VTT-R-02439-13

Opportunities and challenges in utilization of life cycle data in consumers' portable batteries with focus end of life

Authors:
VTT Minna Nors, Saija Vatanen, Kaarle Jaakkola, Hannele Tonteri, Kaj Nummila
Metropolia University of Applied Sciences: Antti Laurikainen, Petteri Koivu

Confidentiality: Public

Abstract

The study concludes observations on consumers' portable batteries' life cycle based on literature and on life cycle data acquisition (LCDA) project. The scope covered life cycle assessment (LCA), end-of-life (EoL) and life cycle data acquisition (LCDA) related to environmental performance of consumers' portable batteries. Among the goals was the aim to understand consumers' portable batteries' life cycle in order to improve recycling and traceability of them.

LCA provides beneficial information about potential environmental impacts of products which can be used to prioritise actions and to avoid trade-offs in life cycle. The reviewed studies gave ideas about life cycle data acquisition of the consumers' portable rechargeable batteries and especially environmentally aware aspects about the batteries' end of life.

A proof of concept device was made for LCDA test run of the tags on different types of consumers' portable batteries. The test run demonstrated automatic new low-cost ultra-high frequency (UHF) radio frequency identification (RFID) based sorting system for inbound materials at EoL-phase of consumers' portable batteries. Identification was checked against a database which contained key product information. As a result of the test, RFID tags could be used to identify batteries even at the end of their life cycle where optical methods become unreliable due to dirt. The greatest barrier in implementing RFID in battery waste handling is that a sufficient portion of manufactured batteries should be tagged, which they currently aren't. If such identification system were established, it would raise the acquisition to an adequate level and pose a significant improvement in efficiency of material recognition and information of the life cycle. Thus, a clear step towards sustainable management and design for recycling could be achieved.

Important considerations in LCDA of consumer's portable batteries covered several issues. The main need is to follow up relevant product information with minimum information breakdown with the help of identifier such as RFID tag. The attachment of a RFID tag in the manufacturing phase of a product (e.g. portable battery or electronic device including circuit board) would improve cost efficiency and dialogue between design, manufacturing and recycling. It is important to include all relevant product information from Beginning of life cycle (BoL), Middle of Life cycle (MoL) and from EoL. These can be such as detailed information about the product e.g. material content or bill of materials (valuable metals and hazardous materials), identification number, design and production information. Also, such as user phase information and consumer guidance could be helpful as well as information details about collection, sorting, dismantling and recycling. Moreover, there could be key information about the safety issues and main environmental impacts.

Identification of products and management of resources creates an opportunity to connect product's EoL information to design and manufacturing and vice versa, which facilitates sustainability of the whole life cycle and more transparent value network. Thus, the goal to achieve more efficient recycling and waste handling will be closer with the help of unique identification of products. Entirely new business concepts and sustainable service concepts can be enabled.

Glossary

CED	Cumulative energy demand
BAP	Battery assisted passive
BAT	Best available technique
BOM	Bill of materials
CED	Cumulative energy demand
CF	Carbon footprint evaluates the potential GHG emissions of a product, process or company throughout the life cycle. Among development works of ISO standardization on-going are CF of product ISO 14067 and CF of organizations ISO 14069.
CPG	Consumer packaged goods
CPT	Cordless power tools
EC	European Commission
EU	European Union
GWP	Global Warming Potential
HF	High frequency, frequencies from 3–30 MHz
ID	Identification
IOT	Internet of Things
ISO	International Standardization Organization
ISO – standards	Like ISO 14040:2006 and ISO 14044:2006 are base for several environmental tools.
KPI	Key Performance Indicator
LCA	Life cycle assessment (phases: Goal and scope, LCI, LCIA and interpretation)
LCI	Life cycle inventory (one phase of LCA)
LCIA	Life cycle impact assessment (one phase of LCA)
LCT	Life Cycle Thinking
LF	Low frequency, frequencies from 30–300 kHz
PIC	Printed integrated circuits
PLM	Product life cycle management
RFID	Radio frequency identification
RIM	Recycling Information Matrix
SAL	Smart active label
sWEEE	small waste electrical and electronic equipment
UHF	Ultra-high frequency, frequencies from 300–3000 MHz
WEEE	Waste electrical and electronic equipment

Contents

1. Introduction

In the following is described briefly the background of the Life Cycle Data Acquisition (LCDA) research whereby the goal and scope of this study is defined. The LCDA research was coordinated by Metropolia University of Applied Science between years 2011–2013 and it was funded by the Finnish funding Agency for Technology and Innovations (TEKES). Furthermore, the consumers' portable battery market – especially in Europe is introduced.

1.1 Life cycle data acquisition (LCDA) research project

In order to improve recyclability of products, to optimize resource use and enable traceability along a product's life cycle accurate information is required. This is a common case for several products among them portable batteries which are significant part of several consumer products. For example a mobile phone and cordless power tools (e.g. Heavy Duty Hammer Mill) are composed of many different parts, where a portable rechargeable battery is one of them.

The visibility and traceability to the processes and events of products deteriorates quickly after the beginning of life. Generally the information flow breaks down after the delivery of the product to the customer and in the end of life there is quite a little information available for the recycling operators to make end of life decisions. The information breakdown prevents also the feedback of data, information and knowledge, from use, service, maintenance and recycling back to the designers and producers. To enable information sharing over the life cycle products must be more comprehensively identified and life cycle data recorded. [LCDA 2011]

An information system integrated with one or more identification technologies is needed for the collection and storage of the product life cycle information. The system should store the information in such a way that would enable its access in all the phases of the life cycle by use of a unique product identifier. This would enable all the trusted partners (e.g. condition monitoring and service operators) over the life cycle to examine the anatomy and the usage history of a product. In addition, for the end-of-life operators the availability of information what materials the product contains, how to dismantle it efficiently and what should be recovered. [LCDA 2011]

1.2 Portable batteries

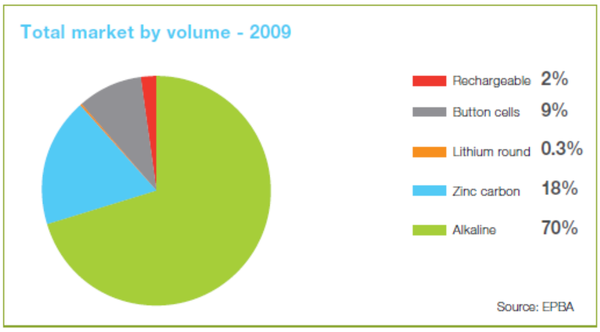
Based on information related to the European Union market of portable primary batteries reveals that approximately 160000 tonnes of portable batteries every year are produced and ultimately deposed of. However, portable primary batteries do not necessarily cause serious damaging environmental impacts during their use phase, these batteries contain metals, which can pollute the environment at the end of their life cycle. Mercury, lead and cadmium are the most dangerous substances present in batteries. The other batteries on the European Union market are estimated to be around 800000 tonnes of automotive batteries and 190000 tonnes of industrial batteries. [Mudgal et al. 2010, Popita et al. 2010]

The batteries containing reusable metals are as such far too good material source to be wasted. According Dittrich et al. [2012] study between years 1980–2008, global consumption of metals increased around 87%. Some metals, such as aluminium or copper, are used in large quantities and for a wide scale of applications. Others, such as indium, are used in small quantities but in everyday high-tech products. With the increasing demand, even more metals are exploited, with the related environmental implications such the degradation of ecosystems through metal mining and emissions to water and soil. [Dittrich et al. 2012]

Due to a strongly increased demand in the period 2000 to 2008, world primary metal production increased by 95% and world primary industrial mineral production 27%. In the year 2008 more than 50% of world metal production was concentrated in only one country for 16 metals, and more than 80% of world production was concentrated in only three countries for a further eight metals. China is the number one producer of 19 metals as it is also the main user for many metals. [Monier et al. 2011]

Roughly over 5 billion batteries went to the market in year 2009 according European Portable Battery Association (EPBA) with alkaline manganese batteries accounting for the largest market share. The statistics for the rechargeable segment only includes batteries sold in the most popular D, C, AA, AAA and 9V sizes, and not batteries or battery packs sold with devices like mobile phones, computers, MP3 players, power tools, etc. Some relevant information about market and environmental performance can be given with help of Figure 1. [EPBA 2010]

The amount of batteries and accumulators in Finland market is estimated to be over 5000 tons with the similarity in shares (e.g. Alkaline 68%) as presented in Figure 1 below. Major part of batteries used by Finns is alkaline batteries. Altogether with other used batteries that is 9 pieces/ inhabitant/ year. The amount of accumulators is around 0.14 pieces/ inhabitant/ on year 2009. [Toppila 2011a]



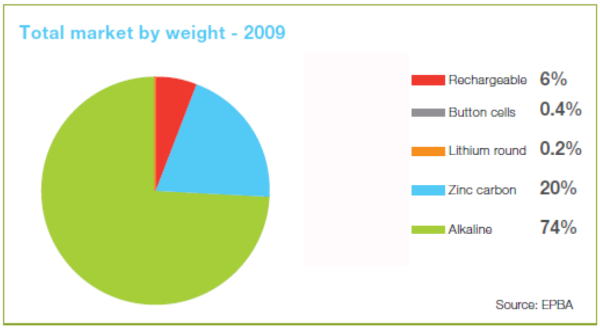


Figure 1. European Battery Market, Total market by volume and weight in 2009. [EPBA2010].

2. Goal and scope

The goal and scope of this study are based on LCDA research objectives whereby those relevant for this report are presented in below. The idea is to understand and describe mainly based on literature the entity of consumers' portable (secondary i.e. rechargeable) batteries' life cycle with the focus on end-of-life (EOL). Especially, the focus is in environmental performance and life cycle data of these portable batteries. Understanding about RFID identifications possibilities in order to enable of LCDA information is formed in Chapter 5. Then, one example of EOL phase of consumers' portable batteries' is presented in relation to the portable battery treatment company Akkuser (covering relevant business experience about collecting, recycling and further processing batteries) in Finland. Example covers also evaluation of outcome of LCDA research test run which is presented in chapter 6.4.

Objectives relevant for this literature study:

1. The life cycle data of portable secondary (rechargeable) batteries will be identified with the help of flow-sheets.
2. Utilization is analysed as improvements for design for environment focusing on end of life recyclability and other environmental point of views.
3. End-of-life phase information and its usability for design for environment decisions. E.g. reuse, replace, repair, refurbish or recycle.
4. Link between end-of-life decisions and the use phase information
5. Product information management considerations and future needs based on evaluated literature, discussions and LCDA research test run.

Some key definitions used in the Battery Directive and in literature are relevant for this study, why they are explained here:

- "Battery" or "Accumulator": terms refer to any source of electrical energy generated by direct conversion of chemical energy and consisting of one or more primary battery cells, which are non- rechargeable or consisting of one or more secondary battery cells, which are rechargeable.
- "Portable battery or accumulator": means any battery, button cells, battery pack or accumulator that is sealed and can be hand-carried, and is neither industrial battery or accumulator nor automotive battery or accumulator. These are meant to be in use of general-purpose with the weight less than one kilogram.
- "Consumer portable batteries" can be
  - Portable primary i.e. non rechargeable batteries such as alkaline, manganese, zinc carbon, nickel ox hydroxide and lithium iron.
  - Portable secondary i.e. rechargeable batteries/ accumulators such as nickel metal hydride (NiMh), nickel cadmium (NiCd), lithium ion (Li-ion), lithium polymer (Li-polymer).

3. Regulations, requirements and producer responsibility

In the following is presented regulations, requirements and other issues, such as producer responsibility in order to reveal circumstances around portable batteries.

Noteworthy is that the directives has been implemented in various ways, from EU country to another EU country, and one can spot different approaches e.g. in WEEE recycling.

