Journal of Cleaner Production xxx (2009) 1–9

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Improved recycling with life cycle information tagged to the product

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ARTICLE INFO

Article history:
Received 22 August 2008
Received in revised form
27 October 2009
Accepted 27 October 2009
Available online xxx

Keywords:
Recycling efficiency
EcoDesign
Waste electrical and electronic equipment
WEEE
Design for environment
Product development

ABSTRACT

Rising demand for product means that the recycling of materials is now more important than ever, saving a lot of energy embedded in materials, thus reducing CO_2 emissions. Providing relevant information can raise the recycling efficiency, which is too low at present.

A Recycling Information Matrix (RIM) concentrating on Waste Electrical and Electronic Equipment (WEEE) is suggested in order to facilitate and improve materials recycling. Each RIM focuses on a recycling target, and for each type of product a WEEE vector is constructed. The WEEE vector contains nine hexadecimal numbers where core-recycling info is stored.

The WEEE vector can provide direct recycling information escorting the product. Another possibility is to individually identify every single product via RFID technology, giving the potential to look for relevant recycling information in databases. This offers the opportunity to add waste-handling information *after* the product has entered the market. This would be useful, for example, in tracking substances regarded as non-toxic at time of production which might later be proven to be the opposite.

This paper is based on study visits at recycling facilities in Sweden and on many student EcoDesign projects including disassembly of consumer products. Research is done on a focused disassembly of dishwashers and on a polymer recycling experiment at a recycling plant for freezers and refrigerators. Possible escort memories are also studied, especially Radio Frequency Identification Devices (RFID).

1. Introduction

Recycling is coming more and more into focus as a source of material for products. In Western countries a new household appliance is usually an exchange for an out phased one of the same kind. In developing countries, however, purchasing a refrigerator is often connected to welfare improvements. In Europe two major EU directives guide the recycling process; Directive of End of Life Vehicles (ELV) [1] and Directive of Waste Electrical and Electronic Equipment (WEEE) [2]. Both directives focus on the input side of recycling. ELV states that by 2015 end of life automotives should be recycled to 95%. WEEE states collection goals on how much to collect on a per capita basis. The output side of recycling is sparsely addressed.

In addition the WEEE Directive sets requirements for pre-treatment and recycling operations. It is also connected to the Directive (2002/95/EC) on Restriction on Hazardous Substances (RoHS), which sets limits for the content of certain hazardous substances in products (covered by WEEE). Incorrect handling of WEEE is already putting human health at risk. Swedish newspaper Dagens Nyheter reports from Longtang in China, where lots of WEEE is ending up in manual dismantling operations with dangerous and toxic environments as a result. The reason is said to be found in the fact that it is up to ten times cheaper to export WEEE than to take care of the waste - for example in the US [3]. Yang et al. reports from WEEE handling in China and concludes that “Informal WEEE recycling is currently the dominant practice”[4]. Even if Sweden does not export WEEE but the non-magnetic metal fraction after shredding is mostly exported containing an unknown mix of copper, aluminum, stainless steel and residues.

These waste products contain valuable material such as copper, gold etc. For example a dishwasher contains approximately 1 kg copper, giving a copper content of 2–3% [5]. The economic level for a copper mine is a copper content of 0.3–4%. For example Boliden reports for their mine at Aitik an average copper content of 0.36% in the ore [6].

In Sweden during 2007 160 000 tons of WEEE was collected according to statistics from El-Kretsen one of the companies responsible in Sweden for WEEE. This makes 17.5 kg/person [7]. However, there are no openly available statistics on, for example, how much copper this represents, or any open statistics on how much copper is extracted out of this waste stream. The conclusion is that copper material recycling efficiency is commonly unknown. To illustrate with a metaphor: -*We measure what the cow eats but forget to measure what the cow produces.*

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doi:10.1016/j.jclepro.2009.10.023

A factor still sparsely addressed is the embedded energy connected to high-level materials such as metals. Boustead & Hancock report as much as ten times the energy requirement for electrolytic copper from ore compared with electrolytic copper from impure scrap (p329 ref [8]). Rules of thumb for mechanical engineering give a factor 7 for aluminum and a factor 3–4 for steel depending on quality. Thundal reports (from several references) the following percentage levels for re-melted/primary energy requirements: Aluminum 4%, Copper 13%, Steel 38%, Magnesium 2%, Titan 41%, Nickel 11%, Zinc 28% [9].

