suggest that a much higher volumes of mobile phones were sold in the market than the estimated figures from the mentioned studies. On the other hand, due to the economic conditions in Egypt and the restrictions on mobile imports, the volumes have dropped from 2022 to 2024. Those recent fluctuations were not accounted for in this study.

3.1.2 Key Economic Assumptions

Egypt's economy was hit hard by external shocks over the last three years starting with the pandemic and significantly exacerbated by the Russia-Ukraine war that was followed by Gaza war. The external shocks exposed the economy's structural imbalances and external vulnerability driven by a wide current account deficit (reaching as high as USD -18.4 bn in FY 2020/21), non-flexible exchange rate regime, and high reliance on external borrowing and foreign portfolio investments helped largely by the lucrative real interest rates offered due to previously low inflation levels and fixed exchange rate, in addition to the expansion of the role of the state and public sector in the economy, in contrary to private sector development.

Pressures on the economy accelerated heavily with the flight of foreign portfolio investments "Hot Money" of more than USD -20 bn in response to the war and the accompanying global price shocks and strict monetary tightening in advanced economies, in addition to the resulting supply chain disruptions. That has led authorities to devalue the currency three times in less than 10 months since March 2022 (losing around 50%

of its value) under rising external balance pressures while agreeing with the International Monetary Fund (IMF) on another Extended Fund Facility (EFF) of USD 3 bn over almost 4 years. However, the successive devaluations haven't yielded much benefit considering that the currency gets fixed afterwards, leading to persistent parallel market activity and shortage of FX in official channels. The IMF completed its two reviews and accordingly a devaluation has taken place along with several structural changes.

In April 2024, the IMF published the first and second reviews under the extended fund facility (EFF). A 46-month USD 3 bn was initially arranged for in December 2022 but was never disbursed due to the undermined credibility of the authorities as they returned to a fixed exchange rate. The first and second reviews were hence delayed. Upon reviving the negotiations, there has been an augmentation of the original program to reach USD 8 bn considering the challenging macroeconomic situation. The investment deal in Ras El-Hekma as well as reinstating the adoption of a flexible exchange rate while raising the policy rates presented the needed prerequisites for the commencement of the program.

Commitment to a stronger policy package by the GoE was needed due to the delays in taking timely policy action. This commitment was shown in the form of 1) unifying the exchange rate in March 2024, as the premium provided in the black market was unreasonably high, 2) an unprecedented hike in policy rates by 600 basis points to tighten the monetary policy to limit liquidity in the market, curb inflation, and mitigate/limit exchange rate overshooting, 3) a contractionary fiscal policy, including the reduction of the untargeted energy subsidy through increasing gasoline grade fuels prices.

To account for such developments in the economic and financial analysis, it would be mandatory to forecast several economic indicators over the modelling period. For the current model, below are the key assumptions used, based on Dcode forecasts:

Exchange rate:

Following the floatation, the EGP/ USD rate is expected to stabilize at around 47 EGP/ USD in 2025 and then depreciate by an average of 6% yearly. The EUR/ USD rate is assumed to remain the same throughout the projected period.

Inflation rate:

High in 2024 (25%) and relatively high in 2025 (20%) and then on a downward trajectory.

Interest Rate:

Currently very high around (28.75%) and going gradually downwards towards the end of the year and further downwards in the following years.

Investment

Investment law incentives are assumed to be applicable to the project.

3.1.3 Key Model Assumptions

Revenues (based on prevailing international market prices):

- Black mass which is exported to full processing facilities
- Copper and Aluminium sales

CAPEX (based on offers received from actual technology providers):

- Machinery and Equipment: Production line and other necessary equipment.
- Production line(s) with relatively low capacity of 200 kg/hr are to be installed (up to 1450 ton/ year).

- Chinese Make: around $250,000

OPEX (mostly based on local market prices):

- Raw Material (EoL Batteries prices to be paid by the facility are linked to international market prices)
- Utilities (electricity and Natural gas)
- Labour (direct, indirect and management)
- Rental
- Logistics including administrative costs for exports.

Training and know-how building is to be provided by the OEM during commissioning.

