Recyclability Index Based on Supply Chain Management: A Review of Literature

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Keywords: Product Lifecycle Management, Supply Chain Management, End-of-Life, Recyclability Index, Green Engineering.

Abstract. Environment becomes a vital part to consider in engineering nowadays. The environment consciousness produces supportive system with many type of new management knowledge. Green thinking helps develops factor of a new system of green engineering. Through the product lifecycle management (PLM), the developments of new product until product end-of-life (EOL) can be well manage. A technique called supply chain management (SCM) was introduced to produce systematic method for development of new product. EOL method should be introduced as early as possible in the design stage to have a meaningful impact. SCM itself helps to verify the green thinking when green supply chain management (GSCM) was explored in many current researches. In this research, the recyclability index (RI) is introduced in the early design stage with the idea of managing EOL systematically based on SCM and green engineering.

Introduction

Green engineering introduced 12 principles [1] which incorporate with lifecycle thinking into engineering design. This all principles introduced to minimize the impact to the environment in all stages of product life. These actually describe how critical the design stages in order to relate the environment consciousness.

To consider the environment, the proper manage of EOL need to understand carefully. Based on the design for X (DfX) by referring to design of environment, there are 5 methods highlight including recycle, reuse, remanufacturing, disassembly and disposal for EOL management. This all 5 methods currently become main factor to get best result in EOL stage in most industries.

To realize this issue, many methods involving the system, idea and process related with EOL management introduced. To get the best result, there are better to get the best idea of EOL management in the early Product development so that the other stage toward the process can relate directly to EOL management. The idea of recyclability index is the method introduced which the predictable index of EOL introduced in design stage of Product Lifecycle Management (PLM).

Supply Chain Management provides the information network connecting the process of production, marketing and finance. Nowadays, the idea of green thinking introduced in the SCM as environment consciousness as major responsibility. Because of that Green Supply Chain Management (GSCM) introduced in order to relate this both factor.

Green Engineering

a. Design for X (DfX)

Design of X (DfX) is the information made to specialize the data close to design activities. In design, there are specialties to overview in the angle of concepts, application, and perspectives. Because of that, the green engineering directly will involve in such types of DfX. Green engineering will be concentrates on the design for environment (DfE), design for recyclability (DfR), design for disassembly (DfD), Design for Lifecycle (DfLC) and design for maintainability (DfMt). DfE is the systematic consideration during new production and process development, of design issues associated with environmental safety and health over the full product lifecycle [2]. The scope of DfE was stated by MCC, 1993 including environmental risk management, product safety, occupational health and safety, pollution prevention, ecology, resource conservation, accident prevention and waste management.

b. Lifecycle Analysis (LCA)

Lifecycle Analysis (LCA) is the technique used to evaluate the environmental impact of a product throughout its lifecycle, encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling and final disposal [3]. It also the method used for environmental manner which standardize by ISO 1997. Currently, most researchers use this method in the DfE methodology to measure the environmental impact on the product design [4].

c. Quality Function Deployment Environment (QFDE)

QFDE is a tool developed by modifying extended QFD. This method used to support ecodesign developed by incorporating environmental aspects into QFD [5] and extending so as to evaluate improvement concepts. There are four procedure introduced in QFDE by [6]:

- Phase 1: Voice of Customers (VOC) and Voice of Environment (VOE)
- Phase 2: Identifying Product Specification
- Phase 3: Generating Product Concept
- Phase 4: Evaluating Solutions

d. End-of-Life (EOL)

In development of new product based on the green factor, the most important part to consider is the End-of Life (EOL) of the product. The management of EOL product is under main consideration because of to reduce the waste cause by the remaining product. As many researcher suggest to get the closed loop of raw material used, there are many technique develop to introduced for managing the EOL product properly.