The WEEE directive places the producer responsibility 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/import from outside of a certain country and then the producer responsibility is transferred to the retail chain. Fig. 1 presents the current situation. Retailers have obligations to pay for the recycling treatment. In Sweden El-Kretsen and others organize the process and handle the cash flow involved. The waste treatment companies in the end of the process are paid with what they can extract from the waste stream.

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 - the so-called free riders. 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.

WEEE-organized retailers pay for something impossible to control Fig. 1.

Today retailers transfer these costs to their customers so in the end customers pay for something they don't get - namely an effective recycling on a high level of efficiency. From a society perspective, with reference to Fig. 1, housekeeping with resources is a matter of prosperity to mankind.

1.1. Recycling efficiency

The WEEE directive is implemented in various ways, from country to country, and even within the same country one can spot different approaches on WEEE recycling. In Sweden some recycling sites disassemble before shredding, others fragment first and sort afterwards. Different machines are used such as hammer mills, hurricane machines, ring mills or roller knifes. Sometimes WEEE is processed exclusively in so-called campaigns with handpicking after shredding. Many companies do a good job but there is no general surveillance on the outcome of recycling. Recycling efficiency is generally speaking unknown. This problem can be solved by preparing products for recycling in the design phase, and to industrialize the end of life process of products. Design can facilitate disassembly pre-steps before shredding and different fractioning processes can raise the outcome and purity of valuable fractions.

Recycling in general has a low degree of industrialization compared to manufacturing of new products, and there are today no strong arguments for not trying to raise the industrialization of materials recycling. The efficiency is not measured in a life cycle perspective and recyclers are often paid by what they can extract from the waste stream. From a society perspective this 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.

One cannot expect citizens to know about this, and even if they do, people don't always do what they know is right. One could say that the market shifts the cost to us, the customer, and we shift it further on to the recycling system. Although as citizens we pay, the material resource is partly wasted. The economic rationality creates this system and as long as it is felt that we are paying, everyone is content. To use another metaphor: *we pay for beef at lunch without knowing it is mule*. In this case the taste of the meal might reveal the fraud but the wastefulness with valuable materials in WEEE must be seen as a society responsibility.

1.2. Recycling information

With planning and industrialization, recycling could be much more effective. This can be done via information following the product, making a first sorting on the main recycling target possibilities. Other pieces of this same information can be used for preparing and planning the rest of the process. If a pre-step before standard fragmenting is beneficial, this step can be guided by attached information. The authors of this paper have earlier suggested a conceptual metaphor, Material Hygiene (MH), for treatment of materials in the product life cycle. MH is associated with treatment of provisions like meat, vegetables, canned food etc.; unbroken chain of a cold environment; origin of production; list of contents etc. The concept of material hygiene is focused on optimizing the reuse of materials in products with the following definition [5]:

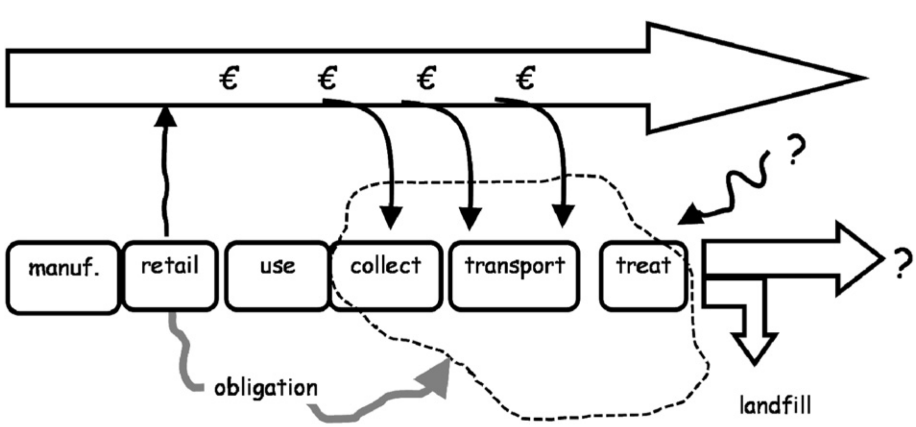

Fig. 1. WEEE-organized retailers pay for an obligation they cannot monitor.

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Material Hygiene (MH) is, in every step of the product life cycle, to act towards larger amounts and increased purity of useful material obtained from recycling, to be used on the same quality level as before or degraded as little as possible.

A high level of material hygiene means a high degree of effectiveness in materials use. The necessary changes towards higher MH should be implemented early in the design process when design freedom still exists. Additional changes during the production phase will only be of a superficial nature [5]. The goal is to design products in such a way that as much as possible of used materials is kept in the eco-cycle and used in the most effective way.