3.1.4 Revenues

- Li-ion batteries that are mostly used in small electronics are LCO and NCM. The prices of Black Mass from those types of batteries in 2023 averaged:
    1. LCO (Lithium Cobalt Oxide) Black Mass **$11,130** per ton
    2. NCM (Nickel-Cobalt-Manganese) Black Mass **$10,040** per ton
- Aluminium price is **$2,667** per ton
- Copper price is **$10,200** per ton
- Non-Metallic Plastics has a negative value around **$90** per ton
- Cost of EoL lithium-ion batteries is around **$2,500** per ton
- Revenues are mostly obtained from exports accordingly they're VAT exempt

Box 3: Key trends for 2024 in the battery recycling market

1. Oversupply of battery metals has pushed down prices
2. Weak metals prices are causing black mass payables and inferred prices to fall
3. Lower metal demand is leading to lower recycling utilization rates
    - many new entrants joined the recycling market. Due to lower investment requirements, we are seeing shredding facilities come online much faster than refining leading to overcapacity for shredding
4. Refining under capacity will grow as an influx of end-of-life (EoL) black mass hits market
5. Black mass payables expected to fall until 2026 before strong recovery
6. Black mass inferred prices to increase over next 10 years

Source: https://www.fastmarkets.com/insights/eight-key-trends-2024-battery-recycling-market/

3.2 Option 1: Key financial assumptions & results

- Black mass prices are assumed to be **$6150/ ton** and will decline annually till 2026 where it will grow at a faster pace for two consecutive years before it grows with inflation only in 2029.
- Black mass recovery rate is assumed to be 35%, a conservative value for the technology considered. The black mass recovery rate depends on many factors but it's usually in the range of (30-40%) for small electronics and higher (50-60%) for EV batteries. This was further confirmed from the proposals of the OEM and from the local potential manufacturers model, who suggested up to 50%. Accordingly, this study uses a conservative average of 35% in the model and run sensitivity analysis to show how the feasibility varies with the change in the recovery rate.
- Capital Structure is based on 50% Equity and 50% Debt

- Cost of debt uses the prevailing interest rates at local commercial banks.
- Cost of Equity is estimated at 40%

Financial Feasibility	Results
Discount Rate	32%
NPV (EGP Mn)	3.2
IRR (%)	15%
Simple Payback Period (Years)	4.7

N.B.: The discounted payback period is more than 6 years (beyond the model duration).

Based on the baseline assumptions, while the project is technically feasible, as the NPV is positive, the IRR is lower than the cost of capital rendering the project financially ***unattractive to private investors*** *under current conditions.*

3.2.1 Sensitivity Analysis

Though financially feasible according to the stated assumptions, a sensitivity analysis was required to assess the impact of changes in certain variables, namely:

1. **Prices**: Due to the high volatility in black mass prices during the previous year and the forecasted drop in price until 2026. It is important to assess the impact of such price changes on the model. It is reasonable to assume that price drops in black mass and other products would result in a similar drop in price of EoL Li-ion batteries (input material).
2. **Collected Volume**: There is some uncertainty in the volume of EoL Li-ion batteries that are generated annually and an even higher degree of uncertainty in the effectiveness of the collection process. Accordingly, a sensitivity analysis was run on a volume range of +/- 15 from the baseline scenario

NPV (EGP mn)

Black Mass & Li-ion Battery Price (+/-)	Li-ion Battery Collection Volume (+/-)						
	-15%	-10%	-5%	Base	+5%	+10%	+15%
-30%	**-15.9**	**-15.1**	**-14.2**	**-13.4**	**-12.6**	**-11.7**	**-10.9**
-20%	**-11.2**	**-10.1**	**-9.0**	**-7.9**	**-6.8**	**-5.6**	**-4.5**
-10%	**-6.5**	**-5.1**	**-3.7**	**-2.3**	**-0.9**	**0.5**	**1.8**
Base	**-1.8**	**-0.1**	**1.6**	**3.2**	**4.9**	**6.6**	**8.2**
10%	**3.0**	**4.9**	**6.8**	**8.8**	**10.7**	**12.6**	**14.6**
20%	**7.7**	**9.9**	**12.1**	**14.3**	**16.5**	**18.7**	**21.0**
30%	**12.4**	**14.9**	**17.4**	**19.9**	**22.3**	**24.8**	**27.3**