The managing of flow information for the product started the early product development is the best way to manage the technique used for the product EOL. Nowadays, many methods used to manage product EOL like:

- Disposal
- Recycle
- Remanufacture
- Rebuild
- Reuse

Green Materials

a. Metals

Types of the materials which easily to recycled but this materials easily corrode. Until now, there have a lot of information about metals which directly used to recycle. Metals which include such of materials like steel, aluminum and titanium are strong, durable, inexpensive and easily molded/shaped/formed/machined. Metals are environmentally friendly in that they have a mature reclamation infrastructure [7], they are easy to recycle, and they can be easily separated from one another.

b. Natural Organic Materials

Natural organic materials, which include such materials as wood, bamboo, and cotton are inexpensive, light, durable and strong, renewable, can be machined and woven, and have been studied with a mature understanding of design and performance issues. Environmentally, they easily decompose and can be burned.

c. Composites

Composites, which include such materials as graphite epoxy, polyester fiberglass, have an extremely high strength to weight ratio, are highly corrosion resistant, and have been studied with a good understanding of design and performance issues. It is expensive to produce this material. Environmentally, they have no reclamation infrastructure and the separation technology is not yet mature.

d. Ceramics

Ceramic, which include such materials as porcelain, mineral glass, and metallic oxides, are nontoxic, hard, durable, noncorrosive, can tolerate high temperatures, and have been thoroughly studied with a vast amount of knowledge that is readily available. This materials is brittle and difficult to machine. Environmentally, they tend to have low toxicity but have a limited reclamation infrastructure, and the separation technology is not mature.

e. Polymers

Polymer is a large molecule that comprises repeating structural units joined by the covalent bonds or a polymer is a group formed by repeated linking of small molecules.

1. Elastomers

   A polymer has properties of rubber which include isoprene, neoprene and styrene butadiene. Polymers that can be formulated as elastomers are polyurethane, butyl rubber, silicones and specially treated ethylene-propylene copolymers [8]. This polymer is inexpensive, light, extremely tough, impact resistant, easily molded/ shaped/formed, corrosion resistant and has been studied with a good understanding of design and performance issues. Environmentally, they are difficult to recycle and have limited reclamation infrastructure and the separation technology is not yet mature.

2. Thermoplastics

   Polymer thermoplastic, which includes such materials as acrylic and polypropylene, are inexpensive, light, though, easily molded/shaped/formed/machined, corrosion resistant and have been studied with a good understanding of design and performance issues. The environmental advantages include their easy remelting property and maturing separation technology and reclamation infrastructure.

3. Thermosets

   Polymer thermosets, which includes such materials as epoxy and poly urethane, are inexpensive, light, very though, easily molded/shaped/formed/machined, corrosion and high temperature resistant and have been studied with a good understanding of design and performance issues. Environmentally, they are difficult to recycle, pulverize, or burn. Additionally, they have a poor reclamation infrastructure and the separation technology is not yet mature.

Product Lifecycle Management (PLM)

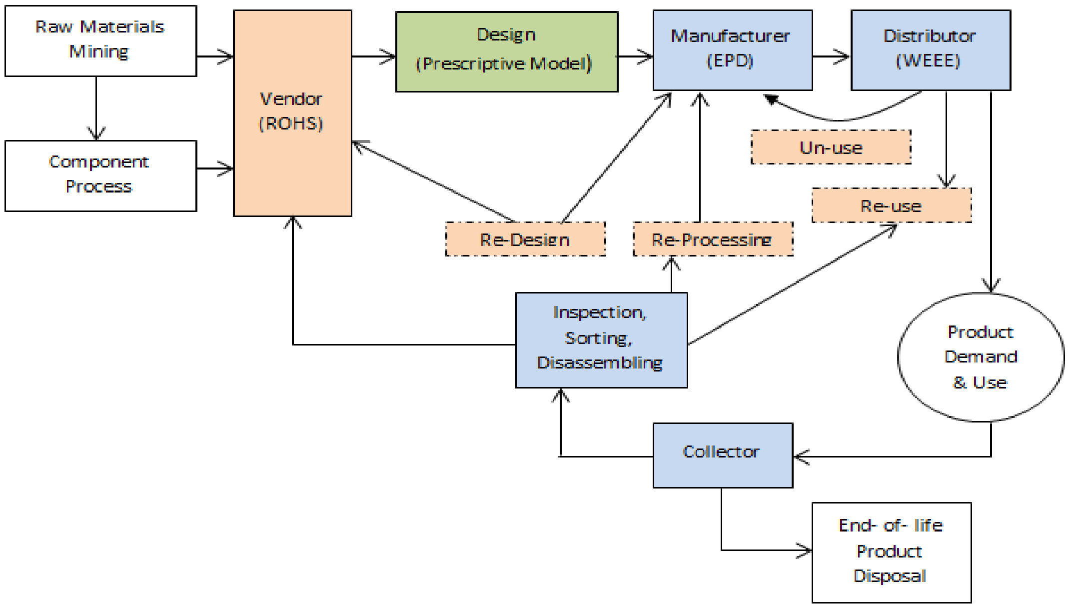

Figure 1: Green Product lifecycle Model [3]