However, the first step towards higher MH is to provide information for present products that will be useful in the end of life phase. Without a good picture of present recycling efficiency, it is not possible to measure the benefit of future design efforts towards higher MH efficiency. Product Life cycle Management (PLM) is a new concept where product information and data is gathered and organized in such a way that all the necessary information concerning a product is available during the whole life cycle of the product. This requires a complex set of Information Technology solutions where end of life data is just a small part.

An important application is the Aerospace industry where each aeroplane has its own identity as well as all exchange parts. It must be possible in maintenance to have a total view of which parts are exchanged with what new parts. In complex products information requirements for end-of-life products can be crucial and auto identification is an important means to reach this goal [10]. A common problem in PLM is the loss of information. The lower the value of the product, the more information is lost. Especially during use phase the information available decreases rapidly. Thomas et al. states that information technology can reduce both life cycle information loss and transaction costs [11].

1.3. Storing recycling information

Recycling information must be expressed in such a way that it is possible to visualize in the end of life phase. 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 visibly written on a sticker in common language. The information can be coded in a bar code sticker or programmed into a Radio Frequency Identification Device (RFID). In this second case the information must be coded in a systematic manner that can be understood by the work force at the recycling plant. Wäger et al. suggests four precautionary measures to avoid introducing adverse environmental effects from the RFID tags themselves [12]:

- Use in closed loop systems, i.e. reusable containers
- No tagging of products with short life span
- EcoDesign labels to avoid the use of both toxic or hazardous materials in the labels
- Using label material adapted to the products they are attached to

In order to adapt to present 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 but in order to get a robust system the most basic information is suggested to stay inside 36 data bits. The term escort memory is custom for all possible memory that follows a product and can be anything from a piece of paper to an RFID.

Embedded memory is a special case of escorting memory inside a product, like Random Access memory (RAM) or Read Only memory (ROM) inside a computer. These memories, together with text or bar codes on the casing, the manual etc. are all different escorting memories.

2. Method

A model is proposed on how 9 hexadecimal numbers could store the most basic recycling information. This is based on several pillars:

- A lot of experience from disassembly of small household appliances is gained from an EcoDesign course given at KTH and elsewhere, recurrent since 1996. In this course approximately ten different products are always disassembled and analyzed. Improvements are then proposed by students on performance in manufacturing, use and end of life.
- Earlier work is made by Luttropp on disassembly and structure of products [13].
- Johansson has proposed a model platform for the concept of Material Hygiene (MH)in his thesis [14].
- An LCA is made on the environmental benefit of a pre-step operation compared with standard procedure today [15].
- A survey is made by Luttropp on available technical means such as. RFID to store the proposed information structure.

3. What does the scrapper want to know?

When a product reaches end of life two options occur. If the product is still functioning upgrading or repair is a possibility. If the product is obsolete the standard main procedure for WEEE treatment is fragmenting. A lot of research is done on end of life 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 [10].

In this paper the main focus is on materials recycling, when upgrading, repair etc. are not an option. When a scrapping product reaches the treatment plant a decision is made on how to treat the product. If it is a product containing something hazardous this is removed as a pre-step according to legislative regulations. In this paper pre-step means actions and processes taking place before shredding, and post-step means actions and processes taking place after shredding. In order to handle the waste product effectively a correct set of pre-steps and post-steps is essential. In order to do this properly certain amounts of information is needed. If the product contains something valuable this is can also be removed as a pre-step. This pre-step is sometimes done by unauthorized persons with connection to the transport chain or by nightly visits from burglars on scrap yards handling WEEE. The goal is then to extract valuable material and deliver it to the black market. To treat a WEEE-product effectively in the scrapping situation there are a few important things to know:

- How do I penetrate this product and what is the correct direction and means?
- Who is paying, how much, and how?
- What will I find?
- How do I identify valuable and/or hazardous substances?
- What is the correct and most effective recycling sequence?

From a recycling point of view, a more material oriented view is beneficial. The concept of Material Hygiene (MH) points out the importance of a more industrialized recycling process. In a MH

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dominated end of life process the outcome of the material is in focus [5].

4. Technical means for escort memories

The trivial way to have an escort memory is to publish the information in common language, or coded, sending it along with the product as a manual or as a sticker on the product. A second possibility is to use a common bar code for example EAN-13. This is a bar code in 12 decimal numbers where the first two are a land code, with Sweden as 73. The next ten numbers give a possibility to express information coded in ten decimal numbers. Code 128 is another bar code standard with eight ASCII figures for each position. Yet another possibility is to use Radio Frequency Identification devices (RFID). A broad description of RFID and its implications is given in RFID Sourcebook [16].

