A Comparative Analysis of End-of-life Strategies for Home Appliances in Japan, America and the European Union

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ABSTRACT: The present paper analyzes diverse end-of-life strategies for electronic and electric appliances implemented in Japan, the United States and the European Community. A comparative analysis is presented on the basis of available information. Fundamental differences regarding conceptual and logistic aspects of the models are depicted and discussed. The analysis indicates that The Japanese model, a recycle-oriented strategy, presents certain advantages in terms of collection rates and recycling efficiency. However, operational costs are significantly higher than in the other two models due to elevated expenditure on labour, services, taxes and, technology developments. Considering that consumers absorb such costs, the economic model of this strategy is highly dependent on consumer's willingness-to-pay. Subsequently, between strategies, Japan presents the highest associated social expenditure. In addition, although the current average recycling target in the Japanese model is lower than the European one (15 to 25% less), the total material mass recovered after recycling is slightly higher. This 'hidden mass' is the result of a different definition of recycling. Concerning design matters, the Japanese strategy broadly focuses on a design toolbox optimized for disassembly and recycling, the American strategy focuses on design for reuse and disassembly and, the European one on an integrative design for environment throughout life cycle. Although the end-of-life strategies covered by the present study are at their trial stage, it is reasonable to assume that important achievements can be gathered if all potential advantages and weaknesses in the currents models are considered in further regulatory decisions.

KEYWORDS: End-of-life Strategy, Home Appliances, WEEE, Environmental Management, EOL

1. INTRODUCTION

During the last decades, the electronic and electric industry has presented an accelerated growth trend aided by a sustained technological development. Such a trend has implied a rapid replacement of technologies – and consequently of obsolete equipments – by new and improved products. The increasing resultant flow of discarded products has been commonly buried into landfill sites or incinerated without treatment. Moreover, it has been proved that severe environmental impacts and threats to public health occur during these conventional disposal practices[1)]. Therefore, in both the international and the national context, new regulatory frameworks have been implemented in order to deal with such concerns. Nowadays, diversified end-of-life strategies based on recycling and reuse of the discarded appliances are emerging as a formal downstream activity with potential benefits for both the environment and the economy. The present paper analyzes different end-of-life strategies for electronic and electric appliances implemented in Japan, America and Europe.

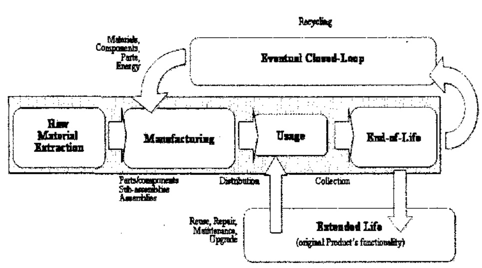

Figure 1 Generic Product Life Cycle

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(1) The Product Life Cycle

All products have a *life cycle* that can be defined in terms of an *economic* or a *physical* lifespan. An *economic lifespan* includes all steps that a product passes through from its conceptual development until its effective permanence in market ceases. Instead, a *physical lifespan* considers a sequence of interrelated stages, from acquisition of raw materials until the final disposal of products[2]. Both the physical and the economic lifespan of a product can be *extended* over time (**Fig.1**). An *extended life* considers the reuse of products as originally designed[2]. A *closed-loop*, instead, broadly focuses on the recovery and recycling of valuable materials, components and/or energy to supply the manufacturing process of new products[2) 3)]. Since all phases in a product's life cycle have an impact on environment[3) 2)], the life cycle provides a *referential framework* to evaluate systematically potential risks and environmental impacts associated with the flow and conversion of material and energy throughout the entire productive system.

