# Standardized Reporting Requirements for Single-Use Batteries

## Technical Document

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**ABSTRACT**

This Technical Document is part of the project background resources that is intended to support the discussions of the Advisory Committee by providing basic information about battery products, current battery waste material management, and legislative constructs that affect its management.

The information for the technical document was supplied by Waste Diversion Ontario and gathered from open sources.

## Contents

## Background and Objectives

Waste Diversion Ontario (WDO) seeks to develop a common set of reporting requirements that includes definitions and measurement methodologies to enable it to monitor the performance of all programs that manage single-use batteries, equitably and consistently, and within the requirements set under the *Waste Diversion Act*.

Recycling Council of Ontario (RCO) and the Canadian Standards Association (CSA) Group have been retained by WDO to work with an Advisory Committee (AC) to review, discuss, and gather feedback to support the development of these reporting requirements. The AC's recommendations will be reviewed by independent experts before being finalized. WDO will use the final recommendations to update its policy document: *Data Requirements for Monitoring the Effectiveness and Efficiency of Waste Diversion Programs in Ontario*, as appropriate.

There are two primary objectives for the project: 1) develop a common **definition for battery recycling;** and 2) establish a methodology to calculate **recycling efficiency rate (RER) of battery recycling**. Although the two objectives are not mutually exclusive, it is expected that by defining *recycling*, a common and accepted calculation for measuring and reporting recycling efficiency rates can be achieved.

An AC of relevant stakeholders has also been established by RCO to guide the project, and is composed of invited members to contribute their technical and operational knowledge of the topics under discussion: battery stewards, battery material processors, Industry Funding Organizations, program auditors, and other experts.

Independent peer reviewers have also been selected; they have been chosen for their technical knowledge to provide input to the committee upon request, and review any recommendations developed by the AC.

This Technical Document is part of the project background resources that is intended to support the discussions of the AC by providing basic information about battery products, current battery waste material management, and legislative constructs that affect its management.

## Battery Types and Compositions

*Single-use battery* is used to distinguish between non-rechargeable and rechargeable batteries; examples of single-use batteries identified in the MHSW Program Plan include:

- alkaline-manganese
- zinc-carbon
- zinc-air
- lithium
- silver-oxide

Typically alkaline-manganese and zinc-carbon batteries are produced in a range of sizes such as AA, AAA, C, D, and 9v; zinc-air, lithium, and silver-oxide are typically button cells.

**Table 1: Chemistry and composition of battery types as a percentage of weight**

| Material | Alkaline-Manganese | Zinc-Carbon | Mercury Oxide Button | Zinc Air Button | Lithium Button | Alkaline Button | Silver Oxide Button |
|---|---|---|---|---|---|---|---|
| Iron & Steel | 24.8 | 16.8 | 37 | 42 | 60 | 37 | 42 |
| Silver | 0 | 0 | 0 | 0 | 0 | 0 | 31 |
| Lithium | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| Mercury | 0 | 0 | 31 | 1 | 0 | 0.6 | 0.4 |
| Manganese | 22.3 | 15 | 1 | 0 | 18 | 23 | 2 |
| Lead | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| Nickel | 0.5 | 0 | 1 | 0 | 1 | 1 | 2 |
| Zinc | 14.9 | 19.4 | 14 | 35 | 0 | 11 | 9 |
| Other metals | 1.3 | 0.8 | 0 | 0 | 0 | 0 | 4 |
| Alkali | 5.4 | 6 | 2 | 4 | 0 | 2 | 1 |
| Carbon | 3.7 | 9.2 | 1 | 1 | 2 | 2 | 0.5 |
| Paper | 1 | 0.7 | 0 | 0 | 0 | 0 | 0 |
| Plastics | 2.2 | 4 | 3 | 4 | 3 | 6 | 2 |
| Water | 10.1 | 12.3 | 3 | 10 | 0 | 6 | 2 |
| other non-metals | 14 | 15.2 | 0 | 3 | 13 | 14 | 4 |
| other material | 0 | 0 | 7 | 0 | 0 | 0 | 0 |
| **Total** | **100.2** | **99.5** | **100** | **100** | **100** | **102.6** | **99.9** |

*Source*: Composition of batteries: Battery Waste Management Life Cycle Assessment, 18 Oct 2006*, summary of tables 2.12 to 2.18, shows composition as a percentage. Prepared by: Karen Fisher, Erika Wallén, Pieter Paul Laenen, and Michael Collins*