3.1 Battery directive 2006/66/EC

According the legislation the batteries and accumulators are dived to portable batteries and accumulators (primary disposable and secondary rechargeable batteries), vehicle and industry batteries/accumulators. An example of portable batteries are AA and AAA-batteries as well as those batteries used in mobile phones, laptops, toys, cordless power tools, electric toothbrush, shavers. Vehicle batteries and accumulators are used for starting, ignition and lightning. Industry batteries and accumulators are designed only for industry- or professional use or electric vehicles. [Ympäristöhallinto 2013]

The Battery directive applies to all batteries and accumulators placed on the EU market. The primary objective of the Directive is to minimise the negative environmental impact of batteries/ accumulators and of waste batteries and accumulators on the human health and the environment, in order to contribute to its protection. The Directive takes into account the European legislative requirements to decrease the use of hazardous substances and the management of hazardous waste. [Directive 2006/66/EC, ECEUROPA Waste management]

Furthermore, the Directive requires that all portable and automotive batteries and accumulators be marked with a capacity label. The aim of capacity label is to provide useful information for end-users. For example information about the appropriate battery type which may lead to reduction in battery waste by achieving market transformation towards higher capacity batteries and accumulators. [Directive 2006/66/EC, ECEUROPA Waste management]

The battery directive prohibits the placing on the market of certain batteries and accumulators with a proportional mercury or cadmium content above a fixed threshold. In addition, it promotes a high rate of collection and recycling of waste batteries and accumulators and improvement in the environmental performance of all involved in the life-cycle of batteries and accumulators. The aim is to cut the amount of hazardous substances - especially mercury, cadmium and lead - dumped in the environment and by reducing the use of these substances in batteries and by treating and re-using the amounts that are used. Batteries or accumulators which do not meet the requirements of the Directive should not be placed on the market after September 2008. [Directive 2006/66/EC, ECEUROPA Waste management, Teknologiateollisuus Paristo- ja akkudirektiivi, Malmström 2012, EC ESWI 2009]

To ensure that a high proportion of spent batteries and accumulators are recycled, Member States must take sufficient measures to promote separate waste collections and prevent batteries/ accumulators being thrown away as unsorted municipal refuse. The batteries directive set an overall collection target for all spent portable batteries of 45% by 2016. In principle, it must be possible to remove batteries and accumulators readily and safely. Thus, to ensure that manufacturers design their appliances accordingly. Aim is to ensure that the batteries and accumulators that have been collected are treated and recycled using the best available techniques. The recycling of battery and accumulator content to produce similar products or for other purposes has target levels dependent on the type of battery to be reached. [Directive 2006/66/EC, ECEUROPA Waste management, EC ESWI 2009]

3.2 WEEE and RoHS directives

Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) has been recast to be Directive 2012/19/EU on WEEE. See further information link: ECEUROPA and Teknologiateollisuus WEEE. The aim is to prevent the generation of electrical and electronic waste and to promote re-use, recycling and other forms of recovery in order to reduce the quantity of waste discarded. It requires the collection of WEEE and the recovery and re-use or recycling of waste collected. [Directive 2012/19/EU, ECEUROPA WEEE directive, Teknologiateollisuus WEEE-direktiivi]

In relation to WEEE directive the new collection targets agreed, an ambitious 85% of WEEE generated, will ensure that around 10 million tons, or roughly 20 kg per capita, will be separately collected from 2019 onwards. The existing binding EU collection target is 4 kg of WEEE per capita. By 2020, it is estimated that the volume of WEEE will increase to 12 million tons. [ECEUROPA WEEE Directive, Saarinen 2010]

The new WEEE Directive will give more tools to fight against illegal export of waste more effectively. A serious problem is illegal shipments of WEEE disguised as legal shipments of used equipment, in order to circumvent EU waste treatment rules. Along with the new Directive is forced exporters to test and provide documents on the nature of their shipments when the shipments run the risk of being waste. [ECEUROPA WEEE]

The WEEE Directive is also connected to the Directive on Restriction on Hazardous Substances (RoHS 2). The RoHS Directive is intended to restrict the use of certain hazardous substances in electrical and electronic equipment. Directive RoHS is requiring heavy metals such as lead, mercury, cadmium, and hexavalent chromium and flame retardants to be substituted by safer alternatives. Furthermore, the recast of RoHS Directive 2011/65/EU (RoHS 2) requires Member States to transpose the provisions into their respective national laws by January 2013. [Directive 2011/65/EU, ECEUROPA RoHS Directive, Teknologiateollisuus RoHS-direktiivi, ECEUROPA RoHS Directive]

3.3 Producer responsibility

The WEEE directive and Battery directive places the producer responsibility on the company or organization that puts a certain product on the market. There are general challenges in EU level and in Finland concerning producer responsibilities.

3.3.1 WEEE flows

On overall, it has been evaluated that WEEE amounts globally are around 20-50 million tonnes yearly, and the growth rate is around 3–5%. Based on several studies around EU the amounts of WEEE for one inhabitant do vary between 15–24 kg. [Luttropp et al. 2010, Zoeteman et al. 2010]

The common challenge is that incorrect handling of WEEE is putting human health at risk and WEEE has been ending up in manual dismantling operations with dangerous and toxic environments as a result. One reason is said to be that it is up to ten times cheaper to export WEEE than to take care of the waste. Based on the amount of WEEE collected by producer responsibility systems, it is obvious that a significant share of WEEE is carried along the unofficial path formed e.g. operators not belonging to the official system. Thus, there is not complete degree of safety about the accumulation amount of the WEEE. So it seems a huge challenge for collection systems under producer responsibility to reach 100% collection rate. [Luttropp et al. 2010, ETC/SCP 2009, Toppila 2011a, Ongondo et al. 2011]

However, WEEE contains valuable material such as copper, gold etc. For example a dishwasher contains approximately 1 kg copper, giving a copper content of 2–3%. The economic level for a copper mine is around a copper content of 0.3–4%. One example from Sweden illustrated the challenge; there was 160000 tons of WEEE collected according to statistics. But, there was no openly available statistics on how much copper this included, or any open statistics on how much copper was extracted out of the waste stream. Thus, the copper material recycling efficiency was unknown. [Luttropp et al. 2010]

Furthermore, an issue still rarely addressed is the embedded energy connected to high-level materials such as metals. The energy requirement for electrolytic copper can be as much as ten times from ore compared with electrolytic copper from impure scrap. Rules of thumb for mechanical engineering give a factor 7 for aluminium and a factor around 3–4 for steel. The following percentage levels for re-melted/primary energy requirements was indicated Copper 13%, Steel 38%, Titan 41%, Nickel 11%, Zinc 28%. [Luttropp et al. 2010]

The WEEE consists of materials which can be categorized to the mainly five material groups: ferrous metals, non- ferrous metals, glass, plastics and other materials. Even over 1000 different materials are recognized to be in different kind of WEEE. Based on weight volumes of WEEE there is mainly metals such as iron, steel, aluminium, and copper (roughly around 60%) and the next common materials are plastics (around 21% of total weight). The content of WEEE is changing due to development of technology and new material components.[ETC/SCP2009, Ongondo et al. 2011]

Although precious metal concentrations in sWEEE are very low, these metals also have economic and environmental relevance. The results revealed in Chancerel Doctoral Dissertation that for example in 2007 over 370 000 tonnes of sWEEE were generated in Germany, containing 1.9 to 2.4 tonnes of gold and over 580 kg of palladium. The collection rates were as high as 77% of the generated sWEEE, but still 72% of the gold contained in the sWEEE was discarded in Germany and therefore lost for the recycling economy. The economic value of the discarded gold and palladium estimated to be between 34 - 44 million US. [Chancerel 2010]

In practise, the producer responsibility applies on the company or organization that puts a certain product on the market. Large producers mostly have a retail organization selling products e.g. to retail chains. The retail chains can themselves buy and import from outside of a certain country and then the producer responsibility is transferred to the retail chain. Retailers have obligations to pay for the recycling treatment. The waste treatment companies in the end of the process are paid with what they can extract from the waste stream. Those retailers not connected to the system often claim that they handle take back themselves, which is mostly not true. Citizens have a tradition to return all WEEE to the common collection system. The situation then arises that not all the retailers are attached to the system and those who are have to pay for those who are not. In short, connected companies and organizations pay for a service they cannot monitor since the efficiency of the system is unknown and not everyone is paying his share. Figure 2 presents the situation. [Luttropp et al. 2010]

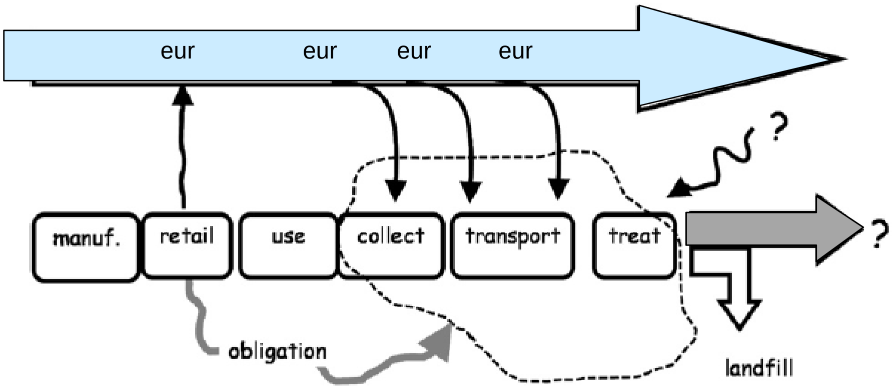


Figure 2. WEEE- organized retailers pay for an obligation they cannot monitor. [Luttropp et al. 2010]

Those WEEE materials handled by actors and operators not belonging to the producer responsibility systems and organizations are mainly ending up from illegal markets, where it is delivered especially to the Far East and to the Africa. [Chancerel 2010, IPCWG 2009, Toppila 2011a] In the developing countries in small workshops the valuable materials are removed from WEEE, after which they are dumped to the landfill, sank to the rivers or see or alternatively they are incinerated. [EIA 2011, Toppila 2011a]

According Toppila [2011a] study in Finland even half of the yearly WEEE-scrap ends up somewhere else that to the official collection points arranged by waste management operators. A point of view of a Finn, he or she produces around 10 kilograms such WEEE of which there is not correct information has the official collection happened. The main causing of these secondary flows was recognized to be based on positive economic value of the WEEE whereby those actors and operators outside the official collection system are gathering widely WEEE and competing on the same time with the collection system of the official producer responsibility. Thus, they are causing the main part of the yearly WEEE secondary flows. There are similar observations in relation to WEEE collection in other EU-countries. [Toppila 2011a, Luttropp et al. 2010]

3.3.2 Portable batteries’ waste flows

The producer responsibility in relation to portable batteries applies to all kind of batteries and accumulators. Also it applies to those batteries and accumulators, which are imported inside vehicles or electric devices etc. Those who are involved to producer responsibility in Finland are importers and producers. The producer responsibility is based on Finnish laws about waste (1072/1993) and other Finnish regulations such as Council of State (422/2008) [Ympäristöhallinto 2013].

The producers or importers can manage their responsibilities related to portable batteries by joining and belonging to an organization of producers as a member. The approved organizations of producers are Recser Oy and ERP Finland ry in Finland. For producer the membership in organization of producers means that the producer moves its producer responsibility obligations under the management of the organization of producers. Furthermore, shops and commercial enterprises which are selling batteries and accumulators should receive free of charge all the used portable batteries and accumulators from consumers. The importers and producers of the batteries and accumulators are responsible of the waste management and the cost of it onward from the shop. [Ympäristöhallinto 2013]

The study of Toppila [2011a], which received a commission from the national supervising authority of the waste management and producer responsibility called ELY-centre of Pirkanmaa (www.elykeskus.fi/pirkanmaa), opens up the challenging situation for the portable primary and secondary batteries. Since year 2008 portable batteries are obliged to follow the producer responsibility. The evaluation of the yearly accumulation of the waste of primary and secondary batteries is difficult, because of different length of the lifetime of the products dependent on the quality and purpose of use. The statistics available do not represent the whole market (neither Europe nor Finland), only those who belong to the producer responsibility systems. In addition, one third of portable batteries and accumulators are inside electrical and electronic equipment when ending up to market. The situation in relation to waste of batteries and accumulators is that over half of it finds a way out in secondary flows outside the official collection system. See Figure 3 presenting main secondary flows of portable batteries and accumulators.

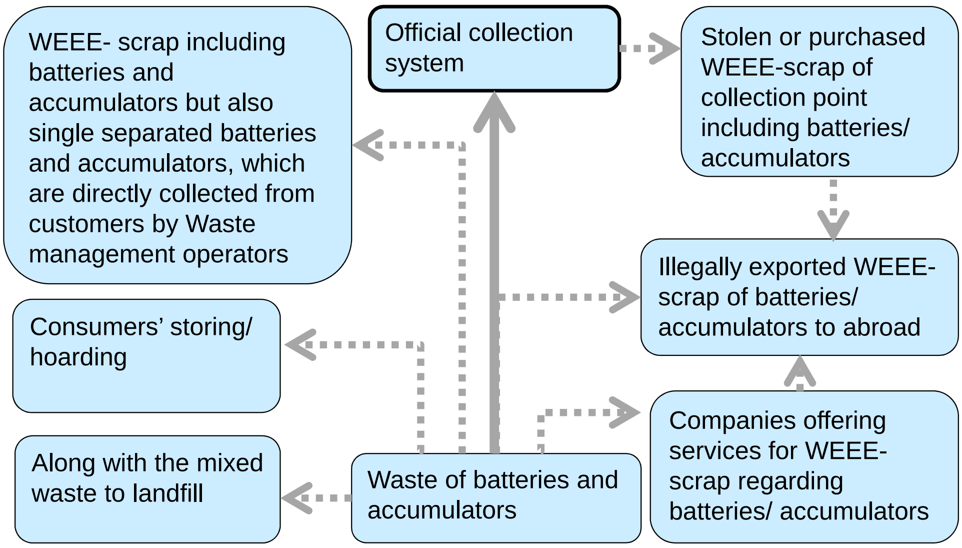


Figure 3. Main secondary flows of portable batteries and accumulators in Finland (Modified based on [Toppila 2011a, b]).

The secondary flows of portable batteries are strongly bound to WEEE secondary flows, but the causing mechanisms behind are different. In contrast to WEEE, the secondary flows of portable primary and secondary batteries are mainly due to insufficient and unaware behaviour of consumers in relation to recycling practises and official collection system of portable batteries. [Toppila 2011a]

In order to end up to the official collection system those products belonging in to the producer responsibility are influenced on how easy and practical the collection system itself is. If the collection system is complicated or access is difficult, the consumers tend to find another easier way to get rid of used portable primary and secondary batteries. According several studies quite often this seems to be among the municipal waste to the landfill in significant amounts. Thus, the consumers' insufficient behaviour in recycling has significant role related to portable primary and secondary batteries by forming even 87% of the official collection systems' secondary flows. In addition, the consumers tend to hoard portable primary and secondary batteries as well as WEEE (e.g. mobile phones) at households even for several years. The estimation by EU was that roughly 30% of used portable primary batteries and even 60% of used portable secondary batteries are hoarded at households instead of recycling. [Chancerel 2010, Malmström 2012, Directive 2006/66/EC, Popita et al. 2010, Toppila 2011a]

The waste amount of portable primary and secondary batteries was estimated around 2300 tonnes on year 2009 in Finland and around 429 g / inhabitant / year. The secondary flows were estimated to be around 1260 tonnes, which is 55% of yearly based waste of portable primary and secondary batteries.