(2) Extended Life Cycles: End-of-life Strategies

There are several definitions for end-of-life strategies aimed at extending the product's life or maximizing the material efficiency (**Fig.1**). Among them, there is consensus about five basic strategies, their conceptual definition as well as their hierarchy of efficiency accordingly with *economic* and *environmental* criteria[2)4)]. Such strategies are: 1) *reuse* that represents the recovery and trade of used products or their components as originally designed, 2) *servicing* a strategy aimed at extending the usage stage of a product by *repair* or *maintenance*, 3) *remanufacturing* which considers repair, *refurbish* or *upgrade* parts or components of used product for a new utilization in different artifacts, 4) *recycling* that consist of treatment, recovery and reprocessing of materials contained in used products or components in order to replace virgin materials in the production of new goods and, 5) disposal via incineration or landfill of waste products. Frequently end-of-life strategies are combined in order to maximize *profitability* and *efficiency.* [2) 3) 4)]

(3) The Role of Design in the End-of-life Stage

From a methodological point of view, the *design process* can be divided into three basic stages: *product definition, conceptual design and detailed design*[2]. During *product definition,* all attributes of a product are predetermined. However, during the *conceptual design*, approximately 80% of the product's life-cycle cost is set as well as the final functionality and performance[2]. Since all characteristics of a product are defined during the design process, design also defines the *best end-of-life practice* for a given product. The contemporary design process regards such specifications in diverse ways. The most important design concept in terms of innovations is the *design toolbox* or *'design for X'* (DfX), an integrated approach to product's design and processes for cost-effective and high quality life cycle management[2]. Some examples of DfX are the Design for Assembly, Disassembly, Process, Serviceability, Environment (DfE), Product Variety, Supply Chain, Quality and the Design for Recycling.

(4) The Recovery of End-of-life Products

Take-back systems are aimed at recovering sold products or their components for specific industrial purposes such as recycling or reuse[5]. In general, the quantity, frequency and quality of recovered products are important constraints to the recycling and reuse efficiency[3) 5)].

The most common collection methods to support take-back are based on five models[5]; the *drop-off model*, the *permanent collection depot*, the *curbside collection*, the *point-of-purchase model* and, the *combined/coordinated model.*

2. HOME APPLIANCES AS A SOLID WASTE

Discarded home appliances are usually disposed into municipal landfills or incinerated without treatment[1]. The presence of hazardous substances in all appliances implies several environmental impacts, at different magnitudes and scales, in all disposal routes[1]. Often collected via combined kerbside programs[5], home appliances do not represent a significant percentage of the total municipal solid waste by concept of collected mass but their contribution to the total volume is likely larger. Overall, electric or electronic equipments require a proper disposal that in turn involves specific treatments. Therefore, the discard, collection and storage of end-of-life appliances entail several logistic considerations in order to increase the possibility and efficiency of reuse, recycling or sound disposal. **Table 1** depicts common components and substances to all electronic or electric equipment[1]. The material composition of

Table 1 Generic Structure of Electronic and Electric Equipment

Basic Building Blocks	**Hazardous Substances**
➢ Printed circuit board/assemblies ➢ Cables ➢ Cords and wires ➢ Plastic containing flame retardant ➢ Mercury switches and breakers ➢ Display equipment such as cathode ray tubes and crystal liquid displays ➢ Accumulator and batteries ➢ Data storage media light generating devices ➢ Capacitors ➢ Resistors and relays ➢ Sensors and Connectors.	***Heavy Metals:*** Mercury, Lead, Cadmium, Chromium. ***Halogenated Substances:*** Chlorofluorocarbons or **CFCs**, Polychlorinated biphenyls or **PCBs**, Polyvinyl chloride or **PVC**. ***Brominated Flame Retardant:*** Asbestos, Arsenic

Japanese home appliances[6] is depicted in **Table 2**. It has been indicated that the future material composition will include a larger amount of plastics[7].