**Table 2: Weight percentage comparison of different component parts in five type new and spent batteries**

| Components | AAA type | | AA type | | C type | | D type | | 9V type | |
|---|---|---|---|---|---|---|---|---|---|---|
| | New (%) | Spent (%) | New (%) | Spent (%) | New (%) | Spent (%) | New (%) | Spent (%) | New (%) | Spent (%) |
| Whole battery | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Steel casing | - | - | 17.83 | 17.47 | 13.97 | 14.00 | 11.73 | 11.08 | 16.79 | 16.65 |
| Polyethylene | 1.39 | 1.48 | 1.21 | 1.08 | 0.90 | 0.88 | 0.48 | 0.69 | 1.30 | 1.30 |
| **Zinc casing** | **34.44** | **29.44** | **22.14** | **16.98** | **17.19** | **15.54** | **16.68** | **13.69** | **8.32** | **6.45** |
| Upper steel plate (1) | 1.28 | 1.16 | 1.27 | 1.26 | 1.87 | 1.93 | 1.40 | 1.43 | 7.60 | 6.50 |
| Upper steel plate (2) | - | - | - | - | - | - | 0.25 | 0.34 | - | - |
| Lower steel plate | 1.53 | 1.54 | 1.04 | 1.23 | 1.48 | 1.57 | 1.31 | 1.17 | - | - |
| Cardboard paper | 4.72 | 4.70 | 9.83 | 9.66 | 3.29 | 2.67 | 6.12 | 6.01 | 12.47* | 12.52* |
| Sealing rings | | | | | 1.83 | 1.607 | 0.11 | 0.08 | - | - |
| **Electrolyte paste** | **45.56** | **47.65** | **39.97** | **42.97** | **53.55** | **54.68** | **54.76** | **59.24** | **52.01** | **55.56** |
| **Carbon electrode** | **7.64** | **7.46** | **6.10** | **6.12** | **5.55** | **5.51** | **5.71** | **5.54** | - | - |
| Loss | 3.44 | 6.57 | 0.63 | 3.22 | 0.37 | 1.613 | 1.46 | 0.71 | 1.51 | 1.023 |

*Source:* Characterization of Spent Household Zinc-Carbon Dry Cell Batteries in the Process of Recovery of Value Metals, 2012, *Majharul Haque Khan and A.S.W Kurny, Materials and Metallurgical Engineering Department, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh*

As battery composition can change during use, any reporting requirements or performance measurements methodologies used to evaluate recovery and recycling activities should consider composition, type, and age of the batteries being processed.

## Battery Management Approaches

This section provides a brief overview of different battery processes commonly used to manage spent batteries.

There are several primary processing facilities in North America and Europe that process battery materials. Of note, there is no single facility that is able to manage all battery types; before processing, whole batteries must be sorted into their specific chemistry types. The identification and separating may be completed prior to reaching the primary processor, or, at the primary processor.

When separated at the primary processing facility, batteries that are incompatible with the process are sent to other primary processing facilities. Primary processors in this context are facilities that receive fully or partially spent, whole batteries, and are the first along the management chain to change the form of the battery by initiating the materials reclamation process.

Regardless of approach, the most common materials reclaimed are steel and iron, zinc, and manganese. Collectively these four materials make up 60 per cent of single-use batteries by weight.