IRR (%)

Black Mass & Li-ion Battery Price (+/-)	Li-ion Battery Collection Volume (+/-)						
	-15%	-10%	-5%	Base	+5%	+10%	+15%
-30%	-39%	-34%	-30%	-26%	-23%	-20%	-17%
-20%	-18%	-15%	-11%	-8%	-6%	-3%	0%
-10%	-5%	-2%	1%	4%	7%	10%	12%
Base	5%	8%	12%	15%	18%	20%	23%
10%	14%	18%	21%	24%	27%	30%	33%
20%	22%	26%	29%	33%	36%	39%	42%
30%	30%	33%	37%	41%	44%	48%	51%

- **With the low collection volume, the financial feasibility indicators change significantly with the changes in prices of products (revenues) and input material (cost).** A 10% reduction in prices results in a negative NPV and reduces the IRR to just 4%, rendering the project financially unfeasible for potential investors.
- **The model is less sensitive to changes in volumes than to price fluctuations**. However, a 10% increase in collected volume is sufficient to maintain a positive NPV, even with a 10% drop in prices.
- **This suggests that a key de-risking mechanism should be to prioritize increasing the collection rate of EoL Li-ion batteries**, which can help mitigate the impact of price fluctuations.

	Recovery Rate of Black Mass (+/-)						
	-9%	-6%	-3%	Base	+3%	+6%	+9%
NPV	-52.2	-33.7	-15.2	3.2	21.7	40.2	58.6
IRR	NA	NA	-36%	15%	42%	66%	87%

The recovery rate of black mass is crucial to the feasibility of the project, especially during the early stages when know-how is still being developed and processes are being optimized.

The project is not feasible if the recovery of black mass is less than 35%, assuming all other variables are the same.

Note: *the model assumes that the non-recovered rate is wasted. Accordingly, any reduction in black mass means that the revenue is reduced, however, the costs (fixed and variable) remain the same and hence the EBITDA is significantly reduced. Moreover, the capex and investment costs are all the same which results in a drastic reduction in the NPV.*

This study uses a conservative average of 35% in the model and to run sensitivity analysis to show how the feasibility varies with the change in the recovery rate.

USDEGP FX Rate Annual Increase (%)							
	0%	2%	4%	Base	8%	10%	12%
NPV	-4.8	-2.2	0.4	3.2	6.2	9.2	12.5
IRR	1%	6%	11%	15%	18%	22%	25%

The revenues from exported black mass and other metal products along with the cost of Li-ion batteries, are either generated in USD or at least correlate with its global prices denominated in USD thus, the model is less sensitive to changes in the exchange rate.

Conclusion:

- The financial analysis indicates that while the project is technically feasible, as the NPV is positive, the IRR is lower than the cost of capital. This makes the project **financially unattractive to private sector investors** under current conditions.
- The main factors contributing to the low return are the low collection rates of EoL lithium-ion batteries and the relatively high cost of capital due to prevailing high-interest rates. Additionally, the fluctuating black mass prices increase the sensitivity and risk of the project, further impacting its financial attractiveness.
- To improve the project's financial viability and make it attractive to investors, de-risking measures are needed. Focus should be placed on increasing collection rates and reducing the cost of capital, as price fluctuations are beyond the project's control.
- **Potential De-risking Measures** include introducing an EPR fee and allocating funds primarily to enhance access to waste and increase collection rates. A smaller portion could also support the processing facility to compensate for price volatility. Additionally, reducing the cost of capital through mechanisms such as blended finance, concessional loans, or low-interest debt from environmental funds can improve the project's financial attractiveness.

3.2.2 Extended Producer Responsibility (EPR) Mechanism

Extended Producer Responsibility (EPR) is an environmental policy approach that extends the producer's responsibility for a product to the post-consumption phase. In Egypt, this concept has gained traction with the Waste Management Law 202/2020, which mandates that producers contribute to the cost of managing the waste generated from their products. For industries dealing with e-waste, especially lithium-ion batteries from small electronics, EPR can play a critical role in addressing financial and operational challenges by ensuring that producers bear part of the waste management cost. Through EPR, producers contribute fees that support waste collection, treatment, and disposal, thus ensuring that hazardous fractions like lithium-ion batteries are processed safely and sustainably.[5]