Table 2 Generic Material Composition of Japanese Home Appliances

Material	TV Set	Refrigerator	Washing Machine	Air-Conditioner
	Mass Ratio (%) by Product			
Iron and Ferro-alloy	9.7	49	55.7	45.9
Copper (and Cu Alloy)	1.5	3.4	2.9	18.5
Aluminum (and Al Alloy)	0.3	1.1	1.4	8.6
Other Alloy	1.4	1.1	0.5	1.5
Plastics	16.1	43.3	34.7	17.5
Glass	62.4	0	0	0
Gas (CFC/others)	0	1.1	0	2
Circuits Boards	8.1	0	1.5	3.1
Others	0.4	0.7	3.3	2.8
Total Ratio	99.9	99.7	100	99.9

3. ENVIRONMENTAL IMPLICATIONS

From a life-cycle perspective, it has been reported that the dominant environmental impact carried out by electric and electronic equipment occurs during the usage stage followed by the extraction of raw materials and disposal[2]. Additionally it has been indicated that large environmental impacts are associated to landfill and incineration of electric or electronic equipment. Such impacts include emissions to soil, underground water, and air[1].

4. RESULTS

The present chapter depicts the results obtained on this study. In order to allows comparison, all monetary values indicated on this paper have been converted to Japanese Yen (exchange rate at August 2003: 1 USD = 119 Yens, 1 Euro = 134 Yens) and material flows are expressed in tons. **Table 3** summarizes either the qualitative and quantitative results. Additional information is given in the following sections.

Table 3 Summary of Qualitative and Quantitative Results

	Targeted Products / categories	Collection			EOL Strategy						
					Disposal	Refurbishment	Repair	Reuse	Recycling		
		System	Cost Yens/ton	Stream Tons/Year	%	%	%	%	Current %	Target %	Cost Yens/ton
Japan Case 1 (EHARL)	4 / 1	Kerbside / Retailer	*69,444 – 138,888*	*648,000*	*40 – 50*	*Not Considered*		Considered *but not* specified	*50 – 80*	*50 – 60*	*66,666 – 127,777*
EU Case 1 (WEEE) Case 2 (UK)	81 / 10 6 / 5	Combined Collection	27,000 – 54,000 15,200 – 26,220	1,500,000 419,240	0 – 20 0 – 20	4 – 45		0 – 80 Over 0 – 63	1 – 63	50 – 80 over 50 – 76	1,350 – 67,500 8,550
USA Case 2 (EPR2 Pilot) Case 1 (Massachusetts)	10 / 5 2 / 2	Combined Collection	48,022 28,441	291 460	0 – 15 0 – 5	5 – 10 25 – 40 (Including Exportation)			Up to 75 60 – 75	NO	44,560 Not Specified

(1) Japan

The Japanese end-of-life strategy is based on the *Designated Household Appliance Recycling Law* enforced in April 2001 (also known as EHARL), a basic policy concerning the collection, transport, and recycling of waste products from specifically targeted household appliances such as *TV sets*, *air-conditioner units*, *refrigerators* and *washing machines*[8]. All together, the four-targeted products represent the 80% of the total discarded appliances by householders and approximately the 2% of the total municipal solid waste annually generated in Japan. This amount signifies that about 20 millions of units are discarded per annum with an equivalent mass of 733,000 tons[8].

The targeted recycling rate is 60% for Air-conditioners, 55% for TVs and 50% for Refrigerators and washing machines.

The average lifespan of recovered products is about 10 years. On the other hand, the design toolbox has been broadly focused on Design for Disassembly and Recycling.

The basic EHARL strategy is shown by **Fig.2**.

(2) America

Sponsored by the Environmental Protection Agency (EPA) *The National Electronics Product Stewardship Initiative* (NEPSI) proposed in 1999, is aimed at financing a national end-of-life system focus on TVs and personal computers[10]. At Federal level, also sponsored by EPA, several programs and pilots such as the voluntary

WasteWise Plan, the *Computer Display Project* and, the *Electronic Product Recovery and Recycling project* (EPR2) have been implemented.

On this study were analyzed the reports on two pilot initiatives at federal; a report on *EPR2 programs* implemented in five different states[5] and the report of the *Massachusetts initiative* on demanufacturing[11].

Both initiatives were structured in a common logistic base (see **Fig. 3**), but with different product targets. As pilot programs, both initiatives considered and evaluated different collection methods in order to identify a cost-effective system. The participation of all stakeholders was of a voluntary nature. Local authorities and businesses shared collection and recycling cost. There was no specific information about modifications to the design toolbox for new products. However, it was indicated that EPA is coordinating a national initiative on DfE with the electronic industry in order to improve the efficiency on demanufacturing.