## Primary Processing

### 1. Pyrometallurgical Processing

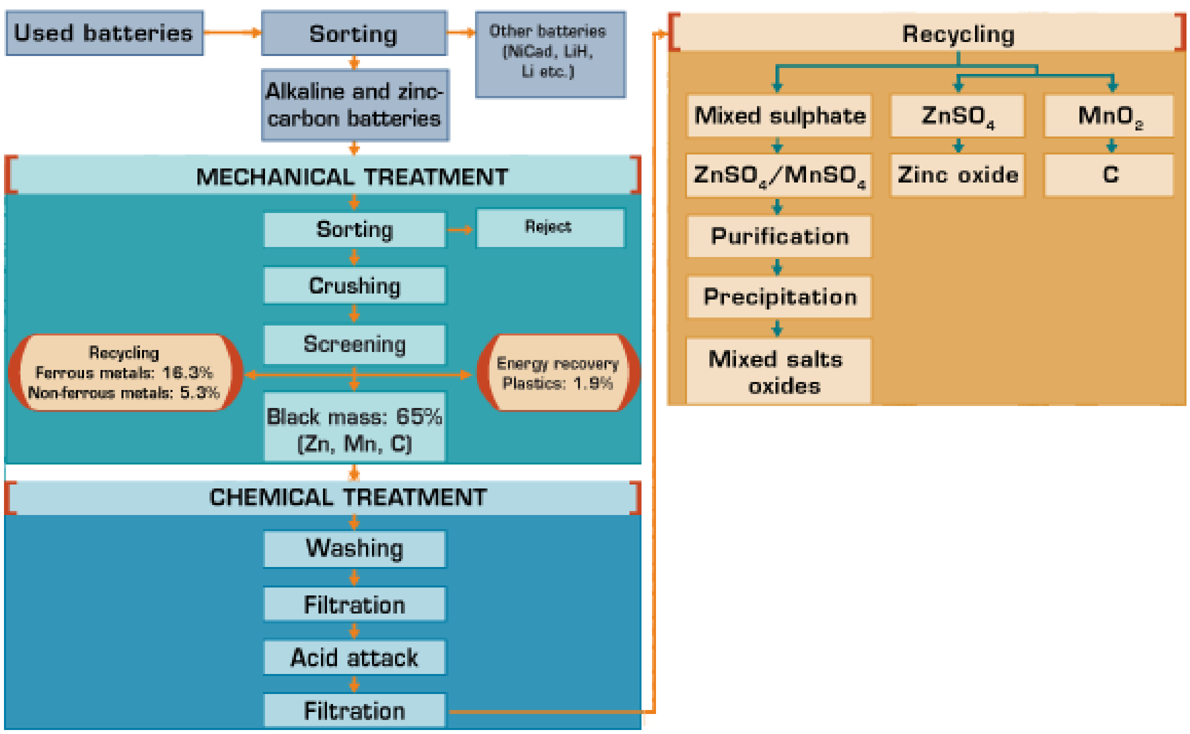
Battery materials (either whole batteries or components of batteries) is introduced into a high temperature furnace where low melting point components, such as zinc and mercury, are volatilized (to cause to pass off in vapour), while iron and manganese are retained in liquid form and sent for steel production. Organic materials, such as paper and plastic, are consumed in the process. The volatilized components are recovered by cooling the vapour stream and then sent to a secondary process.

**Figure 1: Pyrometallurgical process used by Accurex in Germany**

## 2. Hydrometallurgical Processing

Water-based chemicals dissolve, separate, and recover various materials within batteries. Battery materials are then dissolved in acid and the components are selectively precipitated from the solution to recover metals or metal compounds.

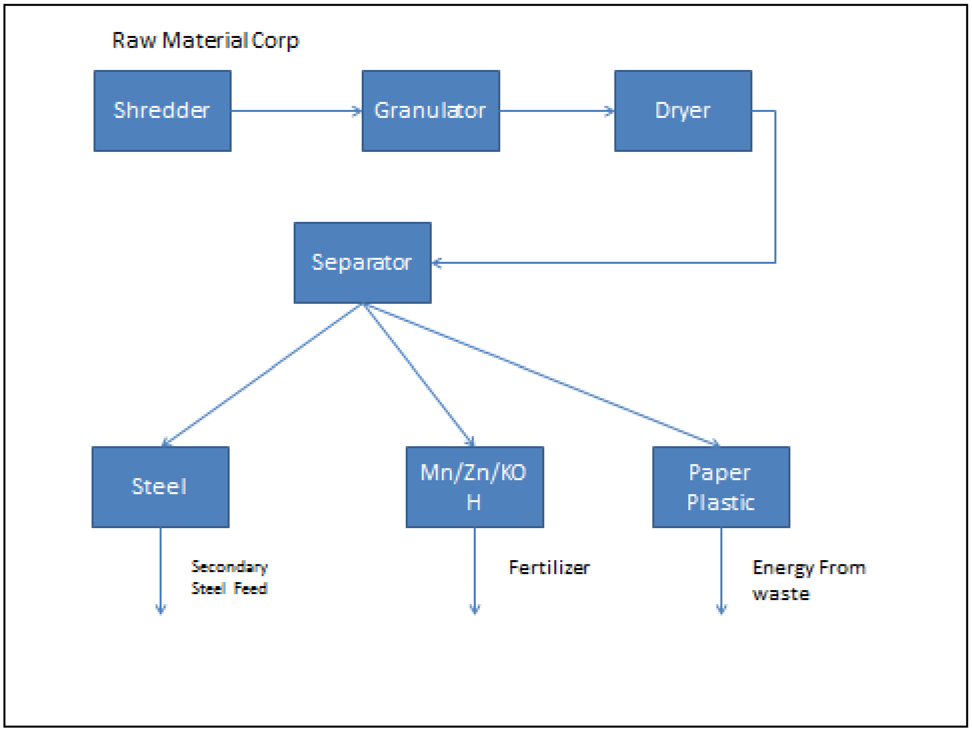
**Figure 2: Hydrometallurgical process used by Revatech in France**