4.1. Radio frequency identification as escort memory

RFID tags can be active or passive. The active tag has a power source included. The passive tag gets power from a magnetic field on the correct frequency. This energy is used for sending back the tag information, a row of binary digits. In this paper we only discuss passive RFID tags. According to the RIKCHA project all RFID systems can be characterized by the following three features [17]:

1. *"Electronic identification: The system makes possible an unambiguous labeling of objects by means of electronically stored data."*
2. *"Contactless data transmission: Data identifying the object can be read wirelessly through a radio frequency channel."*
3. *"Transmit when requested (on call) A labeled object only transmits data when a matching reader initiates this process."*

"BRIDGE (Building Radio frequency IDentification solutions for the Global Environment) is an Integrated Project funded by the European Commission. The objective of the BRIDGE project is to research, develop and implement tools to enable the deployment of RFID and EPCglobal Network applications. The project will develop easy-to-use technological solutions for the European business community including SMEs, ensuring a basis for collaborative systems for efficient, effective and secure supply chains." [18] GS1 and Logica CMG report from a recent study that …"In 2007 almost 80% of end users will invest in RFID, and average volumes for both tags and readers are increasing compared to 2006. This is mainly driven by a small number of companies that will purchase more than 1 Million tags and more than 50 readers, which indicates large scale implementations. We expect these implementations in 2007 to be in baggage tagging in aviation and item-level in retail [19]. Typically three different frequencies are used for Radio Frequency Identification devices (RFID) or RFID tags, Low Frequency (LF) 125–134 kHz, High Frequency (HF) 13.56 MHz and Ultra High Frequency (UHF) 865–868 alt. 915 MHz. The positions of these frequencies according to other radio frequencies are visible in Fig. 2.

The information in an RFID-tag is stored in binary code. Eight bits together is called a byte. A byte can be any number between 0 (0000 0000; eight positions) and 255 (1111 1111; eight positions) in the ten decimal system that we use commonly in society. With one byte it is possible to store digits or letters according to the American Standard for Information Interchange (ASCII) which is a 7-bit code and ISO 8859 which is an 8-bit code. For example in ISO 8859-1 the decimal number 13 (0000 1101) represents Carriage Return, the decimal number 48 (00110000) represents the digit 0 and the decimal number 81 (0101 0001) represents capital Q; lower case q is decimal 113 (0111 0001). Normal text in a computer is built by numerous bytes where each byte represents one letter; space is e.g. decimal 32 (0010 0000). Another common representation is dividing bits into sets of four, giving a hexadecimal number 0-F for each set of 4 bit. Hexadecimal 0 is (0000) and hexadecimal F is (1111). It is essential to know if the information is to be understood according to a particular standard and if so which one. If there is no standard, a number of bits will be interpreted as a number. For example ten zero digits in a row (00 0000 0000) will be zero in any system and ten one digits in a row (11 1111 1111) will be the decimal number 1024.

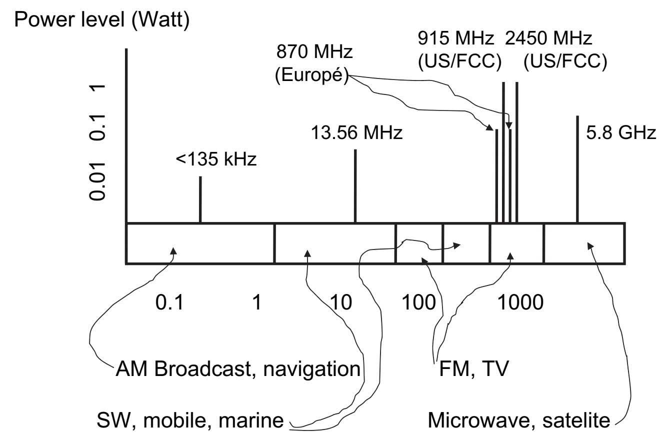

Fig. 2. Worldwide frequency allocations for radio frequency identification [17].