(3) European Community

The European Commission approved in October 2002 two regulatory directives such as the *Directive on Waste from Electronics and Electronic Equipment* (WEEE) and *Directive on Restriction of Hazardous Substances* (RoHS).

On this study, we have analyzed the targets of the WEEE directive[1] and the report presented by the United Kingdom in conformity with the new regulatory framework of the community. **Fig. 4** depicts the current end-of-life model proposed by the WEEE Directive.

The expected recovery rate is about 4 kilograms/year/inhabitant. Reuse of products and components is consider and important target to be achieved by implementation of DfE initiatives during the product development. All cost associated to the system are assumed by producers and importers. However, costs will be absorbed via increasing the price of new products by 1-3%.

The results obtained during the first year of compliance in the United Kingdom differ from the targets and costs specified by the WEEE Directive. The achieved recycling rates were slightly lower. Collection and recycling cost, on the other hand, were significantly lower than expected.

5. DISCUSSION AND CONCLUDING REMARKS

The Japanese model, a recycle-oriented strategy, presents certain advantages in terms of collection rates and recycling efficiency. Since the nature of the strategy lies on a regulatory framework, and collection as well as recycling are obligatory actions, the resultant material flow can be easily predicted and consequently, efficiently managed. However, operational costs are significantly higher than the other two models due elevated expenditure on labour, services, taxes and technology developments. Considering that consumers absorb such costs, the economic model of this strategy is highly dependent on consumer's willingness-to-pay. Subsequently, between strategies, Japan presents the highest associated social expenditure. In this context, the WEEE Directive,

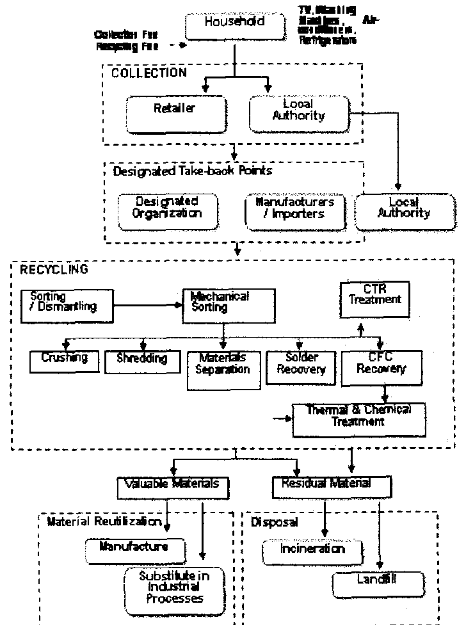

Figure 2 Representation of the Japanese End-of-life Strategy (EHARL)

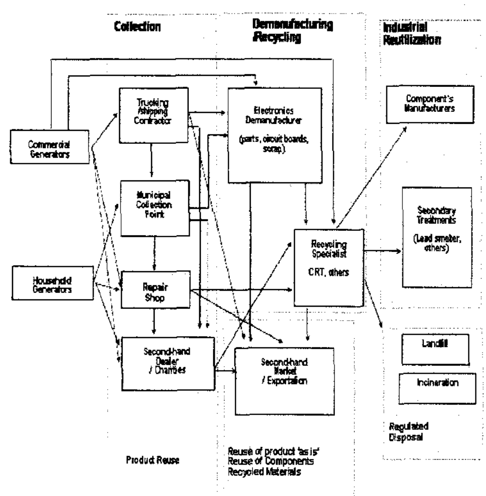

Figure 3 Representation of the American End-of-life Strategy

that considers a cost-abatement strategy while increasing the price of new products, expects in the long-term a minimal social impact due to the inelastic nature of the demand for most kind of electronic products [1]. In the American approach, costs are likely to be shared by local authorities and demanufacturing bodies, but it has been proposed that in order to increase the overall profitability, additional fees may be paid by consumers[5]. However, it was proven that consumer's willingness-to-pay is significantly lower than expected [5][11].