## 3. Physical Separation Processing

Battery casings are mechanically separated from the internal components, which involves mechanical shredders that separate materials followed by the use of magnets and eddy currents to remove metal components. The resulting component material streams are sent for further processing.

**Figure 3: Physical separation process employed by Raw Materials Corporation of Ontario**




## Secondary Processing

Battery processors target the recovery of four main composition materials: iron and steel, manganese, and zinc. The extent to which secondary processing is required depends on the primary process.

Steel and Iron

Single-use batteries have iron and steel components; both steel and iron are segregated from the other wastes and sent to steel mills for re-processing into new steel (i.e., used for its original purpose)

Manganese and Zinc

Once the iron and steel components are removed the remaining material, primarily a mixture of manganese salts, zinc and zinc salts (commonly referred to as "black mass") may be sent to:

1. A smelter for the recovery of zinc,
2. A fertilizer production facility, or,
3. Chemically separated to produce manganese salts and zinc salts

**Table 4: Disposition of Recovered materials from Primary Processing**

| Process | Iron and Steel | Manganese | Zinc | Paper |
|---|---|---|---|---|
| Hydrometallurgical | Sent to smelter/steel mill | Recovered: Manganese salts | Recovered: Zinc salts | Sent to energy-from-waste |
| Pyrometallurgical | Recovered: Steel alloy (Fe, Mi, Cr, Cu)<br><br>Recovered: Ferromanganese slag (Fe, Mn, K) | Recovered: Zinc co-product (black mass) | Recovered: zinc co-product (black mass) | Consumed in process energy-from-waste |
| Physical separation | Sent to smelter/steel mill | Recovered: Zinc co-product (black mass) | Recovered: Zinc co-product (black mass) | Sent to energy-from-waste |

# Definitions

WDO currently oversees two programs that manage single-use batteries: the Municipal Hazardous and Special Waste (MHSW) and Waste Electronic Electrical Equipment (WEEE) programs. Oversight requires that WDO review actual program performance against performance measures, using data that is transparent and complete. The establishment of common terminology and methodology will enable WDO to set baselines and comparators that are consistent and transparent. The following terms are identified within the terms of reference for this project, as necessary to define in order to achieve the project's outcomes.

- Recycling
- Process and Processing
- Product and By-product

## Recycling

The Ontario Ministry of the Environment and Climate Change (MOECC) has not explicitly defined recycling in legislation or in policy. The *Waste Diversion Act*, which is the framework that designates batteries as a subject material, does not require specific material management approaches and does not provide details on the operational standards on how the waste materials must be managed.

The *Waste Diversion Act* does describe specific material management approaches that are not to be promoted: (Section 24(2)(2) *burning, landfilling or application of a designated waste to land*. Program

Plans approved under the *Waste Diversion Act*, by the WDO and the MOECC, may have requirements regarding material management, performance targets, and reporting. Once approved by WDO and the Minister, these become the minimum program requirements unless WDO and/or the Minister agree or direct otherwise

Although there is no legally sanctioned or official definition of recycling in Ontario, many regulations use exclusionary principles that narrow down what is and what is not considered a recycling process. That is, the regulations define when material becomes waste, and then offers a series of exclusions to describe management approaches that are acceptable, or operations that would be considered or not considered recovery and recycling of that waste.