The implementation of an EPR scheme is essential for de-risking the establishment of a semi-processing facility for lithium-ion batteries in Egypt. The volatility in black mass prices and recovery rates, along with

[5] *End of Life Management Costs for Select ICT Products in Egypt – Towards an EPR System, SRI, 2024.*

fluctuations in the volume of collected waste, can pose significant financial risks to such a facility. By dedicating a portion of the EPR fees to ensuring access to waste and improving collection systems, the facility can maintain a stable feedstock of end-of-life batteries, thereby improving recovery rates and ensuring long-term financial viability. Additionally, the EPR mechanism can help finance the processing of other challenging waste fractions, such as plastics and metals, ensuring a more comprehensive and sustainable recycling ecosystem.

In Egypt, there are challenges related to the access to waste and collection costs of EoL Li-ion batteries. Consumers, especially households would expect to receive an incentive to return their EoL devices. Moreover, recyclers of mobile phones and laptops currently use alternative methods of disposal for the Li-ion batteries and hence need to be incentivized to supply the li-ion batteries to the new semi-processing facility.

Accordingly, the EPR fee shall be allocated to cover the total system cost including access to waste, collection, transportation, treatment and disposal. The net costs for mobile phones and laptops are negative in Egypt based on the current practices of recyclers.[6] Accordingly, it is assumed that 60% of the EPR fee revenue will be allocated to treatment and disposal and the other 40% will be allocated to access to waste, collection and transportation. This shall ensure that the collection rate of EoL Li-ion batteries increases, and hence supports the de-risking of the project and subsidize the processing costs under unfavourable of reduced prices or recovery rates.

3.2.3 Feasibility Analysis with EPR Scheme – Increased Collection Rates Only

- Upon implementing an EPR mechanism, it is assumed according to the End-of-Life Management Costs for Select ICT Products in Egypt – Towards an EPR System, SRI, 2024 that the collection rates will be incentivized and around 50%.
- For this study, a more conservative assumption is required for the collection rate of EoL Li-ion batteries from mobile phones and laptops to the semi-processing facility. That is due to the higher share of household waste in those two types of devices which makes the access & collection of their waste more challenging. A collection of 25% in the first 3 years and increasing to 30% in years 4 & 5, are used.
- Based on those updated assumptions, and even without allocation of EPR fees to the semi-processing facility, the project becomes financially feasible with IRR well above the cost of capital and a decent NPV.

Financial Feasibility	Results
Discount Rate	32%

[6] ibid

NPV (EGP Mn)	21.9
IRR (%)	47%
Discounted Payback (Years)	4.5

3.2.4 De-risking the project using EPR fees under unfavourable conditions

- To estimate the EPR Fees needed to be allocated to the new facility to keep the project feasible, under unfavourable conditions, such as reduced prices and collected volume and lower black mass recovery rates, two scenarios are used for demonstration.
  - Scenario-1: Moderate reduction of 15% drop in prices, 15% drop in collected volume and only 32.5% black mass recovery rate
  - Scenario-2: Significant reduction of 30% drop in prices, 20% drop in collected volume and only 30% black mass recovery rate.
- The table below shows the impact of those scenarios on the project indicators and the EPR fees needed to be allocated to the semi-processing facility to keep the project financially feasible (NPV positive and IRR at least equal to the discount rate).
- It is important to note that the EPR fees per ton to be allocated to the semi-processing facility is based on **the collected volume of EoL Li-ion batteries** to be processed at the facility.
- On the other hand, the total EPR fees from mobiles and laptops are based on the suggested flat rate equal to **EGP 23,000 per ton of quantities Put on Market (PoM) for all devices multiplied by the total quantities PoM,** based on one of the alternatives suggested by the SRI End of Life management costs for Select ICT Products in Egypt study.