The Product Lifecycle Management (PLM) will play a vital role as the framework of this study, as it involve the whole lifecycle of a product from inception to disposal. Figure 1 showed model of green product lifecycle which involve all stages from raw materials until end of life (EOL) product disposal. Thus, EOL issues can thus be studied involving recyclability and this can be done at the early stages of product development. Nowadays, environmental issue is one of the main concern factors, the development of new product need to connect the information of product use, sustainable and disposal, so that it can be managed properly.

Customer wants performance, quality and reliability at the lowest feasible costs. PLM provide all the elements which will make the most successful product. Although simple in concept, lifecycle issues are frequently difficult in concept because it demands knowledge of wide spectrum of engineering disciplines [9].

The growing emphasis on the product lifecycle design for sustainability requires that the harmful side effects to workers, users and local and global natural ecosystems must be minimized by reducing the rate of material and energy consumption that lead to the harmful side effect [10].

Basically, PLM can be divided into five processes through lifecycle of the product. This involves product development process, consumer used and disposal as the main process involve. Here are the general steps of product lifecycle management:

a. Conceive
b. Design
c. Realize
d. Service
e. Disposal

Product Data Management (PDM)

Product Data Management (PDM) is one of the applications of knowledge management in the product development process. PDM is one of the PLM platform which will be explain further in the chapter of relationship between PLM, PDM, ERP, SCM and CRM. PDM can be divided into two parts which is product design management and process planning management.

Total Design

Prescriptive design process model describe the general design model attempt to encourage designers to adopt improved ways of working. They usually offer a more algorithmic and systematic procedure to follow, and are often regarded as providing a particular methodology [11].

Although the systematic procedure in the model, there are procedure still need understood clearly that no important elements of it overlooked and that the real problem is identified such a model introduced by Pugh in Figure 2.

Total design is one of the best prescriptive models introduced by Pugh. Total Design may be defined as the systematic activity necessary from market/user need to the selling of a successful product to satisfy that need.

Bill Ion through his paper methods of total design give brave explanation about a total design. They are mentioned that total design emphasizes the need to place greater effort on the initial stages of the design process where greatest return can be achieved for the least cost and risk. The approach also emphasizes the “front end” of the design process and includes many methods which are of direct relevance to the understanding of the market requirement.

In his paper, he concluded that total design approach to new product development provides a systematic, yet flexible, framework for new product development. The method also provides increases the possibility of market success through improved time to market and customer satisfaction.

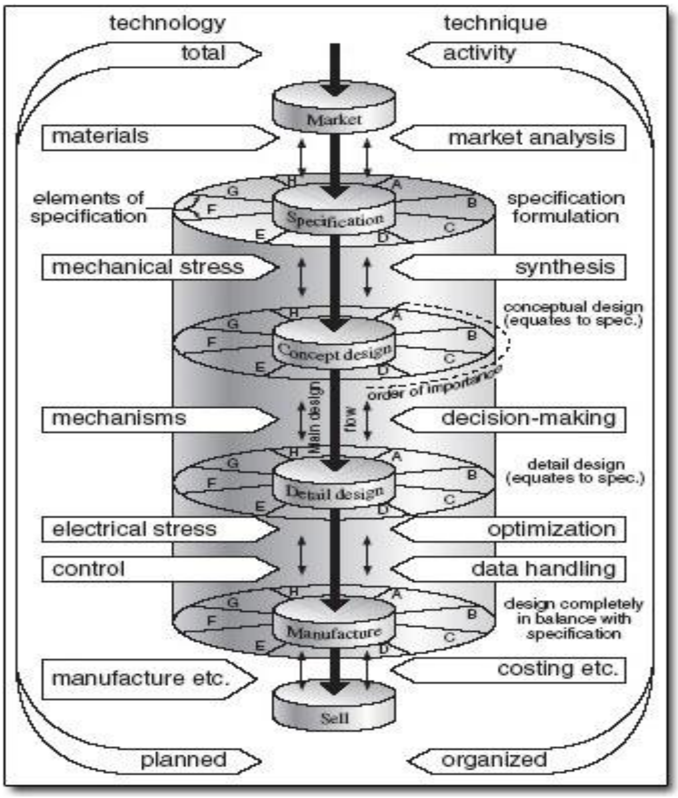

Figure 2: The Total Design Activity

Enterprise Resource Planning (ERP)

Enterprise Resource Planning (ERP) System, as a name implies, should refer to the system meant for planning the resources of an organization. ERP also known as a set of application software package that integrates manufacturing, finance, sales, distribution, human resources and other business function.