4.1.1. Low frequency (LF)

An LF tag typically uses 125 kHz, one of the oldest frequency standards. Used code standards are for example EM 4100, EM4550 (EM Marine), T5557 (Amtel) or Hitag (Philips). EM4102 is a common and widely used standard for access control systems with cards or key-tags. Typically 40 data bits are free for users, giving a possibility, for example, to store a ten digit hexadecimal number. Example of common properties:

- Reading distance app. 2 m
- Robust and simple technique
- The signal penetrates most materials
- Can only read one tag at a time

4.1.2. High frequency (HF)

An HF tag typically uses 13.56 MHz and ISO 14443 for communication. Such a tag has a few bytes for a unique serial number and a few kilobytes for information. This type of tag is common in different types of smart cards. Example of common properties:

- Reading distance app. 1 m
- The signal does not penetrate liquids
- Well standardized
- Can read several tags

4.1.3. Ultra high frequency (UHF)

An UHF tag typically uses 865 MHz or 915 MHz (USA). GS1 has defined an Electronic Product Code EPC defining a standard present in more than 140 countries. EPC defines a 96 bit memory area in four fields. The UHF tag with EPC has potential to dominate product labeling in the near future. Example of common properties:

- Reading distance 3–6 m depending on surrounding environment
- The signal does not penetrate liquids

- Low price on tags
- Can read several tags

4.2. EPC standard

The international standards organization GS1 has defined a standard for RFID tags called Electronic Product Code (EPC). This code prescribes that the tag should contain exactly 96 bits divided into a number of fields according to EPCglobal p 21 [10]. The first field is always an 8 bit long header defining overall length, identity type and structure of the EPC Tag Encoding. Depending on the value of this first field the rest of the tag information should be read according to a specific standard. For example a hex value of 30 (0011 0000) indicates a Serialized Global Trade Item Number (SGTIN). The SGTIN-96 is a five field standard, compliant with EAN.UCC, identifying a consumer product sees EPCGlobal p 26–29 [19]. This tag then is typically a consumer product e.g. a box of corn flakes see Fig. 3.

If the first 8 bit mandatory field in the EPC standard has a hex value of 35 (0011 0101) it is a General Identifier (GID-96) which is a standard for independent identification and can be used for individual identification of more or less any object on earth (see EPCGlobal p 25 [19]). In this case the 96 bit area is divided in four fields according to the GID-96 specification (see Fig. 4). Together with the Object naming service (ONS) information on a specific object can even be located via the internet.

5. Information structure

There is a lot to gain in using the present standard EPC, which gives two unique possibilities to handle recycling information either via a field in the tag itself or via a product unique id and a recycling information database.

5.1. Product ID and a recycling database

Developments in the manufacturing industry are moving towards Product Life cycle Management (PLM). In this concept all information - from early phases of design up to end of life information - is stored in databases that are reachable via the Internet. An EPC tag on the product displays the product identity and an Object Naming Service (ONS) reports where to find relevant information for exactly this product on the Internet; like a giant switchboard.

Kiritsis et al. state that the life cycle oriented production needs, in the logistic point of view, defined information for all logistic aspects in each station of the product along the value chain. Research projects (like MASCADA, IROMPS, AIKUL, LOCOMOTIVE, INTRAWOOL and AEOLOS) explore concepts for optimizing logistic processes by using multi-agent software systems or other similar respectively more strategic oriented methods. The aim is to develop an 'intelligent product', which means that each product is able to negotiate its own destiny in the logistic process chain. PROMISE will use these experiences with a special focus on reverses logistic and EOL aspects. By developing and testing intelligent methods (i.e. multi-agent systems) and EOL scenarios, PROMISE will improve the reverse logistic and EOL treatment of used products [20].

An interesting option for recycling is to store the identity of the product in an RFID according to the EPC standard as described in Section 3. The GID-96 standard opens a possibility to turn every product into an individual. The recycling information can then be stored in databases and reached by IT solutions. This solution opens up a possibility to add waste handling information after product sales. Substances regarded as safe at time of manufacturing may later be proven as hazardous. This new information can then be added in a recycling information database. The GID-96 standard is then used to identify a unique individual product. The system then can find corresponding recycling information in the relevant database.

0001 0000 to 0010 1110	10 to 2E	NA NA	Reserved for Future Use
0010 1111	2F	96	DoD-96
0011 0000	30	96	SGTIN-96
0011 0001	31	96	SSCC-96
0011 0010	32	96	SGLN-96
0011 0011	33	96	GRAI-96
0011 0100	34	96	GIAI-96
0011 0101	35	96	GID-96
0011 0110	36	198	SGTIN-198
0011 0111	37	170	GRAI-170
0011 1000	38	202	GIAI-202
0011 1001	39	195	SGLN-195
0011 1010	3A		Reserved for future Header values

Fig. 3. A direct quote from the list of headers in the EPC standard showing the header value for some of the present standards EPCglobal p20 [19].