Thus, the official collection system recycling efficiency was estimated to be around 45%. [Toppila 2011a]

Consequently, the important question is how to improve the official recycling and collection system in order to get consumers better give up their waste of portable primary and secondary batteries and in order to decrease the secondary flows of the official collection system, which have economic, social and environmental impacts in Finland as well as abroad.

4. Considerations about the life cycle management in relation to portable batteries

The importance to improve product's life cycle management (PLM) with the help of accurate information and identification through the whole value chain is increasing due to the tightening EU directives and European legislations. In the following is revealed Life Cycle Assessment (LCA) method as a powerful tool to understand and evaluate environmental performance of a product (e.g. a device including portable batteries and/or portable batteries itself).

4.1 Life cycle thinking and life cycle assessment applications

Life Cycle Thinking (LCT) approach seeks to identify possible improvements to products and services in the form of lower environmental impacts and reduced use of resources across all life cycle phases according EU (http://lct.jrc.ec.europa.eu/). The key aim of LCT is to avoid burden shifting. This means minimising impacts at one phase of the life cycle, or in a geographic region, or in a particular impact category, while helping to avoid increases elsewhere (E.g. saving energy in the use phase of a product, while not increasing the amount of material needed to provide it).

The study of Antikainen et al. [2012] related to the FINLCA research produced information on the applications of life cycle thinking and the use of life cycle methods, including examples, in order to improve their use in companies of Finnish society, especially for supporting strategic decision making. Different life cycle methods were studied and good practises related to them. Of these methods life cycle assessment (LCA) is the most scientific approach and it should be used as a basic tool for the environmental assessment of products and services.

Life cycle assessment (LCA) aims at assessing all quantifiable environmental impacts of a service or product from the extraction of the materials required, to the treatment of these materials at the end-of-life phase. For example the environmental impact of portable batteries can therefore be estimated using LCA.

LCA has been developed to gain a better understanding of the potential environmental impacts of products. LCA can be used for:

- identifying opportunities to improve the environmental performance of
- products at different life cycle phases
- informing decision-makers in industry, government or NGO's
- selecting relevant indicators of environmental performance
- marketing products (for example, making an environmental claim or applying for an eco-label). [ISO 14040 2006.]

The ISO 14040 standard addresses some of the requirements for carrying out an LCA [ISO 14040 2006]. The four phases of LCA are the goal and scope definition phase, inventory analysis, impact assessment and interpretation. The four phases of LCA are presented in Table 1. See also ISO standard 14044 [ISO 14044 2006].

Table 1. LCA has four phases.

Goal and Scope	Life Cycle Inventory LCI	Impact assessment LCIA	Interpretation
Definition of goal and scope Intented application audience, publicity Boundaries Functional unit Allocations Assumptions and limitations Data quality requirements Type of critical review	Inputs and outputs of the system unit processes Energy inputs Raw materials inputs Other physical inputs Products, Co-products and waste Emissions to air Discharges to water and soil	Selection of impact assessment method i.e. ReCiPe, EcoIndicator 99, CML Selection of impact categories Category indicators Characterisation models LCI-results classification Calculation of category indicator results i.e. characterization Grouping and Normalization Weighting	Interpretation of results and usability Significance, limitations, comprehensive Opportunities to improve Strategic decision making Selecting indicators Product and process development Environmental information Marketing

However, a full life cycle assessment is not always the most applicable approach in all situations. A simplified life cycle assessment or other life cycle assessment methods or indicators such as carbon footprint, water footprint, ecological footprint and MIPS-method (material input per service unit) can all be appropriate depending on the situation. An overview of how life cycle methods can be used to support long term work in companies was provided, i.e. determining strategy and supporting operative activities. In order to apply life cycle management in the everyday situations of society, the life cycle methods should be considered support tools for eco-design and strategic decisions in companies. [Antikainen 2010, Antikainen and Seppälä 2012]

4.2 Examples of LCA studies

In the following is picked up three examples of reports covering LCA studies in relation to consumers' portable batteries in order to reveal the power of LCA to provide beneficial information about environmental impacts. The reviewed studies were selected against the main interest to find environmental LCDA information about the portable rechargeable batteries and especially aspects in relation to batteries' end of life. Some of the literature found covered reviews of LCA studies made by others (e.g. EPBA Sustainability report etc.) but thorough studies about LCA of batteries were found (e.g. Olivetti et al. 2011) and also evaluated (e.g. Mudgal et al. 2011).

4.2.1 Sustainability report of EPBA

Sustainability report of European Portable Battery association (EPBA) refers to two LCA studies. One of them was conducted by Energizer on its own products in 2009. Furthermore, another study referred was Duracell from year 2010 conducting LCA of alkaline manganese (non- rechargeable) and NiMH (rechargeable) batteries. [EPBA 2010]

Factors influencing battery recycling are complex and include a whole range of elements. Among other things, this will require the industry to carefully assess all factors impacting end-of-life management, including product and process design. The main challenge facing the portable power industry and its stakeholders today is establishing a methodology to effectively quantify impacts, making battery recycling a net positive for the environment. [EPBA 2010]

In the referred Duracell study the LCA of AA-size alkaline manganese and NiMH rechargeable batteries was carried out with the aim of identifying primary drivers of environmental impacts and determining strategies to minimise them. The geographic scope was the European Union and impacts included in relation to the collection and recycling of spent batteries. Almost 80% of environmental impacts (e.g. CED and GWP) across the life cycle of alkaline batteries were found to occur during the mining and refining of materials used to make them. The biggest contributors were mining and refining processes of manganese dioxide, zinc and steel. Among impacts directly under the control of battery manufacturers were those linked to energy consumption during the manufacturing phase, while packaging impacts were shown to be driven more by production of the packaging materials than actual packaging operations. End-of-life impacts, based on the collection and recycling of 30% of batteries sold (the remainder being landfilled or incinerated), accounted for a small net negative environmental burden. [EPBA 2010]

In case of rechargeable NiMH batteries the majority of impacts are split between the extraction and refining of raw materials for battery and charger components, and the way these batteries are utilised and recharged by the consumer. Consumers therefore have an influence on reducing the environmental impact of these batteries. Recycling of NiMH batteries is a net positive for the environment, mainly because of the reuse of high-impact metals such as nickel. [EPBA 2010]

The baseline functional unit of AA NiMH rechargeable batteries was a rechargeable battery used for 80 cycles. The production phase of the NiMH rechargeable battery also included a share of the production impact of materials used in the charger. [EPBA 2010]

Environmental impacts from the use phase were found to account for almost 50% of CED across the life cycle. Total impact was sensitive to different parameters of the use phase, including the number of charge cycles, charger idle time, energy efficiency and electricity mix. Extending the number of charge cycles increased the dominance of the use phase. Extraction, refining and transportation of raw materials required for the manufacture of both battery and charger were the next largest contributors. Metal hydride and nickel were responsible for the largest impacts during raw material production, while transportation accounted for a small percentage of total impacts. End-of-life impacts yielded a 1.5% net positive to CED, due chiefly to the recycling of nickel. Increased collection and improved recycling efficiency of NiMH batteries would therefore make a positive contribution to the preservation of environment. [EPBA 2010]

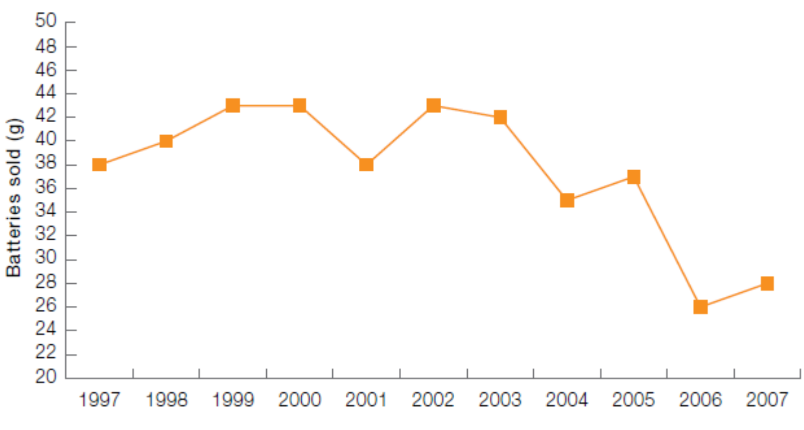


Figure 4. Materials efficiency of rechargeable batteries. [EPBA 2010]

Due to increased material efficiency of NiMH batteries, the average weight of rechargeable replacement batteries on the European market fell by 26% during ten years' time, from 38g to 28g. See Figure 4. During the same time the sales volume of NiMH batteries increased by 120% from the level of 20 million to 90 million. [EPBA 2010]

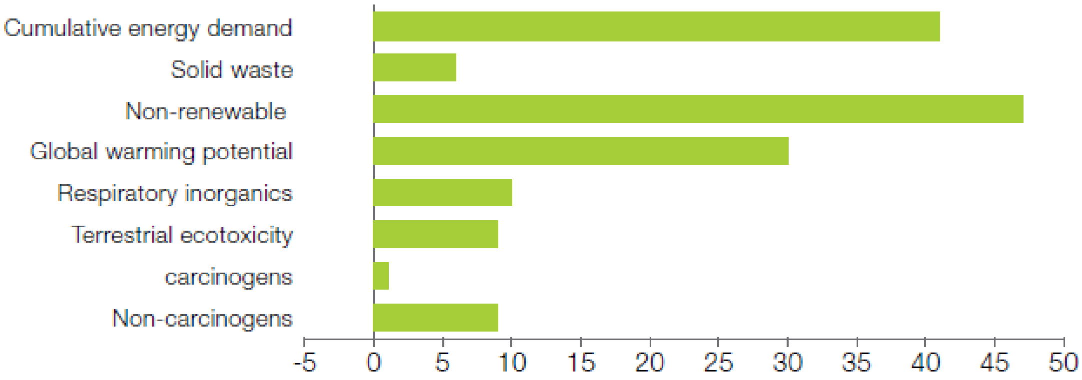


Figure 5. Environmental consequences of rechargeable batteries. Increase in percent (%) between years 1997 and 2007. [EPBA 2010]

Trends in the rechargeable replacement battery market have led to an increase in environmental impacts arising from the mining and refining of nickel, cadmium, iron and rare earth metals. Between 1997 and 2007, impacts actually increased for example in solid waste 6% and in non-renewable materials 47%. The reasons behind are that there is 11% more nickel being used in NiMH batteries on average, compared to their NiCd counterparts, and increasing sales volumes. However, since 2003, a positive trend has been identified for all impacts due to a levelling-off of sales. See above Figures 4 and 5. [EPBA 2010]

In the referred Energizer study was highlighted that general purpose batteries do not have a single use, but multiple applications that vary greatly according to the characteristics of a given device and the way in which, and intensity at which, it is used. It was concluded that:

- The relative impact of batteries on the environment, regardless of type, is very low compared to other daily activities. Over a five-year period, the total impact of battery use in a device will vary according to application and battery type, but will typically be less than driving 8 km in a car during that same time period.
- Among the different categories of environmental impact, depletion of non-renewable resources, global warming and acid rain are the most pertinent.
- No one single battery chemistry (primary or rechargeable) has the lowest impact across the full range of consumer applications. The choice of technology is it primary or rechargeable, depends greatly on the device in question and usage patterns. [EPBA 2010]

4.2.2 Study on elements for an impact assessment proposed options for capacity labelling of portable primary batteries in context of Battery Directive

A study of Mudgal et al. 2010 covers several aspects concerning the portable batteries. The study includes also a summary and literature review about environmental performance of primary (non-rechargeable) versus secondary (rechargeable) batteries based on five different LCA studies.

The results of a LCA study are generally presented through several indicators of environmental impacts. These indicators based on full life cycle could provide useful information e.g. capacity labelling of both portable primary and secondary batteries. However, they are not expected to provide any general statement on the relative performance of portable secondary batteries versus portable primary batteries, because of wide range of system configurations are possible (e.g. primary battery can be alkaline, zinc-carbon, lithium whereas a battery-operated device can be an alarm clock, a digital camera, a flash light, etc.). Thus, establishing general statement valid at EU level covering all situations is not possible. [Mudgal et al. 2010]

The list of studies covered in Mudgal et al. [2010] is presented in below Table 2 and in much thorough in report itself.

Table 2. LCA studies of portable batteries reviewed in Mudgal et al. [2010].