ERP serves as a cross-functional enterprise backbone that integrates all the processes of the business and helps manage the resources of the organization. ERP system enable a manager to take an overall view of the business as a whole instead of having a myopic view of business functions in achieving the mission, goals, and strategies of an organization.

ERP system has their own important component consist of people hardware, database, and model base and processes [12]. Below is simple explanation about all components of ERP.

- People – As ERP systems are user machine systems, people are one of important components of ERP system. Thus, this component includes all the people may be users, top management and IT personnel and so on.
- Hardware and Software – this components represents the computers that include hardware like servers, desktop, peripherals; and software like ERP system software, operating systems and so on.
- Database – This is repository of an organizational data from within and outside the organization.
- Model Base – this is group of various models like mathematical models, arithmetical model, statistical model, financial model, forecasting model and descriptive model which are essential to process the data into information.
- Processes – Include business processes, procedures and policies of an organization.

Supply Chain Management (SCM)

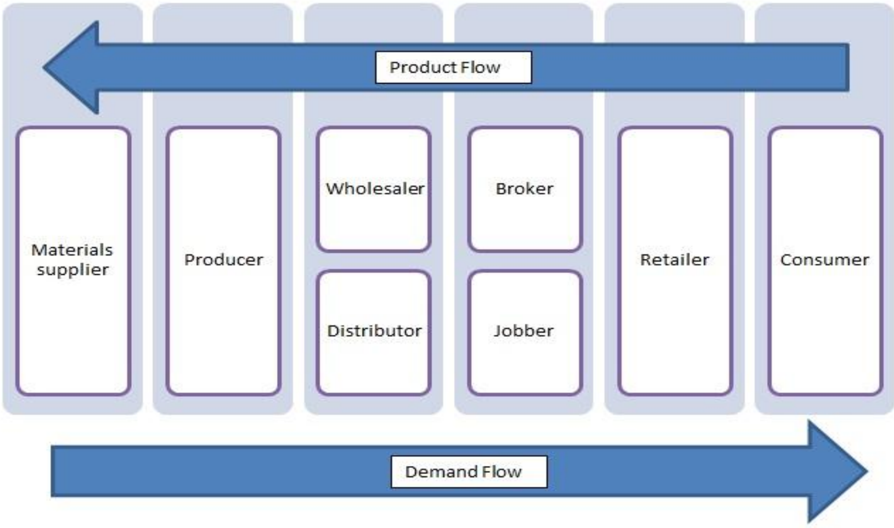

Figure 4: Supply Chain Management (SCM) Pipeline

SCM recognized as network connection of interconnected business that form tight linkage among raw material, resources, production, transportation and distribution of material resources, information and financial flows for ultimate provision of goods and services [3].

It means SCM is the combination of information for the product, suppliers and raw materials. Figure 4 shows a pipeline-like mechanism for the movement of products, information, and financial settlement up and down the channel of supply. SCM pipeline can be composed of a variety of players, each providing a range of specialized functions [13].

Closed-loop supply chain is use for finding profitable ways to recover their used products for remanufacturing, refurbishing and recycling. In addition, it is the typical “forward” flow of materials from suppliers all the way to the end customers [14]. The product development process (PDP) is one of the business processes of SCM [15].

Customer Relationship Management (CRM)

CRM is the core business strategy that integrates internal processes and functions, and external networks, to create and deliver value to targeted customers at a profit. It is grounded on high quality customer-related data and enabled by information technology [16].

There are several important constituencies having an interest in CRM including:

- Companies
- Customers and partners of those companies
- Vendors of CRM software
- CRM application service providers (ASPs)
- Vendors of CRM hardware and Infrastructure
- Management Consultant

Interaction between PLM, PDM, SCM, ERP and CRM

Based on the previous subchapter, all the system has the interaction in order to produce best practice for development of new product based on the green engineering. These single systems itself was developed to get best result in every area of information. The combination of these systems can make the process more efficient and complete started from early process of product development until EOL product. Figure 3 below is the general interaction between all five enterprises showed PLM as the main platform in the knowledge management.