5.2. Recycling information stored directly on the product

Another interesting option is to get a special header for WEEE in the EPC see Section 4.2, making it possible to use the rest of the 96 bits in this standard for recycling information such as

- Who has the producer responsibility for this special product?
- Who has the money that will pay for the recycling?
- Who owns the extracted material? etc.

An essential MH concept is the WEEE-core. This is the electrically active part of a WEEE product. The WEEE-core is, in most cases, physically connected due to its electric functionality and the content is usually a mix of copper in cables, transformers and motors as well as Printed Circuit Boards (PCB), connectors and relays. Light bulbs and displays can also be a part of the WEEE core but sometimes these parts connect more strongly physically to the housing. The lowest separation force between the WEEE core and displays and light bulbs often occur at the cable connection. From experience the WEEE core is 1/3–1/2 of the weight.

If the relevant database is not available or if the data available is outdated, the concept presented in Section 5.1 will not work. The willingness to keep such a database updated is probably directly connected to the value of the waste product – e.g. works for aircrafts but not for hairdryers. Recycling information stored directly on the product must be regarded as more robust and possible to enforce as a mandatory requirement for market entry. To achieve high recycling efficiency a strategy is needed based on content and structure of the end of life (EoL) product. In order to comply with different escort memory standards - even a written label on the product - we suggest an EPC-WEEE tag with the same field orientation as the GID-96. The fields can be used as follows:

- The first field (8 bits) identifies this as a WEEE-tag. There are unused headers in the EPC system that might be used for this purpose (see Fig. 2).

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2.4 General Identifier (GID-96)

The *General Identifier* is defined for a 96-bit EPC, and is independent of any existing identity specification or convention. In addition to the header which guarantees uniqueness in the EPC namespace, the *General Identifier* is composed of three fields - the *General Manager Number, Object Class* and *Serial Number*,, as shown in Table 3.

	Header	General Manager Number	Object Class	Serial Number
GID-96	8	28	24	36
	0011 0101 (Binary value)	268,435,455 (Max. decimal value)	16,777,215 (Max. decimal value)	68,719,476,735 (Max. decimal value)

Table 3. The General Identifier (GID-96) includes three fields in addition to the header – the General Manager Number, Object class and Serial Number numbers.

•The *Header* is 8-bits, with a binary value of 0011 0101. 677

•The *General Manager Number* identifies essentially a company, manager or organization; that is an entity responsible for maintaining the numbers in subsequent fields – Object Class and Serial Number. EPCglobal assigns the General Manager Number to an entity, and ensures that each General Manager Number is unique.

Note (non-normative): Currently, GS1 is only allocating an integer value in the range from 95,100,000 to 95,199,999 for this number.

•The *Object Class* is used by an EPC managing entity to identify a class or "type" of thing. These object class numbers, of course, must be unique within each General Manager Number domain. Examples of Object Classes could include case Stock Keeping Units of consumer-packaged goods and component parts in an assembly.

• The *Serial Number* code, or serial number, is unique within each object class. In other words, the managing entity is responsible for assigning unique – non-repeating serial numbers for every instance within each object class code.

Fig. 4. A direct quote from EPCglobal p 25 [19].

- The second field (28 bits) can be used as a company identifier like the GID-96 (see Fig. 4).
- The third field (24 bits) can be used by the company to state who is carrying the producer responsibility, if the product is put on the national market by someone other than the manufacturer (see Fig. 3).
- The forth field (36 bits) is then open for the actual recycling information. These bits can e.g. be used to form 9 hexadecimal numbers each represented by 4 bit (see Section 4.2).

5.3. Generic recycling information model

The 36 bits in the fourth field of the WEEE tag are enough to organize a 9×16 matrix. A matrix model is proposed to optimize the use of this area: the Waste of Electrical and Electronic - Recycling Information Matrix (WEEE-RIM). The information is stored only as positions. Each position has a predefined meaning: type of product, recycling strategy, quantity, status etc. A simple example can be seen in Fig. 5. A certain product gets a WEEE vector with 9 positions where each position is a hexadecimal number 0-F.

The first column is used as a recycling target header giving a possibility to have 16 different MH scenarios. Each target has 16 information possibilities in 8 positions/columns. The WEEE-RIM is a 9×16 information possibility and each product carries a 9 element WEEE-vector containing a hexadecimal number (0-F) each number represents an information cell from the 9 columns respectively. For example header value 1 (0001) means that copper recycling is a main target for this product (see Fig. 5).