For example, Ont.Reg. 347 (General Waste Management) Section (1.1) (3)

> *The definition of "subject waste" in subsection (1) does not include the following wastes:*
>
> 1. *Waste from the servicing of motor vehicles at a retail motor vehicle service station or service facility that has a written agreement for the collection and other management of such waste with the owner or operator of a waste management system in respect of which an environmental compliance approval has been issued authorizing the collection and other management of such waste.*
> 2. *Intact waste batteries destined for a waste battery recovery facility.*
> 3. *Common mercury waste destined for a common mercury waste recovery facility.*
> 4. *Waste electrical and electronic equipment that is intact and is destined for a site at which it is to be processed for the recovery of materials.*
> 5. *Printed circuit boards that are waste, are intact and are destined for a site at which they are to be processed for the recovery of materials.*

Therefore, end-of-life battery materials are not considered a subject waste if they are destined to a battery recovery facility. As recovery is not defined, it may be interpreted that any processing approach may be allowed or acceptable. The regulation also does not specify what types of materials and how much of those materials must be recovered to meet this exemption.

Processing facilities are required to have in place relevant MOECC approvals that detail their operational allowances and requirements; however, these do not define or dictate a specific material management approach. As such, there is no guidance as to which types of processes are considered recycling and whether materials have been recycled. Recovery or reclamation are terms often used synonymously with recycling, and none of these terms or activities are defined in regulation.

In the absence of any government or industry-accepted definition of recycling, WDO established its own in order to support its oversight function:

> *Recycling in the Ontario context refers to any operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It*

*includes the reprocessing of organic material but does not include energy recovery and reprocessing into materials that are to be used as fuels.*

*Source*: Data Requirements for Monitoring Effectiveness and Efficiency of Waste Diversion Programs in Ontario

WDO's definition of recycling mirrors one that is used by the European Union with one distinction: it has dropped the reference to backfilling as a disallowed material management approach:

*"Recycling" means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and reprocessing into materials that are to be used as fuels or for backfilling operations.*

*"Backfilling" means a recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a substitute for non-waste materials.*

*Source:* Directive 2008/98/EC on Waste

The current WDO definition of recycling can also be interpreted to account and allow for all materials (products, materials or substances, or by-products) generated through single-use battery processing that are reclaimed in any form, as long as they are not repurposed for fuel or energy recovery. This would allow for battery component materials to be re-incorporated as feedstock into the manufacturing of new batteries (original purpose) or in by-products (other purposes). In this context, *by-product* is not defined or specified.

## Process

A standard definition is required to identify those management activities or operations and the scope of activities that should be included in performance calculations.  For example, Oxford Dictionary's definition of *process* (as a verb):

*Perform a series of mechanical or chemical operations on (something) in order to change or preserve it.*

Based on this definition, processing does not include collection, consolidation, transportation, and/or sorting of any sort. This means that calculating performance begins once materials are brought into the primary processing facility and is continually applied to all subsequent processing facilities until the materials are recovered in a form that can be directly inputted into another application for final use.

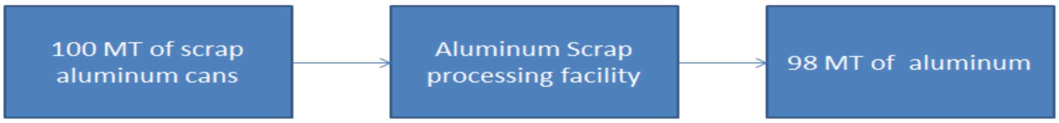
## Chain of Custody

Tracking spent battery materials and the processes that manage the component materials throughout the entire "waste to by-product" journey provide transparency and accuracy in performance measurement. Measurement of each process should be tracked and measured until the component material is consumed (used) or no further change is applied to it.

## Calculating Recycling Efficiency Rate

Recycling Efficiency Rate (RER) is a mathematical formula applied to a process or series of processes that determines the effectiveness of processing to recover materials of interest. In its simplest form the calculation is a ratio, usually expressed as a percentage, of the output divided by the input.