	Baseline	Scenario-1	Scenario-2
Price	Baseline	-15%	-30%
Collected Volume	Baseline	-15%	-20%
Black Mass Recovery Rate	35%	32.5%	30%
NPV (EGP Mn)	29	-14.1	-36
IRR	57%	-31%	N/A
EPR Fees needed per ton to the Facility (EGP'000)	0	11.5	22
NPV (EGP Mn) with allocation of EPR Fees	29	10.8	9.1
IRR with the allocation of EPR Fees	57%	32%	32%
Average Percent of Total EPR Fees	0	2%	4%

- From the table above, EGP 22,000 per ton (of collected Li-ion batteries) needs to be allocated to the semi-processing facility to ensure the project's financial feasibility under severely unfavorable conditions. This represents around 4% of the EPR fees to be collected for mobile phones and laptops only during the model period.
- This percentage appears to be reasonable for de-risking the project and attracting private sector investors. Furthermore, a lower EPR fee could be allocated to the semi-processing facility, even under similar unfavourable conditions, if the cost of capital is reduced through concessional loans or grants. For example, by reducing the discount rate from 32% to 20%, the required EPR fee would decrease from EGP 22,000 per ton to EGP 19,090 per ton of collected batteries—a reduction of 13.2%.

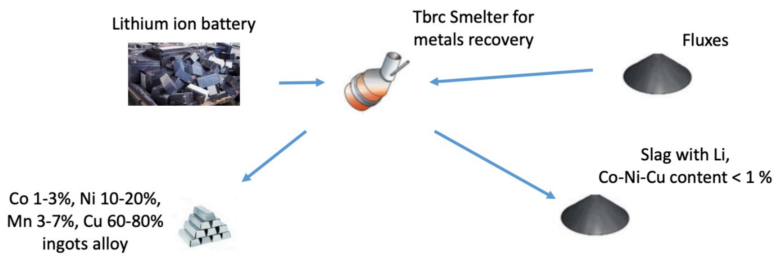
Recommendation:

Since the fees required differ according to the changes in several variables, we recommend setting an initial **EPR fee that includes a built-in buffer to account for potential fluctuations in key variables** such as collection volumes, processing costs, and market prices. This buffer will provide stability during the initial phases of the project, ensuring that unforeseen changes do not immediately compromise financial feasibility. After this initial fee is established, we propose adopting a **dynamic fee adjustment structure,** where the EPR fee is reviewed and recalibrated annually based on actual costs and market conditions. This approach allows for flexibility in response to real-world developments while maintaining the project's financial sustainability. By adjusting fees based on actual costs through regular annual reviews, the system remains fair, transparent, and adaptable to both favourable and unfavourable market shifts.

3.3 Option 2: Pyrometallurgical Process (Smelter)

The Capex for the smelter is very high, amounting for EUR 2.755 Mn ex-works including installation and commissioning for a 1000 litres capacity (around 2 tons/ day) which is the smallest capacity available at the supplier. Given the low volumes of EoL Li-ion batteries to be processed, the utilization rate of such as small capacity is reduced, makes using this process not feasible. However, the project team tried to investigate the intrinsic value of the project through secondary and primary research with a single Italian OEM who provided limited details on the know-how and costs. Below is a summary of the findings for elaboration.

3.3.1 Key Project Scope Assumptions



- Using a Top Blown Rotary Converter (TBRC) for smelting Li-ion batteries is a pyrometallurgical process designed to recover valuable metals.
- The smelting process using a Top Blown Rotary Converter (TBRC) indicates two main products:
  - Ingots Alloy with the following composition:
    - Co 1-3%, Ni 10-20%, Mn 3-7%, Cu 60-80%
  - Slag with Li, Co-Ni-Cu content < 1 %
- The recovered ingot alloys represent around 35% of the input EoL Li-ion batteries and the rest are slag and waste.

3.3.2 Key Model Assumptions

Revenues (based on prevailing international market prices):

- The price of the Ingots Alloy is driven based on the lower range of composition and the average international market price of the components:

Component	Lower Range	Weight (kg)	Price (USD/kg)	Total Value (USD)
Cobalt	1%	10	33.42	334
Nickel	10%	100	22.00	2,200
Manganese	3%	30	2.50	75.00
Copper	60%	600	10.20	6,120
Total		1000		8,729.20

CAPEX (based on offers from technology providers):

- Machinery and Equipment: Production line and other necessary equipment.