1) Study title	The environmental impact of disposable versus re-chargeable batteries for consumer use
Goal	Validate that the secondary batteries have a lower impact on the environment when compared to the primary batteries
Authors& source	Parsons D (2007): The Environmental Impact of Disposable Versus Re-Chargeable Batteries for Consumer Use. Int J LCA 12 (3) 197–203. www.springerlink.com/content/r104g3640u736674/fulltext.pdf
2) Study title	Uniross study on the environmental impact batteries
Goal	Assess the environmental impact of the portable primary and secondary batteries throughout their life cycle including production, sale, use phase and end of life.
Authors& source	BIO Inteligence Services (FR), Fraunhofer Institute IZM (DE) for critical review, 2007. http://www.rechargeonslaplanete.net/_docs/UNIROSS_Study_-_Environmental_impact_of_batteries.pdf
3) Study title	Battery waste management life cycle assessment
Goal	To determine the environmental impacts associated with collection and recycling targets and to estimate the financial cost of alternative scenarios for implementing the requirements in the Directive on Batteries and Accumulators
Authors& source	Environmental Resources Management, 2006. http://www.defra.gov.uk/environment/waste/topics/batteries/pdf/erm-lcareport0610.pdf
4) Study title	Environmental assessment of battery systems
Goal	Evaluate the environmental impact of recycling rechargeable NiCd batteries
Authors& source	Rydh, C.J., Sweden, 2003 www.te.hik.se/personal/tryca/battery/Rydh_2003_Battery_metal_flows.pdf
5) Study title	Life-cycle methods for comparing primary and rechargeable batteries
Goal	Evaluate the total environmental impact of portable primary and secondary batteries
Authors& source	lankey, R.L.,Mcmichael, F.C., U.S. Environmental protection agency, 2000 Environment Science Technology, 2000, Volume 34, pages 2299–2304

Based on Mudgal et al. [2010] review in relation to Table 2 studies following conclusions and remarks were presented:

- Studies provide useful insights on the relative performance of primary batteries versus secondary batteries. However, none of these studies cover extensively the overall scope of such a comparison.
- Study 1: Substantial contribution to the impact of rechargeable batteries comes from the production phase, electricity used for wholesaling and retailing, transport to landfill and the copper and other components in the battery charger. An impact caused by the generation of electricity for recharging the batteries is also significant, amounting to about 10% for the NiMH batteries. The study supports rechargeable battery over disposable i.e. primary batteries based on environmental impact of each of the criteria studied.
- Study 2: The use of portable secondary (NiMH) batteries is better for the environment than the use of portable primary (alkaline) batteries. NiMh batteries generate less environmental impacts than alkaline batteries irrespective of the capacity of the battery or the end-of-life route (municipal solid waste or recycling). Limitations were that it does neither consider other possible chemistries of batteries nor the scenario of slow drainage rate.

- Study 3: Increasing recycling of batteries is beneficial to the environment. However, it is achieved at significant financial cost when compared to disposal. Limitations were that the manufacturing and use phase were not considered.
- Study 4: Excluding the user phase of the battery, 65% of the primary energy is used in the manufacture of batteries while 32% is used in the production of raw materials. Metal emissions from batteries to water originate (96–98%) from landfilling and incineration. Batteries manufactured with recycled nickel and cadmium instead of virgin metals has 16% lower primary energy use. Recycled cadmium and nickel metal require 46% and 75% less primary energy, respectively, compared with extraction and refining of virgin metal. Limitations were that the manufacturing and use phase were not considered.
- Study 5: Resource use and emissions are substantially lower if a rechargeable battery (NiCd) can be substituted for a primary battery (Zinc alkaline). However, consumer use patterns will affect the relative environmental benefits of rechargeable batteries. Limitations were that no information about the drainage rate during use phase, it's crucial to carry out the comparison as disposable battery capacity is strongly influenced by the characteristics of the electronic device that it is used in.

Although the results of studies more or less agree about the lower environmental impacts of rechargeable secondary batteries compared to disposable primary batteries, these studies do not sufficiently complement each other in order to make concrete recommendations at the EU level. [Mudgal et al. 2010]

4.2.3 Report of comparative LCA of NiCd batteries used in cordless power tools versus their alternatives NiMH and Li-ion batteries

The study of Mudgal et al. [2011] covers objectives to conduct a comparative LCA of NiCd, NiMH and Li-ion batteries and chargers used in Cordless Power Tools (CPTs) and present the respective environmental shares and identify the main steps in the life-cycle of the batteries contributing to these environmental impacts in the EU context. The studied information is further used to support an impact assessment that assists in identifying and evaluating various policy options to reduce the environmental impact and human exposure to cadmium associated with these batteries with a potential to withdraw the current exemption in the Batteries Directive [Directive 2006/66/EC] for cadmium use in batteries for in CPTs. Example of CPT is presented in Figure 6. [Mudgal et al. 2011]

Figure 6. Example of CPT under study: Heavy Duty Hammer drill [Mudgal et al. 2011].

The study provides comprehensive results of the LCA carried out for the three battery types. It also presents the comparative assessment of the environmental impacts of these three battery types over their whole life cycle. Study presents the economic, social, and environmental impacts of three policy options to reduce the environmental impact and human exposure to cadmium associated with these batteries. The latter i.e. policy options are miss out here. [Mudgal et al. 2011]

LCA was carried out for batteries used in cordless power tools (CPT) which include: Nickel-Cadmium (NiCd) batteries, Nickel Metal Hydride (NiMH) batteries, Lithium Iron Phosphate (LiFePO4). In the

LCA, it was included only the main Li-ion technology in terms of market shares: Lithium Iron Phosphate technology. Main characteristics of battery cells and one example about the bill of materials (BOM) of NiMH cells are presented in next tables 3 and 4. [Mudgal et al. 2011]

Table 3. Main characteristics of the cells: NiCd, NiMH and $LiFePO_4$ (Li-ion battery) [Mudgal et al. 2011].

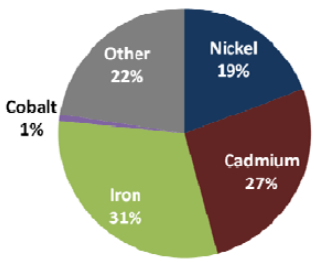
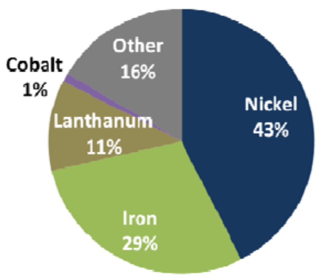
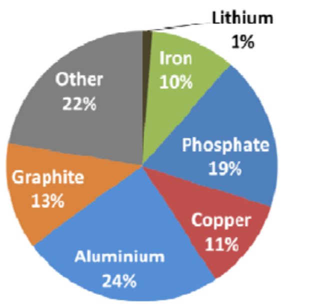
<table>
<tr><th></th><th>NiCd</th><th>NiMH</th><th>LiFePO4</th></tr>
<tr><td>Capacity (mAh)</td><td>2400 mAh</td><td>3200 mAh</td><td>2000 mAh</td></tr>
<tr><td>Voltage (V)</td><td>1.2 V</td><td>1.2 V</td><td>3.3 V</td></tr>
<tr><td>Depth of discharge</td><td>100%</td><td>100%</td><td>85%</td></tr>
<tr><td>Mass (g/cell)</td><td>51.6 g</td><td>58 g</td><td>38.3 g</td></tr>
<tr><td>Mass breakdown</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Table 4. Bill of materials of NiMH cells from LCI data of Ecoinvent 2.2 [Mudgal et al. 2011].

Component	Material	Ecoinvent 2.2 LCI	Country of supplier
Cathode	Nickel hydroxide	• Nickel, 99.5%, at plant/GLO • Sulphuric acid, liquid, at plant/RER • Electricity medium voltage/CN *See § 1.3.2.3.2 page 50*	China
	Cobalt (II) oxide	Cobalt, at plant/GLO used as proxy	China
	Nickel foam	Nickel, 99.5%, at plant/GLO	China
	Yb2O3	Lanthanum oxide, at plant/CN used as proxy	China
	Polystyrene acrylate	Styrene-acrylonitrile copolymer, SAN, at plant/RER used as proxy	China
	CMC	Carboxymethyl cellulose, powder, at plant/RER	China
Anode	Alliage AB5 ($LaNi_5$)	$LaNi_5$ (*GaBi LCI*)	China
	Polystyrene acrylate	Styrene-acrylonitrile copolymer, SAN, at plant/RER used as proxy	China
	CMC	Carboxymethyl cellulose, powder, at plant/RER	China
	PP Fibers	Polypropylene, granulate, at plant/RER	China
	Carbon	Carbon black, at plant/GLO	China
	PTFE	Tetrafluoroethylene, at plant/RER	China
	Nickeled steel	• Steel, converter, unalloyed, at plant/RER • Nickel, 99.5%, at plant/GLO	China
Electrolyte: Aqueous alkaline solution	KOH	Potassium hydroxide, at regional storage/RER	China
	NaOH	Sodium hydroxide, 50% in H2O, production mix, at plant/RER	China
	LiOH	Lithium hydroxide, at plant/GLO	China
	Water	Water, deionised, at plant/CH	China
Plastic separator	Polypropylene / PE	• 50% Polyethylene, HDPE, granulate, at plant/RER • 50% Polypropylene, granulate, at plant/RER • Injection moulding/RER(+)	China
Can	Steel	• Steel, converter, unalloyed, at plant/RER	China
	Nickel	• Nickel, 99.5%, at plant/GLO • Sheet rolling, steel/RER(+)	China

The scope of the LCA included: 2 battery packs and charger (see Figure 7). Thus, to the scope of the LCA was not included the CPT itself, because it will not have an impact to the comparative assessment and on the conclusions. The functional unit chosen was: "1 kWh of energy delivered by the battery to the CPT". Raw data were collected from CPT and battery manufacturers and industry associations and LCI data were mainly taken from the Ecoinvent database.

Figure 7. Items included in the LCA (Illustrative examples) [Mudgal et al. 2011].

The study is representative of a European context. Thus, production reflects the supply chain of CPTs manufactured for the European market. LCA demonstrates that no clear overall hierarchy between the batteries can be defined. A clear conclusion can only be given for a limited number of indicators and some of them are presented here:

- $LiFePO_4$ has a lower impact for Terrestrial Acidification Potential and Particulate Matter Formation Potential but has a higher impact for Freshwater Eutrophication Potential.
- Regarding Natural resources, Human Toxicity Potential and Freshwater Ecotoxicity Potential, comparative results depend on the time perspective chosen for the policy analysis that is based on LCA:
  - For a mid-term perspective, Metal Depletion Potential (from ReCiPe) should be considered. In that case, NiCd appears to have a lower potential impact on resource than NiMH and LiFePO4.
  - For a long-term perspective, Abiotic Resource Depletion Potential (from CML) should be considered. In that case, NiMH and LiFePO4 appear equal and have a lower environmental impact than NiCd.
  - For a short/mid-term perspective related to Human Toxicity and Freshwater Ecotoxicity Potentials: NiCd and NiMH appear to have a lower potential impact than LiFePO4.
  - For a long-term perspective related to Human Toxicity and Freshwater Ecotoxicity Potentials: NiMH and LiFePO4 appear equal and have a lower environmental impact than NiCd.

5. Improved life cycle data management with information tagged to the product

In order to efficiently manage the life cycle of a product, its' life cycle information should be gathered, maintained and even updated in a way that it enables access to the information in all phases of the life cycle with the unique identifier of the products. Consequently, with the help of such identified information is enabled for all the accredited actors significant data of the product. [LCDA 2011]

5.1 Utilization of RFID technology

There are several technologies to be used as unique identifier of the products. The focus in this study is on the Radio Frequency Identification (RFID) technology, and the other possibilities of automatic identification (or auto-ID) technologies are not studied. The “family” of auto-ID technologies that identify objects, collect data about the objects and enter data directly into a computer or computer system, typically includes such as RFID, optical character recognition (OCR), bar codes, smart cards and biometrics. RFID has a large potential for growth in global market. Most of the growth in the sales of tags is expected to be due to the demand for UHF passive tags for asset tracking, but also for apparel tagging. [LCDA 2011, Björk et al. 2011, RAND 2012]

5.1.1 Description of RFID technology

RFID is a wireless data collection technology to identify physical objects in a variety of fields. An RFID system typically consists of a tag (or transponder) physically attached to an object, containing a small microchip with memory that uniquely identifies itself. In addition, an RFID system also consists of a reader (or interrogator) that sends radio signals into the air to activate a tag through an antenna, read the data transmitted by the tag and write data on a tag if needed. Many different shapes and sizes of RFID tags are available. Depending on the functions and uses of RFID, the material to which it will be attached and the type of environment in which RFID is expected to function will determine the frequency of operation (LF, HF and UHF tags), the source of the power and the design for the length of life. A tag needs power to be able to send and receive data to the reader. [LCDA 2011, Björk et al. 2011, RAND 2012]

Depending on how RFID tags obtain their power to operate, tags are classified as passive, semi-passive and active tags. Passive tags have no power source of their own. Thus, they only work when supplied with the radio signal from the reader. Passive RFID is based on modulating the backscattered signal from the transponder to the reader. Recently passive RFID technology has found numerous applications in marking and identifying objects, for example in logistics and in access control. Semi-active tags (also called semi-passive tags) are battery assisted passive (BAP) tags. Such kind of tag is able to response on request of a reader, although it do not have active transmitter. Active tags have their own power source (battery) and an active transmitter. Their read-and-write range is potentially greater (even over 100 meters) than that of BAP tags (roughly around 30 meters) or passive UHF tags (roughly around 10 meters). Write range of a passive tag is somewhat shorter than the respective read range. [LCDA 2011, Björk et al. 2011, RAND 2012,

5.1.2 RFID information tagging to improve EoL

RFID technology is one option to improve recyclability in EoL phase. Thereby, tags can contribute to the efficiency and effectiveness of recycling at different phases in the lifecycles of a wide range of products, ranging from simple items to complex objects containing a variety of materials. [RAND 2012, Seppä 2009]

If the products, especially those that produce hazardous waste, are equipped with RFID tags, they could be automatically identified. Waste disposal trucks could be equipped with RFID reader to detect products containing hazardous waste materials. The tagging of products, such as EEE, would facilitate RFID tracking of parts from point of manufacture to end of life. This would allow for customers to return products to manufacturers to recycle or ensure proper disposal is taken. [LCDA 2011]

Passive UHF RFID tags would serve the identification needs of the end of life and waste management companies. A reader could be used to automate the sorting of recyclable product and product parts, such as cell phone batteries. The linkage between the recycler’s information systems and that of the manufacturers’ via EPCIS would provide the two parties with up to date product information. The recycler would query the manufacturer’s information storage system for the product information such as product composition, recyclable component and disposal procedure. In return, the recycler would update the product’s information with information including the date of its EoL. [LCDA 2011, Seppä 2009]