**Figure 4: Example of RER Calculation**




RER = 98/100 = 0.98 = 98% efficiency

**Figure 5: Current WDO formula for calculating RER**

**Recycling efficiency** is calculated as a percentage with the numerator representing the quantity of materials recycled and the denominator representing the total amount of products or packaging materials collected in the waste diversion program.

$$Recycling\ Effciency\ \% = \frac{Recycled\ (material\ recycling)}{Collected - Reuse\ (component\ \&\ whole\ product)}\ x\ 100$$

**Recycling rate** is calculated as a percentage with the numerator representing the quantity of materials recycled[1] and the denominator representing the quantity of products or packaging materials available for collection.

$$Recycling\ Rate\ \% = \frac{Recycled\ (material\ recycling)}{Available\ for\ Collection\ (1) or\ (2)}\ x\ 100$$

*Source: Data Requirements for Monitoring Effectiveness and Efficiency of Waste Diversion Programs in Ontario*

Measuring RER for spent single-use batteries can be complicated as they are a complex mixture of materials whose composition changes during use as a result of the chemical reactions within the batteries. Furthermore, single-use battery is used to describe a grouping of battery types having completely different chemistries: alkaline, lithium, zinc-carbon, zinc-air, and silver-oxide batteries.

The composition of spent battery inputs into any processing approach will vary the component recovery outputs. General practice is that spent batteries are separated into primary and secondary types, and processed as co-mingled materials. As a result, calculating RER must consider the mix of single-use batteries chemistries co-mingled in the input feedstock.

## Composition of Feedstock

RER outcomes are highly dependent on the composition of the feedstock. In the case of batteries, RER can be affected by type, age, and composition of the battery (which can change over time) of the batteries being processed. Table 5 demonstrates the variability of the component materials that can be recovered or are available to be recovered. The composition may also be affected by battery size. For instance, the percentage of steel in a AAA battery is significantly different from that in a D battery: 2.7 per cent vs 14.02 per cent.

**Table 3: Weight percentage comparison of different component parts**

| Components | AAA type | | AA type | | C type | | D type | | 9V type | |
|---|---|---|---|---|---|---|---|---|---|---|
| | New (%) | Spent (%) | New (%) | Spent (%) | New (%) | Spent (%) | New (%) | Spent (%) | New (%) | Spent (%) |
| Whole battery | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Steel casing | - | - | 17.83 | 17.47 | 13.97 | 14.00 | 11.73 | 11.08 | 16.79 | 16.65 |
| Polyethylene | 1.39 | 1.48 | 1.21 | 1.08 | 0.90 | 0.88 | 0.48 | 0.69 | 1.30 | 1.30 |
| **Zinc casing** | **34.44** | **29.44** | **22.14** | **16.98** | **17.19** | **15.54** | **16.68** | **13.69** | **8.32** | **6.45** |
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| Upper steel plate (2) | - | - | - | - | - | - | 0.25 | 0.34 | - | - |
| Lower steel plate | 1.53 | 1.54 | 1.04 | 1.23 | 1.48 | 1.57 | 1.31 | 1.17 | - | - |
| Cardboard paper | 4.72 | 4.70 | 9.83 | 9.66 | 3.29 | 2.67 | 6.12 | 6.01 | 12.47* | 12.52* |
| Sealing rings | | | | | 1.83 | 1.607 | 0.11 | 0.08 | - | - |
| **Electrolyte paste** | **45.56** | **47.65** | **39.97** | **42.97** | **53.55** | **54.68** | **54.76** | **59.24** | **52.01** | **55.56** |
| **Carbon electrode** | **7.64** | **7.46** | **6.10** | **6.12** | **5.55** | **5.51** | **5.71** | **5.54** | - | - |
| Loss | 3.44 | 6.57 | 0.63 | 3.22 | 0.37 | 1.613 | 1.46 | 0.71 | 1.51 | 1.023 |

*Source*: Characterization of Spent Household Zinc-Carbon Dry Cell Batteries in the Process of Recovery of Value Metals, 2012, *Majharul Haque Khan and A.S.W Kurny, Materials and Metallurgical Engineering Department, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh*

## Other Considerations

### Materials Added to Inputs

In some facilities, battery materials are processed along with other types of waste. If these materials appear in the commodity end-products or in the residual streams, the facility must track their destination and account for them in RER calculation.

### Moisture Content and Losses

All types of batteries contain moisture content that varies between battery types and different composition studies report different moisture levels in each battery type. Moisture content may be in two forms:

- Free moisture that may be driven off in the process, and,
- Crystalline moisture that is part of the chemical composition.

When processed, the moisture is typically lost and, therefore, must be accounted for in RER calculations.

### Components Consumed in a Process

When components of a single-use battery are consumed (used as a reductant) in a recycling process, they are considered a loss and should be represented as such in the RER calculation as there is no material recovered for a secondary application or beneficial use.