A typical vacuum cleaner present in a student project at KTH had a total weight of 3895 g and a WEEE-core of 1410 g. WEEE-core is an internal term for the parts in a product having electric connection. Usually these parts also have a physical connection making it simple to mechanically separate the often copper rich WEEE-core from the rest. A WEEE-vector made for this certain vacuum cleaner could be: (3,D,6,4,5,0,0,A,0). Actions are then supposed to be opening, sorting and then fragmenting WEEE-core and polymer fraction separately. The product is not RoHS compliant or prepared for recycling. The weight of the WEEE-core is between 1200 and 1600 g.

5.4. WEEE-vector storage

Information in the WEEE-vector must be possible to read when the waste product reaches the waste processing unit and three possibilities can be found for the WEEE vector to be stored on the product, as described in Section 4:

- It can be written on the product in writing. This is always possible for products with surfaces out of sight for user/owner such as large household appliances; cooker, freezer, refrigerator, dishwasher and washing machines. Small household appliances often have a small sticker with electric security information that might be extendable.
- It can be presented as a bar code on a sticker on the product. The proposed WEEE-RIM contains 9 hexadecimal numbers making it possible to expose in a bar code. The code 93 bar code

pos.	1	2	3	4	5	6	7	8	9
	Target	Product	Action 1	Action 2	Action 3	Alert	Hazardous	Target weight	Class
0	Resting	Not used	Not used	Not used	Not used	Not used	Not used	<5 g	Not used
1	Copper	Toaster	Cable off	Cable off	Cable off	Mercury	RoHScompl.	5-10	Recycling prepared
2	WEEE-core	Telephone	Crush	Crush	Crush	LCD		10-20	
3	WEEE-core & polymer housing	Hairdryer	Disassemb.	Disassemb.	Disassemb.			20-30	
4	Gold	Camera	Sort	Sort	Sort			30-50	
5	Polymer housing	Computer	Fragment	Fragment	Fragment			50-100	
6	Ferrous metal	Laptop	Open	Open	Open			100-200	
7	Haz. subst.	Radio						200-400	
8	etc.	HiFi	etc.	etc.	etc.			400-800	
9		CRT-TV						800-1200	
A		LCD-TV						1200-1600	
B		Mixer						1600-2000	
C		Remote						2-3000	
D		Vacuum cleaner						3-4000	
E								4-5000	
F								> 5000	

Fig. 5. This is a pedagogic example of how a WEEE-Recycling Information Matrix could look. In this example the target is separating the WEEE-core and the polymer housing. Columns 2–9 are unique for this target. Another target can have a totally different set of columns 2–9.

standards offers eight ASCII figures which is more than needed for the proposed WEEE vector.

- It can be stored in an RFID. An LF tag (see Section 3) offer ten hexadecimal numbers which is enough for the WEEE vector. An HF tag offer far more memory than needed. With such a tag also specified chemical information can be stored according to REACH the new EU legislation on chemicals. An interesting possibility is to use UHF tag and ask the standardization organization for a unique EPC header (see section 3) and then use the next three fields for recycling information.

6. The dishwasher case

6.1. Recycling structure of a dishwasher

In a case study made by the authors 14 dishwashers were disassembled showing a possibility to enhance material outcome via a pre-step copper fraction extraction. The copper content of a typical dishwasher is [5]:

700 g Circulation pump motor
100 g Drain pump motor
100 g Wiring
100 g Electronic components

These parts are connected electrically and this way forming a copper or WEEE-core. There are two options to disassemble this copper core: before shredding when the product still is undamaged or after fragmenting. If the product is directly fragmented without any pre-step, the motor must be handpicked on the ferrous fraction belt. Due to the transformer plates in the circulation pump motor, this part follows the magnetic fraction. The rest of the copper core can end up in several boxes. For example wires can form an airy ball called angelic hair and end up in the light non metal fraction called fluff or After Fraction Residue (AFR). Before fragmenting the copper core can easily be removed after a few minutes of manual work [2]. A copper price of 4500 $/ton (London Metal Stock Exchange, 2009-05-04) is a strong incentive to extract as much copper as possible. One year ago it was 8500$/ton and this price might be back quite soon.

6.2. Recycling information matrix for dishwashers

For the dishwasher a copper target is beneficial, [5]. 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 Fig. 6.

Based on the WEEE-RIM in Fig. 6, a WEEE vector for a specific dishwasher can be set. 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 copper core can preferable be accessed from the bottom in quadrant number 4; which is low, right and close to the front. (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.