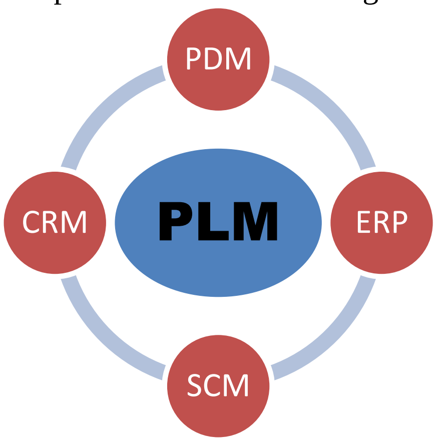

Figure 3: PLM platform

PLM act as the collaborative platform for the PDM, ERP, SCM and CRM as in Figure 4 which holds the promise of seamlessly integrating all the product-related information by using computer network technology, database technology. This platform has such functions as follows; workflow management, project management, personal management, electronic data storage management, product structure management, parts management, product change management product configuration management and so on [17].

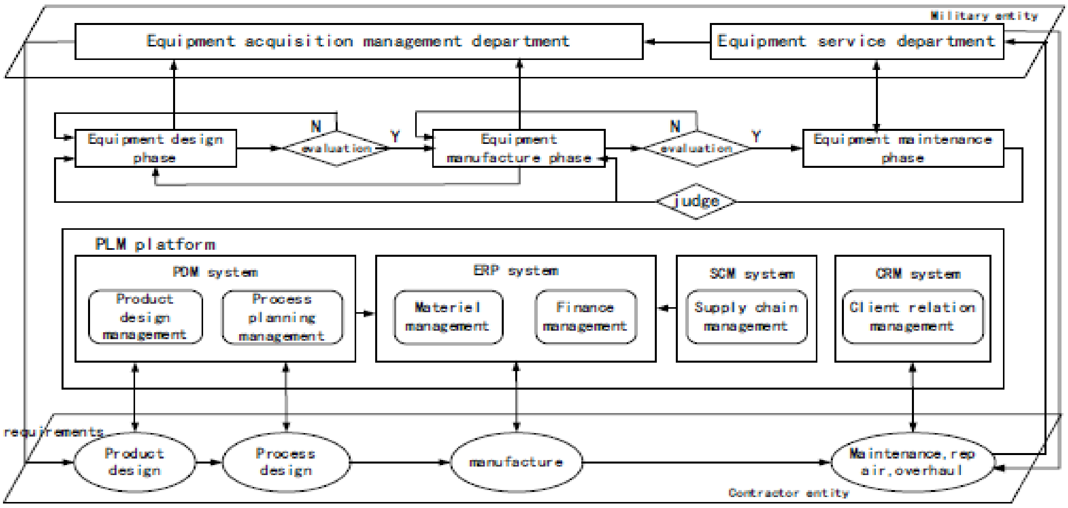

Figure 4: Equipment information flow analysis based on PLM [17]

Recyclability Issue

As refer to the current situation, the recyclability becomes the main issue under product development. So many methods introduced to manage the product at EOL. More researcher nowadays work to slot this issue in the product development process as early this recyclability process can be under the process as good the result of EOL can be manage. The process of total design gives the engineers and designers to think how it can be done in this prescriptive model.

To understand the idea of recyclability more details the reviewing of previous research is important. Table 1 shows some ideas done by previous researcher which related to the recyclability. Although it is done by some of researchers with idea of recyclability system or index, there are still didn't satisfied some of material or product which become major use nowadays.