## Process mapping

Process mapping can be extremely useful and necessary part of tracking management approaches of the target materials at each point in the recycling process. It can be used to show when a material of interest requires no further processing and what application or use is made of component materials.

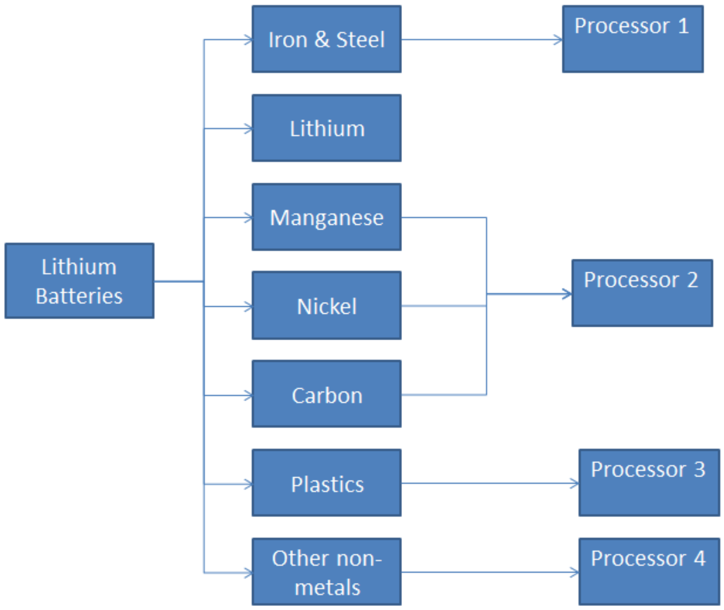
> Definition of process mapping: *the structural analysis of a process flow (such as an order-to-delivery cycle), by distinguishing how work is actually done from how it should be done, and what functions a system should perform from how the system is built to perform those functions.*
>
> *Source: www.businessdictionary.com*

Flow diagrams provide a graphical illustration of the inputs and outputs at each point of material management systems including the destination of whole materials destined to primary and secondary processing facilities (See Graphic 6).

### Sample Application of Mapping and RER Calculations

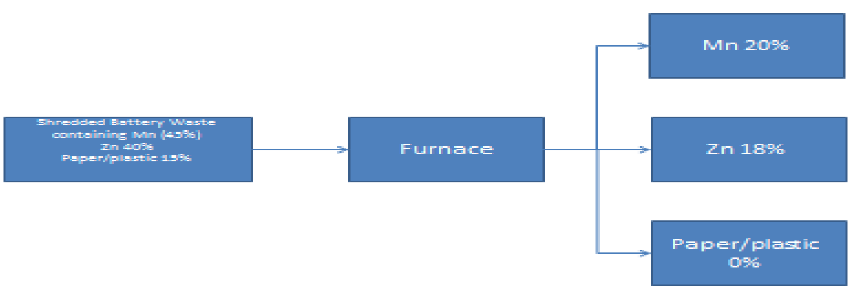
RER must be calculated at each point in the recycling process to ensure a consistent calculation and to facilitate accuracy and comparability between facilities. The total RER will be a function of what is recovered and consumed from each processing facility and what is lost as residual. The total calculation across all facilities will determine an accurate and comprehensive accounting of RER.

**Figure 6: RER for each individual battery type is based on the starting components and their recovery**




In this example, RER is based on the recycling efficiency of four different processors. Each of the subsequent processors must have their process mapped and losses tracked and reported. In addition, process mapping for a basic item such steel is intricate and requires multiple calculations to determine the recovery rate.

**Figure 7: Example RER calculation**



If flow is based on the 100 MT of shredded battery waste, RER calculations:

$$RER\ (SUB) = (RER_{Zn}) + (RER_{Mn}) + (RER_{P\&P})$$
$$RER = (18/100) + (20/100) + 0/100)$$
$$RER = (0.18) + (0.2) + (0)$$
$$RER = 0.38 \text{ or } 38\%$$

## Conclusion

This Technical Document is intended to provide a basic background about batteries, their composition, and current processing approaches that are used by the battery processing industry.

However, it is important to note that tracking and reporting performance of any recycling process requires a clear definition of what which outputs from battery recycling processing should be reported as recycled products. A universal or industry-accepted definition is critical to determining what inputs may be included in calculated the recycling efficiency rates of battery recycling processes.