Furthermore, the environmental performance of a product can be traced and analysed even on an individual level. This means that not only the performance from the own production of a manufacturer will be accessible, but also the upstream processes that constitute the product value chain and the life cycle performance for the product leaving the manufacturer. Monitoring of the environmental indicators e.g. Key Performance Indicators (KPI:s) makes possible to achieve the following advantages:

- Status of environmental performance and detection of potential improvements.
- Basis for optimisation of environmental impact.
- On-line monitoring and control of environmental impact.
- Environmental management and benchmarking
- Marketing purposes such as EPDs or support for eco-labelling. [Björk et al. 2011]

Short-run developments related to the use of RFID to improve recycling are likely to involve spreading of existing pilots with others in the field of waste handling, as well as the development of new methods for using existing tags, e.g., by the inclusion of new data useful in waste collection and disposal. Also, the deployment of RFID as part of a general trend to improve waste handling is likely to produce behavioural changes, new business models and even changes in sectorial organisation (e.g. new intermediary markets for aspects of smart waste handling or changes in vertical integration along the EoL of product chain). In addition, policy would begin to adapt to new possibilities, especially as regards improved traceability and waste stream measurement. Long-run possibilities may be realised through novel whole-systems approaches to waste handling and new forms of integrated lifecycle management. [RAND 2012, Seppä 2009]

RFID may also be seen as an enabling technology facilitating the monitoring and enforcement of waste law at EU. One calculation made is that each year €72 billion is wasted as a result of improper implementation of EU waste legislation. Thereby, RFID can be very useful for the production of statistics on waste management, including shipment of waste, and hence help to improve granularity of data and inform policy-making. [RAND 2012]

5.1.3 Recyclability of RFID tags and their relevance for waste stream

The important criterion to evaluate the impact of tags on the waste management industry and its processes is the identification of the waste stream in which the tag is likely to end up. Quite often passive labels are attached to CPGs, made out of cardboard, paper and plastics. Whereas active tags are very small electronic devices with a power supply in the form of a battery, with regard to their disposal, it is generally considered that interrogators and active RFID tags fall into the category of 'electronic devices' and therefore fall under the scope of the WEEE Directive. Hence, it can be assumed that these tags are disposed of in separately kept waste streams that follow adequate treatment routes and rarely end up in mixed waste streams, such as municipal solid wastes. However, passive tags are considered to be outside the scope of the WEEE Directive and are disposed of with the material/object they are applied to. Passive RFID labels when used on item level in retail or apparel supply chains will end up in packaging waste or mixed municipal solid waste. [RAND 2012]

The recovery of the metals is seen to be feasible way of recovery operations for RFID tags. Especially, the metals and the two general metallurgical routes, the copper route and the aluminium route, are relevant. The outcome of the practical trials showed that it is not feasible to selectively extract RFID tags during waste processing and produce a RFID pre-concentrate. Therefore, RFID tags are only sent for metallurgical recycling if they are attached to materials, which are transferred to nonferrous metal pre-concentrates. As long as no system or process for the selective separation of RFID tags from other waste components has been developed, controlled allocation to specific recycling paths cannot be realised. However, in future dependent on the system the one option could be e.g. the use of Indisbutable Key (IK) – tags, which are biodegradable and also suitable for pulping process. [Pesonen et al. 2009, Björk et al. 2011, RAND 2012, LCDA 2011]

5.2 Examples of studies using RFID to tag information

This chapter includes examples from two studies about tagging information to the product for example with the help of RFID. Thus, to improve LCDA and to improve EoL phase, such as collecting, sorting, recycling and reusing.

5.2.1 Study of Improved recycling with life cycle information tagged to the product

According the study of Luttropp et al. [2010] is provided conceptual approach of the information tagged to the product which can raise the recycling efficiency and same time lead to savings of energy embedded in materials. Thus, the reduction of CO_2 emissions occurs also. The information can be directly attached to the product or the product can be given an identity and relevant information stored elsewhere and read with suitable equipment. The information can be coded in a bar code sticker or programmed into a RFID. In contrast to directly attached information is to individually identify every single product via another RFID technology, giving the potential to look for relevant recycling information in databases. An opportunity to add waste-handling information after the product has entered the market is opened. It can be useful, for example, in tracking substances regarded as non-toxic at time of production or other features which might later be proven to be the opposite. [Luttropp et al. 2010]

In order to adapt the state of the standards on bar codes and a variety of RFID standards, the maximum basic recycling information is set to 36 data bits, giving a 9 digit hexadecimal number. In situations offering more information space, additional information can be added. In the study a WEEE vector is just a conceptual approach to show the potential of proposed information system. The WEEE vector aim is to provide direct recycling information escorting the product. Each Recycling Information Matrix (RIM) focuses on recycling target and for each type of product a WEEE vector where core-recycling information is stored. [Luttrop et al. 2010]

Recycling information must be coded in a systematic manner that can be understood by the work force at the recycling plant. Thus, the possibility to attach information to the product could guide in fragmenting. For example Material Hygiene (MH) is to act towards larger amounts and increased purity of useful material obtained from recycling, to be used on the quality level degraded as little as possible. The products should be designed in such a way that as much as possible of used materials is kept in the life cycle and used efficiently. The first step towards higher MH is to provide information for present products that will be useful in the EoL phase. Without the knowledge of present recycling efficiency, it is not possible to measure the benefit of future design efforts. [Luttropp et al. 2010]

As an example in the study a recycling information matrix for dishwashers is presented where a copper separation is beneficial. In addition, if copper can be removed from the product before shredding, the steel fractions after shredding will be more pure. A WEEE-RIM for products with a copper recycling strategy such as a dishwasher can be seen in Figure 8. For a typical dishwasher the WEEE vector could be: 1,A,4,B,5,0,0,5,3 (nine hexadecimal numbers). The information should be read as:

- Main recycling target is copper.
- It is a dishwasher.
- The product is position mapped in 8 quadrants recognized with the front upper left as Q1. Q4 tells the recycler that the main copper source is situated in the front-bottom-right quadrant and is best reachable from the bottom.
- After copper removal, fragmentation is recommended.
- It contains approximately 1 kg of copper.
- It is prepared for a pre-step dismantling operation before shredding with a potential of 95% of copper fraction yield. [Luttrop et al. 2010]

pos.	1	2	3	4	5	6	7	8	9
	Target	Product	Action	Action	Action	Alert	Hazardous	Weight	Class
0	Resting	not used	not used	not used	not used	not used	not used	<50 g	not used
1	Copper	Washing machine	Front	Cable off	Cable off			50-100	DW 20
2	WEEE-core	Charger	Top	Crush	Crush			100-200	DW 75
3	WEEE-core & polymer	Transformer	Back	Disassemb.	Disassemb.			200-400	DW 95
4	Gold	Refrigerator	Bottom	Sort	Sort			400-800	
5	Polymer housing	Frezer	Left	Fragment	Fragment			800-1200	
6	Ferrous metal	Electric car	Right	Open	Open			1200-1600	
7	Haz. subst.	Heater						1600-2000	
8	etc.	Heat exchanger		Q1				2-3000	
9		Electric motor		Q2				3-4000	
A		Dishwasher		Q3				4-5000	
B				Q4				5-6000	
C				Q5				6-8000	
D				Q6				8-10000	
E				Q7				> 10 000	
F				Q8				> 100 000	

Figure 8. This is a possible WEEE-Recycling Information Matrix for dishwashers [Luttropp et al. 2010].

If products in the waste stream are tagged with this type of information, it is not only the recycling process that can be industrialized – efficiency can be raised and measured as unprocessed copper in products as input, and extracted measured copper as output. [Luttrop et al. 2010]

To conclude a lot of research is done on EoL management of products in order to facilitate upgrading and refurbishing. Lack of information infrastructure, costs connected to manual work and unavailability of product information are the major obstacles for effective end of life management of products. The possibility to store recycling information as presented in the example has the potential both to raise efficiency and to monitor WEEE recycling. If the products were tagged according to the EPC and the GID-96 standard, the necessary information could be present at scrapping of the specific product. There is also possibility to later add new information on e.g. toxic substances in the product not observed at time of manufacture. In addition, during use phase, the individual identity of products can be used in service work. For a service man it is easier to get relevant information on e.g. correct spare parts even before phasing the product if the owner of the product can provide the exact identity of the product in advance. The possibility to monitor transportation of WEEE and correct invoicing is opened. The efficiency of WEEE recycling can also be measured. Currently, there is no possibility to monitor the investments or the efficiency of the treatment in such accuracy as the tagged information offers. In a more industrialized system it is possible to monitor all hazardous substances and valuable fractions from collection all the way back to pure fractions. [Luttropp et al. 2010]

5.2.2 Rand working paper about Smart Trash

The study of RAND 2012 Working paper, funded by the EC, aims to clarify the significant issues of the environmental impact of RFID tags and assessing the environmental advantages that RFID can provide for product life cycle management. The risks arising from the first element and the opportunities from the second have been studied, but have not yet found their general application. The study provides a comprehensive overview of the significance of RFID technology in the context of waste management. The ICT-related perspective highlights the functions of RFID, their contributions to what has come to be called the Internet of Things (IOT), and the network of systemic innovations (e.g., smart transport, smart cities etc.) that depends on the identification of objects. The other reflects the physical properties of RFID tags and the environmental perspective from which product life cycles and waste management are assessed. The difference in perspectives, together with weak integration along product and system life cycles (e.g. poor connections between design, marketing, use and disposal) creates a risk that neither markets nor “stove-piped” environmental and ICT-related policies will attain efficient outcomes, let alone economically and environmentally sustainable development.

The issues picked up here reveal some aspects of the use of RFID to tag information described in part B of the Working paper. Especially, the two use case analysis and their preliminary findings concerning RFID – based waste sorting and WEEE EoL processes are in focus. [RAND 2012]

RFID has the potential to be a technology that can allow for a more holistic approach to product lifecycle management. However, the opportunities presented through RFID tags depend on the agreement of all participants in the product life cycle. In some cases, resources from three continents are used to create a product that is shipped to another country and sold there. See Figure 9 below. [RAND 2012]

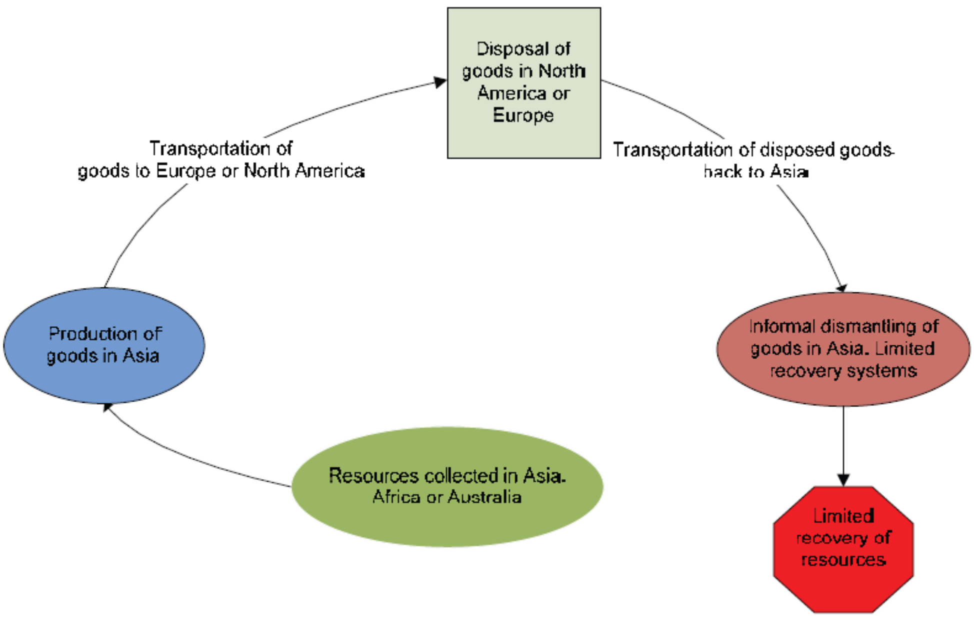


Figure 9. Challenges of resource recovery for “green” technology applications of RFID [RAND 2012].

The Figure 9 illustrates the level of globalisation and the amount of information that needs to be considered for efficient lifecycle management processes. Thereby the “sustainability” is not just the responsibility of one producer in the supply chain. Since RFID tags contain information that do not cover only the physical product, producers can demand more of their production processes and supply chain relationships, while consumers can demand more transparency in relation to the goods they buy. When the environmental indicators of products (such as carbon footprint) are made more visible, producer responsibility, consumer ownership and processing of the product at the end of its life can become shared responsibilities. Linking responsibility in this way can facilitate reuse, recycling, recovery and disposal by making the waste management processes more transparent and the implications more comprehensible. [RAND 2012]

Examples of two use case analyses of RAND Working paper opens several points of view related to the RFID-based information tagging:

RFID-based waste sorting case:

The case describes the use of RFID to enable the extraction of homogenous waste fractions and/or the separation of hazardous materials (e.g., batteries) from non-homogeneous waste mixtures. Besides the required application of RFID tags, the availability of data on the material composition of the tagged products is essential.

The main benefits of RFID-based waste sorting are seen in more purified waste fractions resulting in a higher market value for these fractions and subsequently less waste being disposed of in landfills. The requirement for data on the material composition of products could be problematic for manufacturers who do not want to share this information with competitors. [RAND 2012]

An essential requirement for the use of RFID is the application of RFID tags to the products to which automatic sorting is going to be applied. In addition, the critical mass of products must be tagged to gain efficiency. To identify a product using RFID, embedded information is necessary. Organizational requirements include such as common naming scheme and access to product information for the authorised organisations. Product codes might be used to sort items at a range of points along the EOL supply chain: in households, at kerbside, at recyclers, or for pre-processing before incineration, landfilling or smelting. [RAND 2012]

The main task for RFID is to enable the identification of objects within the waste stream on two ways (as already presented in the example of Luttropp et al. [2010]):

- the identification of the object through additional information such as the material composition of the identified object stored in the tag's memory or
- the identification of an object and the look-up of additional information in a database.