- Production line(s) with capacity of 1000 litres useful are to be installed (minimum capacity of 2-3 ton/day): around **$3,000,000**

OPEX (mostly based on local market prices):

- Cost of EoL lithium-ion batteries is around **$2,500** per ton
- Utilities (electricity and Natural gas)
- Labour (direct, indirect and management)
- Rental
- Logistics
- Flux
- Refractories

The operating cost vary based on several factors, including energy prices, labour, maintenance, and other operational expenses. Based on the OEM, the total running cost is around EUR 600 per ton.

3.4 Option 2: Key financial assumptions & results

- Capital Structure is based on 50% Equity and 50% Debt
    - Cost of debt uses the prevailing interest rates at commercial banks.
    - Cost of Equity is estimated at 40%
- Accordingly, even with applying a high EPR Fee of **EGP 8,625** per ton of processed Li-ion batteries is provided to the processing facility (assuming that the recycling facilities share in the collected EPR will be only 50% and that the allocation of the EPR allocated to the Li-ion batteries recycling specifically will be only 75% of the total allocated to the recycling facilities), the investment indicators are still negative as shown below.

Financial Feasibility	Results
Discount Rate	32%
NPV (EGP Mn)	-150
IRR (%)	N/A
Discounted Payback (Years)	N/A

Based on the assumptions, the project is not financially feasible even when adding the suggested EPR fees.

Recommendations:

Given that the project is not financially feasible under the current assumptions due to high CAPEX and low returns, we recommend exploring alternative strategies to improve the project's financial viability. Specifically, the following key areas should be addressed:

1. **High CAPEX**:
   - **Blended Finance**: Utilizing blended finance structures, which combine public and private capital, can help reduce the financial burden. Public capital, such as grants or concessional loans, can absorb more risk, making the project more attractive to private investors and reducing the overall CAPEX burden.
   - **Concessional Loans**: Offering below-market interest rates and favourable terms, concessional loans can lower the cost of capital. These loans can be sourced from development banks or environmental funds, with longer repayment periods easing cash flow pressures and improving financial outcomes.
   - **Grants**: Non-repayable funds from environmental or governmental bodies, especially those focused on sustainability, can offset initial capital costs, reducing financial risks.

2. **Know-How and Technology Transfer**:
   - **Strategic Partnerships**: Establishing partnerships with technology providers will be critical to ensure the project has access to the latest recycling technologies. These partnerships (e.g. PPP between public and private sector) should be pursued as they can support a higher collection rate through the introduction of an EPR scheme, all while ensuring the facility can operate at optimal capacity with the required technological know-how.

3. **De-risking the Project**:
   - **EPR Fees and Feasibility Analysis**: With reduced CAPEX and a secured technology partner, a detailed feasibility analysis should be conducted to identify the EPR fees required to further de-risk the project. By ensuring the right level of EPR fees, the project can secure adequate funding for collection and processing, thus making it more attractive to investors.

4 Conclusion and suggested priority actions

The study on the management of problematic fractions of e-waste in Egypt has highlighted significant challenges and potential solutions for addressing hazardous materials, specifically focusing on POP-BFR plastics and lithium-ion batteries (LIBs). The analyses of two primary options for each waste stream indicate both opportunities and obstacles that must be navigated for effective waste management.

To overcome the financial, operational, and regulatory challenges associated with the environmentally sound handling of problematic e-waste fractions, specifically End-of-Life (EoL) Li-ion batteries and POP-BFR plastics, a collective set of strategic recommendations are outlined:

1. Addressing High CAPEX Costs

Some of the proposed solutions for both Li-ion batteries and POP-BFR plastics involve high capital expenditure (CAPEX), which can hinder their financial feasibility. To mitigate the high upfront investment, the following financial mechanisms are recommended for consideration and deployment:

- Blended Finance: Combining public, private, and philanthropic capital can reduce risks for private investors while securing essential funding for public goods. This approach could leverage concessional funds from international donors or development banks to improve project feasibility.
- Grants and Concessional Loans: Securing grants from environmental funds (such as the Global Environment Facility or Green Climate Fund) and concessional loans from development banks with below-market interest rates can help lower the cost of capital and ease the burden of high CAPEX.
- Public-Private Partnerships (PPPs): Engaging private entities in co-investment opportunities can reduce financial risks by sharing responsibilities and profits. This model can ensure long-term returns through mechanisms like gate fees or extended producer responsibility (EPR) contributions.
- Government Subsidies: Temporary government subsidies, particularly in the early stages of implementation, can be vital in making the collection and processing of e-waste more attractive, with subsidies gradually reduced as financial sustainability is achieved.