In terms of recycling efficiency the Japanese model – broadly technologically-dependant[8] – presents advantages while recovering materials with high purity. This allows the utilization of recycled materials in diverse manufacturing processes keeping an overall high profitability.

Although, the current average recycling target in the Japanese model is lower than the European one (15 to 25% less), the total mass recovered after recycling is slightly higher. This 'hidden mass' is the result of a different definition of recycling[8]. In Japan, only recovered materials with positive value for upstream activities are accounted as recycled. In addition, we suppose that all those materials without positive residual value are either disposed into landfills or incinerated. In the European model instead, all materials physically recovered in the process of recycling, despite their residual value, are considered as recycled. On the other hand, the American model regards recycling as a sub-process of demanufacture. This sub-process consist on the reductions of assemble parts into valuable scrap. Therefore only the fraction of the product that is reduced into scrap is considered as recycled. Thus, the American strategy does not impose referential recycling targets to demanufacturers because the main purpose of the strategy is to reduce, as much as possible, the material input for disposal. In this context, the pilots achieved disposal rates below 5%, the lowest amount among the strategies. However, it is important to mention that such an achievement includes exportation of components and materials. The Japanese and the European model, instead, are 'in-house' systems in which all material flows are to be treated, reutilized and disposed throughout the national boundaries.

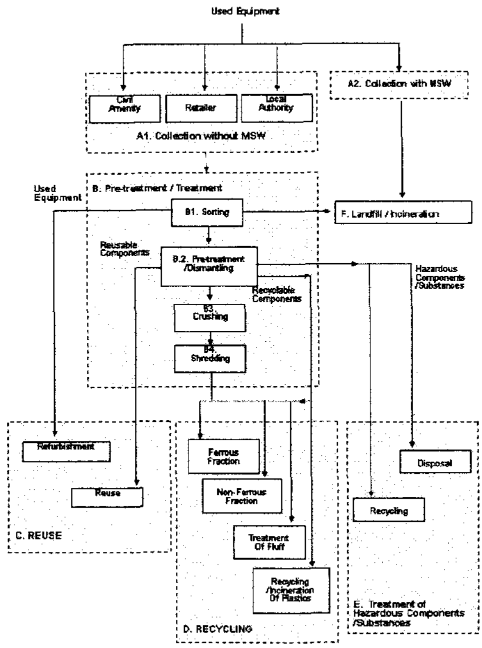

Figure 4 Representation of the European End-of-life Strategy (WEEE Directive)

Another important conceptual difference among models concerns the definition of reuse. In the American and the European models reuse contemplates the action of reutilizing discarded products or components as originally designed while keeping their original functionality intact. In the Japanese strategy, on the other hand, reuse means the reutilization of recovered materials in the manufacturing of new products[8].

Regarding collection efficiency, it was observed that combined methods presents a better cost-effective performance due the allowed logistic flexibility. In addition, voluntary fees and collections strategies free of cost proven to have better reception by consumers[5][11]. In addition, it was observed that the logistic distribution of collection points with respect to recycling agencies was of significant impact in the overall cost-effectiveness of the system since transportation costs have a considerable weight in the total net expenditure[5].

Regarding environmental aspects of the studied models, the Japanese strategy is oriented to reduce impacts associated with landfill and incineration as well as to reduce the overall level of CO_2 emissions throughout the product life cycle. With similar purpose, the American strategy also focuses on dematerialization of production. In contrast, the European model approaches a wider range of actions that includes dematerialization, energy efficiency and removal of hazardous substances, in other words, a life-cycle approach. Respectively, the Japanese model is broadly oriented towards a design toolbox optimized for Disassembly and Recycling, the American strategy focuses on Design for Reuse, Repairing and Disassembly, while the European strategy focus on Design for Environment (or Eco-design).

Although the end-of-life strategies covered by the present study are at their trial stage, it is reasonable to assume that important achievements can be gathered if all potential advantages and weaknesses in the currents models are considered in further regulatory decisions.

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