After an object is identified, the system triggers an automated sorting mechanism or indicates the presence of an object and determines the object's location within the stream. In the subsidiary purification process phase RFID might serve as an additional control mechanism to ensure that pre-sorted waste from municipalities or industry does not contain objects that might contaminate waste fractions e.g., through tagging of hazardous waste like batteries. Items in focus are small electronics, batteries and products containing batteries or electronics etc.

Thereby, two approaches are possible:

- negative selection where a recycling process might benefit from the removal of products containing hazardous materials from the waste.
- positive selection where products containing valuable materials are sorted out. [RAND 2012]

The public interest in increasing the recycling of batteries is based on environmental considerations rather than economic considerations. An environmental assessment of the costs and benefits of battery recycling would include environmental impacts of the entire life cycle of the batteries, their material content, and the relative benefit of recycling versus incineration or land filling. Thereby, there is less hazardous waste in landfills and better separation of impurities, when more purified fractions are of greater value. The main involved stakeholders are recyclers as well as manufacturers, as it is a prerequisite that manufacturers tag their products and/or packaging at an item level and provide information such as the material. [RAND 2012]

Among the barriers of using RFID-based waste sorting can be unnecessary increase in costs if tagged products do not need be extracted from waste fraction. The raw material of the tag can hardly be recycled due to small quantity. The data protection laws may hinder use of stored information and user phase information gathering might break the privacy protection laws. Operational and social barriers can occur with interrupted information chain if tag is removed from product or destroyed tags have negative impact on efficiency. [RAND 2012]

RFID based WEEE EoL processes case:

The case describes the utilisation of RFID to enhance EoL processes for electronic and electrical waste (EEE), which in the EU falls under the scope of the RoHS and WEEE directives. A lot of precious materials but also hazardous substances are contained in WEEE. [RAND 2012]

RFID could enhance collection, disassembly, reuse, refurbishment, recycling, reassembly and disposal processes. The cost-saving effects presumed in electronic equipment EoL handlings are comparable to those in certain retail businesses. RFID could greatly improve the recovery of value from EoL equipment and provide for safer WEEE treatment, enforce individual manufacturer responsibility, and therefore push for more eco-friendly designs. [RAND 2012]

The needs for relatively high investment in necessary hardware installations and for organisational changes in the recycling industry are one of the strongest barriers here. Also, RFID-based procedures can only become effective following a long lead-time, until tagged EEE products have penetrated the market and end up in EOL processes. Common standards for a life cycle-phase connecting PLM or at least for appropriate tag data content could foster the uptake of RFID in WEEE EOL processes. Also setting the right framework, promoting eco-friendly design through a strong manufacturer individual allocation of the direct and indirect disposal costs, could foster the uptake of this. [RAND 2012]

The basic assumption in the case is that future electronic devices will be tagged with an RFID label containing either unique product code data or even a label with more information, enabling item-level PLM. Some concepts even foresee the label containing, for example, the item's individual maintenance history. The consumer's decision whether to dispose of an item or sell it can be supported.

The consumer could assess the tag data with device such as a mobile phone. Should the consumer be advised to dispose of the item in question, RFID can be utilised to facilitate the consumer disposal process, indicating where the equipment needs to be brought to for disposal in a consumer-convenient and environmentally optimal way, fully conforming to the legislative framework in place. [RAND 2012]

At the recycling operator's site, the construction plans of the device could be assessed in order to enable best-practice dismantling operations. In this case a unique product code can be read from the RFID label, enabling the operator to access the device's construction and material composition data via an externally stored database. Having assessed this information, the operator would be able to estimate the value of the device or the precious materials contained within it. Also to obtain information about how to dismantle the device and about potential hazardous substances contained within it. [RAND 2012]

Tracking WEEE EOL devices through RFID would also allow a real assignment of the recycling cost of a device to its manufacturer. So far, this is mostly implemented by making the manufacturers or retailers pay for the recycling of the same number of devices that they brought into the market. Therefore no real incentives currently exist for manufacturers to redesign their products in a more eco-friendly and easy-to-recycle way. [RAND 2012]

6. Modelling LCDA of consumer's portable batteries

In order to better understand the LCDA and the requirements for the efficient recycling as well as for the environmental performance information, the life cycle of consumers' portable batteries is modelled.

6.1 Different kind of consumer's portable batteries

According to studies evaluated there are several kinds of consumer portable batteries, which can be secondary rechargeable batteries or primary non-rechargeable batteries. [Akkuser 2012, Mudgal et al. 2010, EPBA 2010, Mudgal et al. 2011] In the following is picked-up some examples and figures of them.

Li-ion and Li-polymer portable batteries:

These kinds of batteries are usually rechargeable batteries. They are used in mobile phones, laptops, minidisc players; cameras, CPTs, etc. with a clear "Li-ion" mark. See Figure 10 below.

Figure 10. Examples of Li-ion and Li-polymer portable batteries.

Ni-Mh portable batteries:

These kinds of batteries are rechargeable batteries which are usually used in mobile phones, electronic toys, digital recording devices, laptops, CPTs etc. Those can be marked as: NiMh, Mh Ni, MH, Metal Hydride, Hydride, Nickel Metal Hydride, Nickel Metal and Nickel Hydride. See Figure 11.

Ni-Cd portable batteries:

These kinds of batteries are rechargeable batteries which are usually used in electric toothbrushes, radio controlled toys, auxiliary devices, hand-held phones, Mini-disc players, CPTs, etc. They can be marked as: Ni-Cd, NiCd, Nickel Cadmium, NC etc. See Figure 11.

Figure 11. Examples of Ni-Mh and Ni-Cd portable batteries.

Alkaline portable batteries:

These kind of batteries are usually disposable batteries which are usually used in clocks, radio device, flash lights and other lights, digital cameras, remote controls (of TV etc.), meters, fire alarms etc. They are the most common batteries on the EU-market by volume and weight [EPBA2010]. They can be named and marked as: Alkali or Alkaline or Alkalisk and 0% mercury and cadmium. See Figure 12.

Figure 12. Examples of Alkaline portable batteries.

6.2 Life cycle of portable batteries and accumulators

The following flow sheet presents the life cycle phases of portable batteries and accumulators. To fully utilize the life cycle information of portable batteries the life cycle data acquisition should cover all phases of life cycles. The life cycle of products can be divided in many ways. In this case the portable batteries is divided and presented in three parts: Beginning of Life cycle (BoL), Middle of Life cycle (MoL) and End of Life cycle (EoL).

6.3 Life cycle data in BoL, MoL and EoL

In order to manage resources throughout the value chain and to evaluate environmental performance of a product (e.g. Heavy duty hammer mill or portable secondary battery of NiMh) a lot of data is needed along the life cycle's BoL, MoL and EoL. The environmental performance information can be achieved with the help of LCA covering emissions to air, emissions to water and solid waste as well as environmental impacts (e.g. climate change, acidification, eutrophication, depletion of resources…). LCA with its four phases necessitates handling, equating and balancing a lot of data. Hence, utilization of LCA calculation software (such as SimaPro, GaBi, SULCA to name few) enables easier data handling.

The LCA software describes different life cycle phases and processes along the life cycle in terms of modules and flows. Each module represents one unit of the process or combination of processes. The features and functions of each module are presented by a certain number of logically related equations. In order to build up one module (e.g. in Figure 13 red module of manufacture of portable batteries), information on all the inputs (raw materials, energy) and outputs (products, emissions, waste, by-products) related to the process phase needs to be collected and entered into the system. In more detail, this means for example information about material amount and purity e.g. Nickel metal coming in to the process and how much is used and how much lost during production of a product.

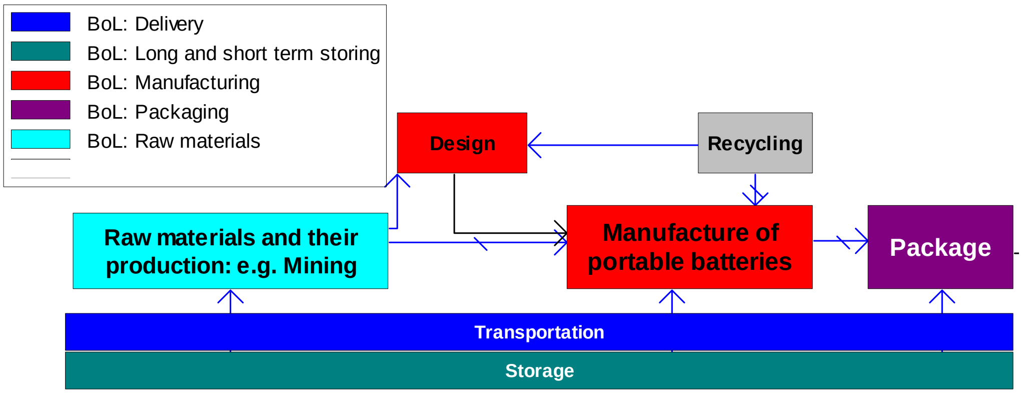


Figure 13. Portable batteries' begin of life cycle can be evaluated for assessment and management of life cycle. Illustration made with the help of SULCA software's colour modules for BoL.

With the help of flow sheet figures 13, 14 and 15 is opened what kind of issues the life cycle data acquisitions could include regarding Beginning of Life cycle (BoL), Middle of Life cycle (MoL) and End of Life cycle (EoL). Aim is to open the issues related to the life cycle data in BoL, MoL and EoL and its usability for end-of life decisions.

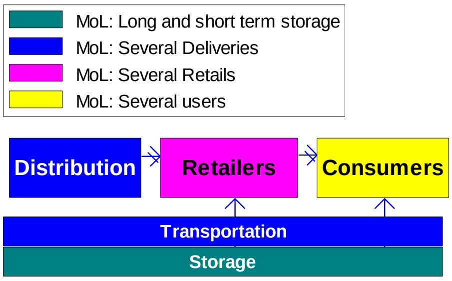


Figure 14. Portable batteries' middle of life cycle can be evaluated for assessment and management of life cycle. Illustration made with the help of SULCA software, a LCA tool.

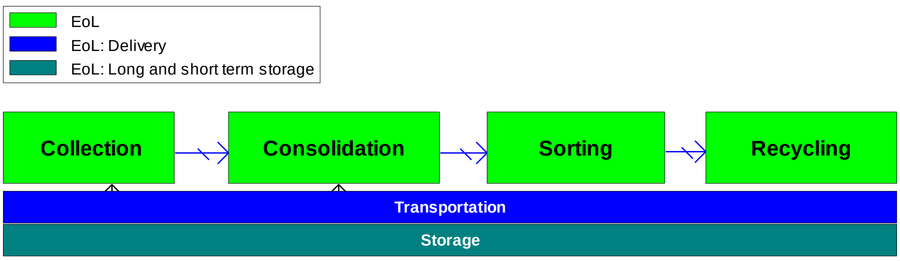


Figure 15. Portable batteries' end of life can be broken down for assessment and management of life cycle. Illustration made with the help of SULCA software.

All the phases described above could be further opened to companies and their unit processes involved to each module box. Consequently, the resource and waste flows of them can be determined. Also there can be several companies or processes operating in each module. Thus, the system forms a complex value chain or value network for example for a certain consumer portable battery (e.g. Ni-Mh portable rechargeable battery). Thus, the possibility to follow-up and gather the information of the life cycle to some extent throughout the whole value chain can bring valuable and beneficial information. In addition, there is possibility to form efficient and sustainable new solutions and business concepts.

6.4 Finnish example of EoL -phase of consumer portable batteries

The legislation requires that all separately collected recognisable used batteries and accumulators should be pre-processed and recycled by using BAT which takes into account the human health and environment. In Finland there is one such kind of company for batteries and accumulators called Akkuser Oy (www.akkuser.fi). They for example handle collected portable batteries and accumulators of Recser Oy (http://www.recser.fi/en/?Home_page). [Toppila 2011, Akkuser 2012]

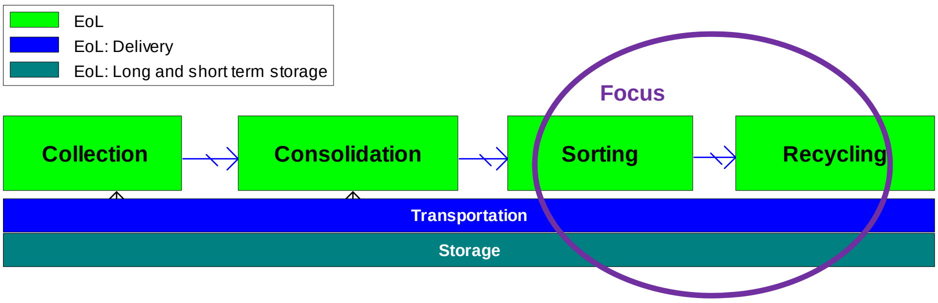


Figure 16. The focus in the example of the company which operates in EoL –phase of consumers' portable batteries.

In the following Figure 17 is description about end of life phase of consumer portable batteries in Finland in relation to Akkuser company operations and processes. The aim is to reveal the importance and on the other hand the challenges related to collection, consolidation and recycling of portable batteries. Thus, to show how a company is receiving, sorting, tracing (as far as possible) and then further processing the portable batteries and other materials with them. Furthermore, a LCDA project's test run of consumer portable batteries with RFID tags is done.