2. Improving Collection Rates

Low collection rates present a challenge for both e-waste streams, as alternative disposal methods (e.g., informal recycling or cheap landfilling) reduce the volume of waste reaching formal treatment facilities, eroding their profits and thus financial feasibility. To address this:

- Enforce Regulations: Strict enforcement of regulations to prohibit environmentally unsound informal recycling and improper disposal of e-waste is essential. Monitoring systems should be established to track production and disposal, while penalties for non-compliance must be clearly defined.
- Innovate Collection Systems for Households: Innovative regulations and solutions to increase e-waste collection rates from households such as digital platforms or mobile apps that can allow households to schedule pickups or drop-offs for e-waste, with tracking features ensuring proper disposal. Additionally, providing small incentives for household participation.
- Increase Fees for Alternative Disposal Methods: After the enforcement of regulations, it would be important to increase the current disposal fees (such as for landfilling at Nasreya) to disincentivize this type of disposal. By raising fees, industries would be encouraged to channel waste through formal collection and treatment systems.

3. Leveraging Extended Producer Responsibility (EPR) Schemes

To support the financial viability of the treatment solutions, an EPR fee should be introduced for both LIBs and POP-BFR plastics. This fee should be designed with a built-in buffer to account for market volatility and ensure stability during the initial phases. Additionally, a dynamic adjustment mechanism can allow the fee to be recalibrated annually based on actual market conditions, ensuring sustainability over time.

4. Developing a Self-Sustaining Revenue Model

For both e-waste streams, the viability of treatment solutions can be strengthened by expanding operations beyond the initial scope. For example, the hazardous waste incineration facility for POP-BFR plastics could process other hazardous materials, reaching economies of scale and generating consistent revenue through gate fees.

5. Technology and Strategic Partnerships

To ensure access to the latest technologies, especially for processes like the semi-processing of LIBs (black mass) or smelting (pyrometallurgical processing), strategic partnerships with technology providers should be established. This can include public private partnerships (PPP) between the state bodies and technology providers, which can ensure the use of state-of-the-art techniques while securing higher collection volumes through a well-implemented EPR scheme.

6. Ownership of Recommendations

It is essential to clearly define who will take ownership of each recommendation to ensure the successful implementation of the proposed solutions. The roles and responsibilities are outlined as follows:

- Government and Regulatory Bodies: The government should take the lead on elaborating on and enforcing regulations, raising landfill fees, negotiating concessional loans or grants, and introducing EPR schemes. These bodies will also be responsible for creating and overseeing the monitoring systems needed to track waste production and disposal.
- Private Sector: The private sector, including recyclers and technology providers, will need to engage in Public-Private Partnerships (PPPs) and take the initiative to entrepreneur and invest in technology and operational improvements. Their role in financing and operationally processing the e-waste is critical, especially for achieving system efficiency, including through economies of scale.
- International Organizations and Development Banks: These institutions, such as the World Bank and environmental funds, will provide technical assistance, concessional loans, and blended finance mechanisms to support the projects. They will play a key role in reducing the financial risk and ensuring the financial viability of these solutions.

5 Annex 1: Bibliography

ESMAP 2020. *Reuse and Recycling: Environmental Sustainability of Lithium-Ion Battery Energy Storage Systems*. Climate Smart Mining Initiative and the Energy Sector Management Assistance Program (ESMAP).

Magalini, F., Clarke, A., Dewage, H.H., Dimitrova, G., Clemm, C. and Maisel, F. 2021. *Lithium-based batteries & the off-grid solar sector*. Sofies Group.

Sojka, R., Pan, Q. and Billmann, L. 2020. *Li-ion battery recycling processes*. ACCUREC Recycling GmbH.

Soliman, F. 2017. *Assessment of WEEE Dismantling: Business Opportunities*. Sustainable Recycling Industries (SRI).

Soliman, F.A. 2022a. *Assessment of the Problematic Fractions*. Sustainable Recycling Industries (SRI).

Soliman, F.A. 2022b. *Solutions for Problematic Fractions from WEEE in Egypt* . Sustainable Recycling Industries (SRI).