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	Transforme r	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	

Fig. 6. This is a possible WEEE-Recycling Information Matrix for dishwashers.

- It is prepared for a pre-step dismantling operation before shredding with a potential of 95% of copper fraction yield. (Classification of dishwashers visible in column 9 is described more extensively in ref [5]

Comment: A dishwasher contains approximately 1 kg of copper and the main target is the large pump motor containing approximately 700 g copper. If this motor can be removed in a pre-step before shredding operation, additional copper will join. The inside of a typical dishwasher can be accessed from the back or from the bottom. With either the back or the bottom as reference a rough positioning of, in this case the large pump motor can help to position the dishwasher correctly for an automated or semi automated dismantling operation. If the pump motor is physically strongly connected to the rest of the copper fraction in the dishwasher a 95% copper recycling efficiency can be reached see [5].

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. The WEEE vector for small household appliances can look quite different. Such products usually have a WEEE-core consisting of wiring, printed circuit boards, small electrical motors, connectors and transformers. This core is often surrounded by a thermo set polymer housing. If such a product is crushed two typical fractions occur: the WEEE core forming an electronic cotton waste and plastic pieces from the housing. A WEEE vector for such a product can be made with help from the WEEE-RIM in Fig. 6. The header now is hexadecimal value 2 (0010) indicating a recycling strategy of separating WEEE core and polymer housing. The hexadecimal value of column 8 shows in this case the weight of the WEEE core. A typical hairdryer would then have the WEEE vector in hexadecimal value 2D1200130 (nine hexadecimal numbers). This information should be read:

- Main recycling target is WEEE core and housing polymer.
- It is a hairdryer.
- First step after waste collection is to cut off the cable in order to facilitate sorting and transporting logistics. Containers full of small products still with their cables attached easily make a terrible tangle. Products and cables together make a solid body hard to handle in sorting etc.
- Second step in processing is crushing or cutting the housing, making sorting in the preferred two fractions possible.
- The product is RoHS compliant.
- The WEEE-core weight is approximately 300 g.

Comment: These two examples of WEEE-vectors are just examples with a pedagogic purpose to explain the approach. Before implementation is possible more research and experiments must be done.

7. Conclusion

This work is based on long experience of waste products, especially small household appliances, starting before the implementation of the present WEEE directive. The WEEE-RIM is just a conceptual approach to show the potential of the proposed information system and is of course influenced by the present recycling system. More research is necessary in order to fully make use of the system. The real benefit of the proposed system can only

Please cite this article in press as: Luttropp C, Johansson J, Improved recycling with life cycle information tagged to the product, J Clean Prod (2009), doi:10.1016/j.jclepro.2009.10.023

be estimated, due to the lack of reliable recycling efficiency information available for comparison purposes today.

The proposed information must be stored in a standardized and simple manner. UHF tags are cheap and there is a worldwide standard available. The simplest and most out of the way concept is to copy the GID-96 field orientation and just switch field number four, the last 36 bits, for specific recycling information. The second field holding manufacturer id can be similar and the third field can be optional for id of producer responsibility. The first field the header must be assigned with a header id according to the EPC standard. Keeping information short like this makes it possible to use all the other information options; bar codes etc. The possibility to store recycling information in escort memories has the potential both to raise efficiency and to monitor WEEE recycling. If all products were tagged according to the EPC and the GID-96 standard, all necessary information could be present at scrapping of this specific individual product. This system also gives a possibility to later add new information on e.g. toxic substances in the product not observed at time of manufacture.

During use phase, the individual identity of products can be used in service work. It is easy for the service man 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. Further potential with this concept is the possibility to monitor transportation of WEEE and to send the bill to the correct address. The efficiency of WEEE recycling can also be measured. In the present situation, where recycling costs are financed by what the scrappers can extract, we have no possibility to monitor our investment or the efficiency of the treatment. 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.

The PLM concept has a lot of potential but the necessary IT volume is immense and the possible loss of information can be a severe problem. Materials' recycling is the very last phase of a product when the product value is low. The information loss is probably directly connected to the attached product value. This last element speaks for a simple recycling tag like the WEEE vector as presented in Section 5.3 attached directly to the product. In this case the information is always present at the right time at the right place.

Acknowledgement

This work is funded by Nordiska Ministerrådet (NMR) in Det nordiska miljöhandlingsprogram 2005–2008. Project title is Märkning för effektivare hantering av WEEE- Produktmärkningens betydelse för omhändertagande av elektriska och elektroniska produkter enligt WEEE-direktivet.

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