The capacity of the company is in such level that it could process and recycle all the batteries and accumulators collected in Finland when possible. The process includes restoring materials of batteries for reuse. The company uses a recycling method called Dry-Technology®, which they have developed. It represents the latest technology which has raised the degree of material recovery from batteries and accumulators. Furthermore, the handling of their reactive materials is safe. The company receives stores and sorts all types of portable accumulators and batteries such as Ni-Mh, Li-ion, Ni-Cd, and lead accumulators and alkaline batteries. After their processes they send them in respective specific form of existence for continued handling, e.g. to foundries and other co-operation partners. The company also handle and recycle WEEE-items according requirements. [Akkuser 2012]

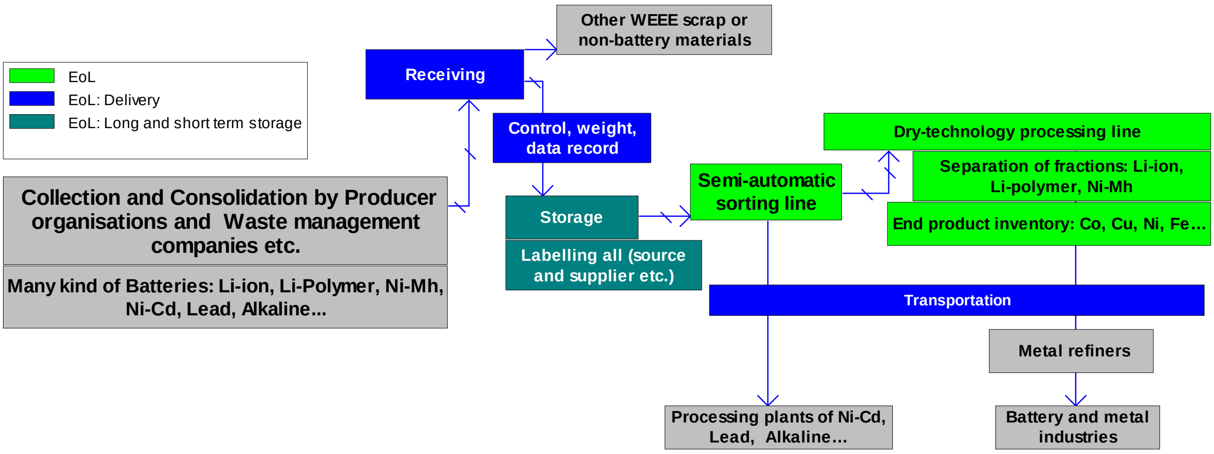


Figure 17. Finnish example of EoL phase value chain and company operations of consumer portable batteries. Illustration made with the help of SULCA software, a LCA tool. Core operations of company marked with colours. [Akkuser 2012]

In the above Figure 17 the process with consumer portable batteries of the company starts with the receiving phase, where all the received materials such as Li-ion, Li-Polymer, Ni-Mh, Ni-Cd, Lead and Alkaline batteries are weighted and data recorded. After this is storing of all raw and finished material and labelling of them in order to be able to trace the source and supplier. The next step is that portable batteries etc. are separated based on the chemical and/or metal content with two semi-automatic sorting lines. In this phase such as the Ni-Cd, Lead, Alkaline batteries are delivered to metal industries to appropriate processing plants (co-operation partners). On the other hand the separated fractions of Li-ion and/ or Li-polymer and Ni-Mh portable batteries continue to the Dry-Technology® line. There is a two phase crushing and the process is same for different fractions:

- Dust collection and returning it into product
- Magnetic iron separation

Next step is the end product inventory of Co, Cu, Ni, Fe materials and their delivery to metal refiners for battery and metal industries to be reused. [Akkuser 2012]

6.4.1 LCDA test run of consumer portable batteries with RFID tags

During the LCDA project a new low-cost UHF RFID tag was developed that works even if placed directly on a metal surface. This tag was designed to be used mainly on metal sheathed flat surfaced batteries, but could be used on other items such as circuit boards. The low tag cost is achieved by using industry standard UHF label tag manufacturing, small size and by leaving out expensive materials.

A proof of concept device was made for testing the tags on different types of batteries and for demonstrating the idea of automatic RFID based sorting for inbound materials at Akkuser company. The sorting apparatus consists of a conveyor belt that has an aperture at one end where four RFID reader antennas are fitted in an overlapping pattern. These antennas are connected to a standard UHF RFID reader. As the batteries move over the antennas the EPC ID of the tag is read. The ID is checked against a database which contains key product information such as manufacturer and chemical composition.

After the tag is read, the system knows in which bin the battery is going to. In the demo, there were three bins: Alkaline, NiMH and Li-ion. When the battery arrived at the correct position a timed trigger caused a blower to deflect it to the correct bin. For the testing a total of 551 batteries were tagged and sorted by the demo system in the first run. After the first run, batteries with faulty tags were removed from the test set. The reason for the faults was most likely excessive mechanical stress to the bond between the RFID chip and antenna structure, which was caused by the rather violent deflection method. See Table 5.

Table 5. The reading percentages of the different battery types from the two test runs of LCDA project.

First Run	Alkaline	NiMH	Li-ion
Total	174	163	214
Read	125	157	211
Read Percentage	71.8	96.3	98.6

Second Run	Alkaline	NiMH	Li-ion
Total	168	154	213
Read	136	151	206
Read Percentage	81.0	98.1	96.7

The results clearly indicate that the tags work well with the (mostly) slim Li-ion mobile phone batteries it was originally designed for. The similarly flat surfaced NiMH batteries, although generally larger, performed equally well. The alkaline test batch however, which consisted of mostly round AA and AAA type batteries, was much harder to read. This was to be expected since the tag wasn’t designed to be used on such highly rounded surfaces. The better results in the second round were due to a more careful manual placement of the alkalines so that they actually went over the reading area and didn’t roll out the line.

The results were very promising considering that the demo line was not optimal from an RFID reading standpoint. To improve the read rates two basic changes to the general design should be made. First is to narrow the read area so that the whole width could be handled by a single antenna. Second is to have two antennas at the read point; one below and one above the passing battery. A custom reader antenna should also be designed for the system instead of using generic off the self products. For an industrial grade sorter redundancy should be added in the form of additional read point. This would be similar to the one described above, except using a slightly different frequency to account for differently tuned tag-battery combinations.

Should RFID be used to identify AA type batteries or other similar items with a higher curvature, a different kind of tag should be designed. The vast majority of batteries of these form factors are alkalines, and according to Akkuser they could be automatically identified using X-ray imaging. Although very cheap, the RFID tags would probably still be too expensive to make tagging of the low cost alkaline batteries economically viable.

In summary, RFID could be used to identify batteries even at the end of their life cycle where optical methods become unreliable due to wear and dirt. The greatest hurdle in implementing RFID in battery waste handling is that a sufficient portion of manufactured batteries should be tagged. Currently none are.

In practise, in order to make even more efficient the separation of battery materials and recycling of them in the company perspective (such as in the test run) more precise information about the life cycle of portable batteries should be available. There are also such materials ending up to the company, which are not suitable for their processes. E.g. the consumers bring in collection boxes such as light lambs, medicines or small WEEE-items, which then end up to the company but are not suitable for their recycling process or are only partly suitable. [Akkuser 2012]

Recycling in general has a low degree of industrialization compared to manufacturing of new products. There are today no strong arguments for not trying to raise the industrialization of materials recycling. The recyclers are often paid by what they can extract from the waste stream, but the efficiency could be better measured in a life cycle perspective. From a society perspective the situation does not comply with common interest since our resources are limited and should be handled with care. From an ecological perspective material resources should be viewed as, on lease, in products. The accurate information about materials in the products and traceability of the product will lead to better overall resource efficiency along with producer responsibility requirements. [Luttropp et al. 2010, Saarinen 2010, Saarinen 2011, Toppila 2011a]

Thus, the better identification of portable batteries and information of their life-cycle and content is needed and will be useful in the future. With the help of this company example is revealed that the EoL -phase of portable batteries includes several issues and chain of companies' processes in order to manage, separate and handle consumer portable batteries according sustainable manner and requirements. Consequently, if such identification system could be established, which would raise the acquisition to the adequate level and pose a significant improvement in efficiency of material recognition and information in the value chain, a huge step towards sustainable management could be achieved.

7. Considerations, discussions and future needs

This chapter covers considerations and a discussion about which kind of information could be relevant in order to improve the sustainable LCDA of portable batteries based on the reviewed studies and the LCDA test run. To remind the reader, the focus of this study has been on the life cycle of consumers' portable batteries – especially in relation to their environmental performance as well as the significance of EoL phase recycling efficiency. Initially, some aspects about the RFID possibilities are highlighted, before LCDA considerations are presented.

7.1 RFID to improve life cycle information tagging

One option to improve recyclability and the overall LCDA of products, such as consumers' portable batteries, could be RFID technology as presented in chapters 5 and 6. RFID technology is suitable for a wide range of products containing a variety of materials. Thus, the tags themselves can contribute to the efficiency of recycling at different phases of a product's life cycle. The main task of RFID is to enable the identification of objects, which can be done in two ways:

- the identification of the object through additional information such as the material composition of the identified object stored in the tag's memory, or
- the identification of an object and the look-up of additional information in a database.

The short-term developments with the help of RFID are likely to extend existing pilots with others in waste handling, as well as the development of new methods for using existing tags, e.g. including new data that is useful in waste collection and disposal. The deployment of RFID as part of a general trend to improve waste handling is likely to produce behavioural changes, the emergence of new business models and even sectorial changes. In addition, the adaption of new possibilities will begin, especially those related to improved traceability and waste stream measurement. In the long term, new opportunities may be realised through innovative whole-systems approaches to waste handling and to new forms of integrated life cycle management. Thus, the transparency of a product's LCDA will be improved significantly.

7.2 Considerations about the LCDA of consumers' portable batteries

In order to improve the life cycle data acquisition of consumers' portable batteries, the following issues are significant – especially if the aim is to manage resources and recycle consumers' portable batteries efficiently. Thus, the aim is to reduce the environmental impacts and to facilitate sustainability throughout the entire life cycle:

- Follow-up of relevant product information with minimum information breakdown, with the help of information tagged to the product e.g. an RFID identifier (presented in the LCDA test run)
  - Including the recovery of the metals (e.g. copper, silver, aluminium) of RFID tags itself in the EoL
  - The attachment of an RFID tag in the manufacturing phase of a product (such as an electronic device including a circuit board or a portable battery) would improve the dialogue and the cost efficiency between design, manufacturing and recycling actions, while the drivers include the tightening requirements of EU directives (Ecodesign, WEEE, etc.)
- Including information of the product throughout the life cycle of the

  BoL phase:
  - ID of product, type of battery, type of product it will be used in, design and producer information, production year, production time/place/country, batch information, size, weight and capacity of battery, etc.
  - Materials: material content, amounts and their purity (BOM). Especially metals (such as valuable, rare and hazardous metals) and hazardous materials. Also, plastic materials and others, specified as specifically as possible (materials in cathode, anode and electrolyte).

  MoI phase:
  - Consumer guidance (safety, use, charging, recycling) and service guidance, etc.

  EoL phase:
  - Collecting, sorting, dismantling and recycling information (how to dismantle, main recycling targets, etc.).

  Also:
  - Safety, economic and environmental information (e.g. safety handling and main environmental impacts and/or emissions, materials and energy consumption, KPIs, etc.).

8. Conclusions

In the following, concluding observations are made based on the literature and the LCDA test run, with the goal to understand the life cycle of consumers' portable batteries. Thus, the scope covers especially the end-of-life (EoL) and the life cycle data acquisition (LCDA) related to the environmental performance of consumers' portable batteries.

The batteries contain reusable and valuable metals. They are as such a good material source and they should be efficiently recycled. For example, the global consumption of metals has increased by over 85% in the last thirty years. With the increasing demand, even more metals are exploited and the related environmental impacts and emissions should be even more effectively managed and reduced.

Furthermore, the collection amount of WEEE scrap is expected to be up to 85%, according to EU targets for 2019. However, such ambitious demands require several new types of action in order to be measurable as well as feasible with the operators' collection management systems in all EU countries. It is important to manage WEEE scrap and waste battery collection and end-of-life procedures according to EU directives and national laws.

In practice, in order to fulfil the regulations, requirements and producer responsibilities, there are common challenges in EU countries based on several studies. According to a Finnish study, over half of the WEEE scrap on an annual basis finds its way outside the official collection system in Finland.

The main cause of these secondary flows was recognised as being based on the positive economic value of the WEEE, whereby those operators outside the official collection system are gathering WEEE widely and are competing with the collection systems of the official responsible producers . The secondary flows of portable batteries are bound to WEEE secondary flows, but the cause mechanisms behind them are different. Around one-third of all portable batteries and accumulators are inside electrical and electronic equipment when they end up on the market. The secondary flows of portable primary and secondary batteries are often due to inappropriate and ignorant behaviour of consumers in relation to recycling practices and the official collection systems of portable batteries. The secondary flows were estimated to be over half the annual waste from portable primary and secondary batteries. These secondary flows of the official collection system have economic, social and environmental impacts in Finland as well as abroad.