Sommerville, R., Zhu, P., Rajaeifar, M.A., Heidrich, O., Goodship, V. and Kendrick, E. 2021. A qualitative assessment of lithium ion battery recycling processes. *Resources, Conservation and Recycling* 165, p. 105219.

6 Annex 2: A list of all entities contacted and/or met with the status

Stakeholder	Description	Main Subject discussed
Governmental organizations		
Waste Management Regulatory Authority WMRA	WMRA is responsible for organizing, following up, monitoring, evaluating and developing all activities related to integrated waste management, and attracting and encouraging investments in the field of integrated waste management to ensure sustainable development in cooperation with state institutions, local administrations, the private sector, civil society organizations and international organizations.	• Li ion batteries exporting status • Expected mechanism for EPR system • Latest regulations governing the sector • Recommendations for stakeholders.
Formal E-waste Recyclers		
Triple RE Recycler	Formal E-waste recycler	The current practices for handling BFR plastics and lithium batteries.
Green place	Formal E-waste recycler	The current practices for handling BFR plastics and lithium batteries.
Battarity Company	New company planning to build new facility for lithium batteries recycling	Discus their business model for operating lithium batteries recycling plant
The Production Cooperative Society for the Recycling of Electronic, Electrical, Solid and Liquid Waste	Society for e-waste recyclers to investigate the e-waste challenges and opportunities	Discussion about the status of e-waste recycling sector and the current practices for handling of plastic containing BFR and lithium batteries
Original Equipment Manufactures OEMs		
Anonymous	Italian supplier for lithium batteries recycling plants (Smelting Technology)	We received an offer for batteries smelter with capacity 1000 ton per year at cost of 2.775 million EUR

Anonymous	Chinese supplier for lithium batteries recycling plants (Partial treatment – Black mass recovery)	We received an offer for batteries primary shredding to generate a black mass with capacity 200 Kg/hr at cost of 76500 USD
Anonymous	Turkish supplier for lithium batteries recycling plants (Partial treatment – Black mass recovery)	We received an offer for batteries primary shredding to generate a black mass with capacity 2 ton/day at cost of 500000 USD
Anonymous	Italian supplier for incinerators could be used for disposal of plastic containing BFRs	We received offer for incinerator with capacity 1 ton per hour at cost of 3 million EUR with option to add turbo-generator with another 3 million EUR

7 Annex 3: Summary of problematic fractions assessment and current practices

Problematic Fraction	Available Practice in Egypt for Treatment /Disposal	Assessment	Proposed Opportunities	Prioritization of Gaps
Printed circuit boards plastic containing BFR.	Disposal at hazardous waste landfill till 2021	Not Environmentally sound solution	Collecting system for exporting to treatment facility such as Tredi.	The export to foreign country is yet to be developed through the following: ▪ A collection center is to be constructed and managed under WMRA supervision. ▪ The center shall store the plastic in an environmentally sound process. ▪ The center shall be certified to export the plastic after packing in accordance to the UN Packing requirements for environmentally sound disposal following Basel Convention requirements • The center must deal with the external facilities that use BAT for the battery's disposal
Plastic of equipment casing containing BFR.	Disposal at hazardous waste landfill till 2021	Not Environmentally sound solution	Collecting system for exporting to treatment facility such as Tredi.	
Lithium Batteries	Stored at formal e-waste recyclers facilities management	Not Environmentally sound solution	Collecting system for exporting to treatment facility or encourage local investor to build environmental sound recycling facility	Need to further investigation with WMRA and recycling facilities
CRT screens	Disposal at hazardous waste landfill	Not Environmentally sound solution	Exporting to environmentally sound recycling facilities as previously done by Medical and Electronic Waste Management Project.	WMRA should follow the process recommended by the Medical and Electronic Waste Management Project for a successful disposal

Problematic Fraction	Available Practice in Egypt for Treatment /Disposal	Assessment	Proposed Opportunities	Prioritization of Gaps
Mercury containing lamps	Disposal at hazardous waste landfill.	Environmentally sound solution.	To proceed with the current available practice.	The practice in Egypt is on- going in an environmentally sound procedure under the EEAA and WMRA control. No gaps in this practice.