Table 1: Literature of Recyclability Issue

NO	RESEARCH	YEAR	USE	SPECIFICATION/CASE STUDY		NOTES
				MATERIAL	*PRODUCT*	
1	Recyclability Index for Automobile [18]	2006	Journal, California	Plastics, lead, mercury, cadmium, hexavalent chromium	Vehicle	This paper is about development of rating system to quantify the environmental impacts of light duty motor vehicles at the end of life cycle based on recyclability, toxic material content and ultimate disposal.
2	Design for Environment: A Method of Formulating Product End-of-Life Strategies [19]	2000	PHD Thesis, Stanford University	Case studies for this research came from Stanford University's graduate level Design for Manufacturability course (ME217). At least 10 case studies a year from 1996 to 2000. Electronic products started small product like cell phone until aircraft engines and generators.		This research used to develop methodologies to formulate end-of-life strategies across a wide range of products.
3	Optimal Design of Disassembly System with Environmental and Economic Parts Selection Recyclability Evaluation Method [20]	2012	Proceedings, Japan	Computer and Cleaner		This study proposes the optimal disassembly system design with the environmental and economic parts selection which harmonizes the recycling rate and profit by using Recyclability Evaluation Method (REM) provided with Hitachi, Ltd.
4	Sustainable Design for Automotive Products: Dismantling and Recycling of End-of-Life Vehicles [21]	2014	Journal, China	Polymers	Car Dashboard, Vehicle.	This paper shows the use of DFD method in dashboard by reducing a number of incompatible polymers and demonstrating the importance of using single material.
5	Measuring the Time for Extracting Components in End-of-Life Products: Needs for a standardized Method and Aspects to be Considered [22]	2014	Proceedings, Italy	Metals, Plastics and others	PCB Circuit for TV Sets	This paper demonstrated that the need of a standardized method to measure the time for extraction of key components from products to better address recyclability of products in product policies.

<table>
<tr><td rowspan="2">6</td><td rowspan="2">Economic and Environmental Assessment of Reusable Plastic Containers: A Food Catering Supply Chain Case Study [23]</td><td rowspan="2">2014</td><td rowspan="2">Journal, Italy</td><td>Polypropylene Polymer (PP)</td><td>Reusable Plastic Container (RPC) – RPC30, RPC50, RPC70</td><td rowspan="2">This paper proposes an original conceptual framework for the integrated design of a food packaging and distribution network. It compares a multi-use system to traditional single-use packaging to quantify the economic returns and environmental impacts of the reusable plastic container (RPC).</td></tr>
<tr><td colspan="2">Wooden Box, Plastic Crate Cardboard Box</td></tr>
<tr><td>7</td><td>A Proposal for Quantifying the Recyclability of Materials [24]</td><td>2002</td><td>Journal, Spain</td><td colspan="2">Most main metals for products development (e.g Aluminium, Copper, Steel etc), Polyethylene terephthalate (PET), High Density Polyethylene (HDPE), Polypropylene (PP), Paper and Glass</td><td>This paper defines recyclability as the ability of material to reacquire the properties that it had in its virgin state, where the virgin state refers to the material in its purest form before being processed or shaped for a specific use</td></tr>
<tr><td>8</td><td>Optimal Multi-material Selection for Lightweight Design of Automotive Body Assembly Incorporating Recyclability [25]</td><td>2013</td><td>Journal, Malaysia</td><td>Metal based Materials (Magnesium, Aluminum, Mild Steel and Carbon Fibre)</td><td>Automotive Door Panel</td><td>This paper presents a novel multi-material selection method for lightweight design, which incorporates recyclability for an automotive body assembly.</td></tr>
<tr><td>9</td><td>Generating Design Alternatives for Increasing Recyclability of Products [26]</td><td>2013</td><td>Journal, Japan</td><td>Polycarbonate ABS (PC+ABS), Polycarbonate, Polystyrene, PET, Aluminum, Steel, Copper, Iron and PVC</td><td>LCD TV</td><td>This paper proposes a design support method for improving the recyclability of electrical and electronic products. The method quantifies the recyclability of products based on EOL scenarios.</td></tr>
</table>

Summary

This proposed the idea of development new recyclability index. This index will be based on the supply chain management (SCM). This new index develops with environment as main consideration. This index in the future should upgrade the design stage which the end-of-life EOL can be predicts in this stage. As supply chain become successful method in manufacturing stage, authors' tries to relate this 3 main stages involving design, manufacturing and EOL in the link related information.

In these recent day, thermoplastic become one of the most non-metal material use in development of new product. This makes this material rapidly develop but it still little technology of management for EOL for this material. Because of that, the authors try to concentrate a lot on this material for this research.

For that material, kitchen appliance such as blender will be used as the specific product as the first case study. As most modern kitchen appliances use polymers materials this case study provide a lot of information about the material and product for development of new index.

Although there are some recyclability indexes were develops previously, there are no indexes apply any specific knowledge management such SCM. Besides, this research will be use 3 tools including Design for X (DfX), Lifecycle Analysis (LCA) and Quality Function Deployment for Environment (QFDE). This research finally develops a new information link started from product brainstorming until EOL base on product lifecycle management (PLM).

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