Examples of studies in relation to Life Cycle Assessment (LCA) concerning consumers' portable batteries were evaluated. The LCA provides beneficial information about the potential environmental impacts of products, and thereby, how the strategic decisions and prioritisation of actions can be done whilst avoiding trade-offs in life cycle. The reviewed studies provided ideas about life cycle data acquisition of the portable rechargeable batteries and especially environmentally aware aspects about the batteries' end of life:

- The main challenge facing the portable power industry and its stakeholders nowadays is establishing a methodology to effectively quantify impacts, making battery recycling a net positive for the environment. This will require the industry to carefully assess all factors impacting end of life management, including production and process design.
- In the case of rechargeable NiMH batteries, the majority of impacts are split between the extraction and refining of raw materials for battery and charger components, and the way these batteries are recharged by the consumer. Thus, consumer behaviour plays an important role in reducing the environmental impact of the batteries. The recycling of NiMH batteries is a net positive for the environment, mainly because of the reuse of high-impact metals such as nickel.
- No single battery type has the lowest impact across the wide range of consumer applications and environmental impacts. The choice of technology, whether it is primary or secondary rechargeable, depends on the device in question and usage patterns.
- Although the results of several studies more or less agree about the lower environmental impacts of rechargeable secondary batteries compared to disposable primary batteries, these studies do not sufficiently complement each other in order to make concrete recommendations at the EU level.
- LCA gives beneficial information about the environmental impacts of consumers' portable batteries and how to reduce them throughout the life cycle. LCA demonstrates that no clear overall hierarchy between portable batteries can be defined. Clear conclusions can be drawn for a limited number of indicators, but the results are dependent on the goal and scope of the study as well as the time perspective chosen, for example.

In order to efficiently manage the life cycle of a product, its life cycle information should be gathered and updated in a way that it is possible to access the information in all phases of the life cycle. Consequently, there is the possibility to improve life cycle management with the help of unique identifiers such as RFID. Then the information breakdown over the life cycle phases can be more effectively avoided. In addition, such information, which is needed in the end-of-life (EoL) is achievable. Tags can contribute to the efficiency of recycling at different phases in the life cycles of a wide range of products, ranging from simple items to complex objects containing a variety of materials. In the short-term, developments in recycling are likely to involve extending existing pilots with others in the field of waste handling, as well as the development of new methods for using existing tags. In the long-term, the new possibilities may be realised through clever whole systems approaches to waste handling and to new forms of integrated life cycle management.

The ICT-related perspective highlights the functions of RFID, their contributions to what has come to be called the Internet of Things (IOT), and the network of systemic innovations (e.g. smart transport, smart trash, etc.) that depends on the identification of objects. The other perspective reflects the physical properties of RFID tags and the environmental perspective from which product life cycles and waste management are assessed. The difference in perspectives, together with weak integration along product and system life cycles (e.g. poor connections between design, manufacturing, marketing, use and disposal) creates a risk that neither markets nor “stove-piped” environmental and ICT-related policies will attain efficient outcomes, let alone economically and environmentally sustainable development. “Sustainability” is not just the responsibility of one producer in the supply chain. Since RFID tags contain information that do not cover only the physical product, producers can demand more of their production processes and supply chain relationships, while consumers can demand more transparency in relation to the goods they buy. When the environmental indicators of products are made more visible, producer responsibility, consumer ownership and processing of the product at the end of its life can become shared responsibilities.

In LCDA research, a proof of concept device was made for the test run of the tags on different types of consumers’ portable batteries. The test run demonstrated the idea of automatic new low-cost UHF RFID-based sorting for inbound materials in the EoL phase of consumers’ portable batteries. The ID was checked against a database which contained key product information. UHF RFID tags could be used to identify batteries even at the end of their life cycle, when optical methods become unreliable due to wear and dirt. The greatest hurdle in implementing RFID in the consumers’ portable battery waste handling is that a sufficient portion of manufactured batteries should be tagged, which is currently not the case. If such an identification system could be established, which would raise the acquisition to an adequate level and represent a significant improvement in the efficiency of material recognition and information on the life cycle, a clear step towards sustainable management could be achieved and a lack of design for recycling could be avoided.

Thereby, the important considerations in the life cycle data acquisition of consumers’ portable batteries covered are:

- The need to follow up on relevant product information with minimum information breakdown with the help of identifiers, such as an RFID tag.
- The attachment of an RFID tag in the manufacturing phase of a product (such as a portable battery or an electronic device including a circuit board) would improve the dialogue as well as the resource and cost efficiency between design, manufacturing and recycling actions.
- With the help of identification, it is significant to include information from Beginning of Life Cycle, Middle of Life Cycle and End of Life Cycle. This can be information such as detailed data about the product, e.g. material content or bill of materials (valuable metals and hazardous materials), ID number, design or production information. In addition, data such as user phase information and consumer guidance could be helpful as well as details about collection, sorting, dismantling and recycling. Moreover, there could be key information on the safety issues, environmental indicators, Key Performance Indicators and main environmental impacts.

With the help of unique identification of products, there is an opportunity to truly connect a product’s end of life information to its design and manufacturing and vice versa, which will facilitate sustainability of the whole life cycle and a more transparent value network of consumers’ portable batteries. Furthermore, entirely new business concepts and sustainable service concepts can be enabled.

References

Akkuser. 2012. Meeting with Arto Erkkilä and Tommi Karjalainen. 5th of June, 2012. www.akkuser.fi.

Antikainen, R. (Ed.). 2010. Elinkaarimetodiikkojen nykytila, hyvät käytännöt ja kehitystarpeet. Reports of Finnish Environment Institute 7/2010. 83 p. ISBN 978-952-11-3734-1 (pdf), 1238-7312 (print), 1796-1637 (online). www.ymparisto.fi/syke/publications.

Antikainen, R., Seppälä, J. (Ed.). 2012 Elinkaarimenetelmät yrityksen päätöksenteon tukena. FINLCA-hankkeen loppuraportti. The Finnish Environment 10/2012. 90 p. ISBN 978-952-11-3990-1 (pdf), 1796-1726 (online). www.ymparisto.fi/syke/publications.

Björk, A., Erlandsson, M., Häkli, J., Jaakkola, K., Nilsson, A., Nummila, K., Puntanen, V., Sirkka, A. 2011. Monitoring environmental performance of the forestry supply chain using RFID. Computers in Industry, 62, (8–9), 830–841. http://www.sciencedirect.com/science/article/pii/S0166361511000984.

Chancerel, P. 2010. Substance flow analysis of the recycling of small waste elec-trical and electronic equipment: An assessment of the recovery of gold and palladium. Technische Universität, Berlin, Doctoral Dissertation. 162 p.

Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators and repealing. Directive 91/157/EEC entered into force on 26 September 2006.

Directive 2011/65/EU (RoHS) RoHS 2 on restricting the use of hazardous substances in electrical and electronic equipment entered into force on 21 July 2011.

Directive 2012/19/EU on waste electrical and electronic equipment. Visited web links on 2013-01-20: http://eur-lex.europa.eu/JOHtml.do?uri=OJ:L:2012:197:SOM:EN:HTML.

Dittrich, M., Giljum, S., Lutter, S., Polzin, C. 2012. Green economies around the world, Implications of resource use for development and the environment. Sustainable Europe Research Institute (SERI), Vienna. http://seri.at/wp-content/uploads/2012/06/green_economies_around_the_world.pdf.

ECEUROPA WEEE Directive. Visited web link on 2013-01-20. http://ec.europa.eu/environment/waste/weee/index_en.htm.

ECEUROPA RoHS Directive. Recast of the RoHS Directive. Visited web link on 2013-01-20. http://ec.europa.eu/environment/waste/rohs_eee/index_en.htm.

ECEUROPA Waste management. Battery Directive summary. Visited web link on 2013-01-20. http://europa.eu/legislation_summaries/environment/waste_management/l21202_en.htm

Environmental Investigation Agency (EIA). 2011. System Failure: The UK's harmful trade in electronic waste. London: Earthside. 16 p. [Online]. Web page visited 2013-01-20: http://www.greencustoms.org/docs/EIA_E-waste_report_0511_WEB.pdf.

European Commission, Expert Team to Support Waste Implementation (EC ESWI). 2009. Study on the calculation of recycling efficiencies and implementation of export article (Art. 15) of the Batteries Directive 2006/66/EC. Final Report. 236 p. http://www.call2recycle.ca/wp-content/uploads/BC%20ISP%20Appendix%2025.pdf.

European Portable Battery Association (EPBA). 2010. Sustainability report. [Online] http://www.epbaeurope.net/Sustainabilityreport.html.

European Topic Centre on Sustainable Consumption and Production (ETC/SCP). 2009. What is Waste: Waste from electrical and electronic equipment. [Online]. http://scp.eionet.europa.eu/themes/waste/#6.

Interpol Pollution Crime Working Group (IPCWG). 2009. Electronic waste and organized crime, assessing the links. Web page visited 2013-01-20. 51 p. www.interpol.int/content/download/5367/45070/.../Wastereport.pdf.

ISO 14040. 2006. Environmental management. Life cycle assessment. Principles and framework. SFS-EN ISO 14040. Finnish Standards Association SFS.

ISO 14044. 2006. Environmental management. Life cycle assessment. Requirements and guidelines. SFS-EN ISO 14044. Finnish Standards Association SFS.

LCDA project report. 2011. Metropolia University of Applied Sciences, Laurikainen, A. et al. Identification Technologies in Life Cycle Data Acquisition, 28 p.

Luttropp, C., Johansson, J. 2010.Improved recycling with life cycle information tagged to the product. Journal of Cleaner Production, 18, 346–354.

Malmström, P. 2012. Federation of Finnish Technology Industries (Teknologiateollisuus http://www.teknologiateollisuus.fi/en/), Meeting with Peter Malström, on 2nd of June, 2012.

Monier, V., Hestin, M., O'Connor, C., Anderson, G., Neubauer, A., Sina, S., Homann, G., Reisinger, H. 2011. Implementing EU Waste Legislation for Green Growth: Final Report prepared for European Commission DG ENV. European Commission DG ENV.

Mudgal, S., Tinetti, B., Kong, M.A., Pahal, S. 2010. Study on "Elements for an impact assessment on proposed options for capacity labelling of portable primary batteries in the context of the Batteries Directive 2006/66/EC. Bio Intelligence Service. 113 p.

Mudgal, S., Guern, Y., Tinetti, B.,Chanoine, A., Pahal, S., Witte, F. 2011. Comparative Life-Cycle Assessment of nickel-cadmium (NiCd) batteries used in Cordless Power Tools (CPTs) vs. their alternatives nickel-metal hybride (NiMH) and lithium-ion (Li-ion) batteries. Final Report of European Commission. Bio Intelligence Service. 298 p.

Olivetti, E., Gregory, J., Kirchain, R. 2011. Massachusetts Institute of Technology, Life cycle impacts of alkaline batteries with a focus on end-of-life. 110 p.

Ongondo, F.O., Williams, I.D., Cherrett, T.J. 2011. How are WEEE doing?: A Global Review of the Management of Electrical and Electronic Wastes. Journal of Waste Management, 31, 714–730.

Pesonen, N., Jaakkola, K., Lamy, J., Nummila, K., Marjonen, J. 2009. Smart RFID Tags, Platform tolerant and platform adaptive tags. In: Turcu, C. (Ed.). Development and Implementation of RFID Technology. Ch. 9, Sec. 2. InTech: Rijeka, Croatia, pp. 159–166. ISBN 978-3-902613-54-7. http://www.vtt.fi/files/research/mel/smart_rfid_tags.pdf

Popita, G-E., Popovici, A., Hategan, R. 2010. Selective Collection of Used Portable Batteries, ProEnvironment 3(2010) www.proenvironment.ro, p. 278–283.

RAND Europe. 2012. Working Paper of Smart trash: Study on RFID tags and the recycling industry, Interim Report (D3). Smart 2010/0042. 255 p.

Saarinen, E. 2010. Sähköromulle tulossa kova keräystavoite. Uusiouutiset, 21, 22–23.

Saarinen, E. Minne katoavat sähköromut ja akut. Uusiouutiset, 22, 4–6.

Seppä, H. 2009. Etätunnistusteknologian kehitys meillä ja maailmalla. Tekes katsaus 249/2009. 38 p.

Teknologiateollisuus. Paristo- ja akkudirektiivi. Directive on batteries and accumulators and waste batteries and accumulators. Visited web link 2013-01-20. http://www.teknologiateollisuus.fi/fi/palvelut/paristo--ja-akkudirektiivi.html.

Teknologiateollisuus. RoHS-direktiivi (RoHS sekä RoHS II). Tiettyjen haitallisten aineiden rajoittaminen sähkö- ja elektroniikkalaitteissa – The Restriction of the use of certain Hazardous Substances in Electrical and Electronic Equipment. Visited web link 2013-01-20. http://www.teknologiateollisuus.fi/fi/palvelut/rohs-direktiivi.html.

Teknologiateollisuus. WEEE- direktiivi. Sähkö- ja elektroniikkalaiteromu (tuottajavastuu) – Waste Electrical and Electronic Equipment. Visited web link 2013-01-20. http://www.teknologiateollisuus.fi/fi/palvelut/weee-direktiivi.html.

Toppila, A. 2011a. Jätehuollon tuottajavastuun jätevirrat. Esimerkkejä Sähkö- ja elektroniikkalaitteet sekä kannettavat paristot ja akut. Jyväskylän Yliopisto, Kauppakorkeakoulu, Pro gradu-tutkielma, 09/2011. 94 p.

Toppila, A. 2011b. Sähköromun keräyksessä suuria ongelmia. Uusiouutiset, 22, 24–25.

Ympäristöhallinto. 2013. Akut ja paristot ja tuottajavastuu. [Online].Web page visited 2013-01-20: http://www.ymparisto.fi/default.asp?contentid=426735&lan=FI.

Zoeteman, B.C.J., Krikke, H.R., Venselaar, J. 2010. Handling WEEE waste flows: on the effectiveness of producer responsibility in a globalizing world. International Journal of Advanced Manufacturing Technology, 47, 415–436.