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Product Life Cycle Design: Integrating Environmental Aspects into Product Design and Development Process at Alfa Laval

Written in cooperation with Alfa Laval

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Abstract

Key words: *product development process, eco design, product life cycle design, eco benchmarking approach, stakeholders*

Many multinational companies create innovative solutions for products. But do they take into account environmental impacts when they design a product and how do they integrate environmental aspects into product design?

The thesis is written in the way in order to let a reader to understand the theoretical concept of life cycle design and its application in the real life situation by taking an example of Alfa Laval's case.

The aim of this thesis is to research and propose how to integrate Life Cycle Design in product design and development process at Alfa Laval. The study investigates external and internal driving forces, implementation barriers, actors around life cycle design at Alfa Laval. Thesis methodology is based on the literature review about Life Cycle thinking, Life Cycle Design and its tools, methodologies and databases; personal observation of the author; adaptive learning method; and systems thinking method.

In the empirical part, a version of integration of Life Cycle Design into product design and development process is elaborated for Alfa Laval. Additionally, eco benchmarking approach is chosen as an appropriate tool for Life Cycle Design at Alfa Laval. The beginning phase of implementation of eco benchmarking approach is described.

Finally, conclusions are followed by a summary of the findings from my research project and critical discussion that provides learned lessons and recommendations.

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First of all, I would like to thank my parents, Igor and Jelena Jeganova, my sister Marina, and grandmother Klaudija, for all of their love and support. A special thanks to my boyfriend, Alex Parker, for being the most patient, supportive, optimistic and understanding person in my life. Thank you!

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List of Abbreviations:

CLD Causal Loop Diagram
DFE Design for Environment
EBA Eco Benchmarking Approach
EICTA European Information, Communication and Consumer Electronics Technology Industry Association
EMAS European Eco Management and Audit Scheme
EPA Environmental Protection Agency US
HE Heat Exchanger
JSPD Journal of Sustainable Product Design
ILCM Integrated Life Cycle Management
LCA Life Cycle Assessment
SETAC Society of Environmental Toxicology and Chemistry
UNEP United Nations Environmental Program

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1. INTRODUCTION

Many people have no doubts about the seriousness of environmental problems in the world. But the most important issue is to find the way in which these problems could be solved (Cattanach, Holdreith, Reinke, Sibik, 1995; Gertsakis, Lewis, Ryan, 1997). The report "Our Common Future"(WCED, 1987), which was introduced by the World Commission on Environment and Development, defines the concept of *sustainable development* as the guiding principle for international policy development regarding rational global resource use and fair global distribution of health and wealth. Environmental problems are so complicated that it is not easy to find the right solution. It is important to change current 'Western' consumption and production radically both from technological and from behavioral point of view. Therefore, in my thesis I will investigate how it is possible to influence the environmental impact of the products significantly and directly making them more sustainable for society.

Many multinational companies create innovative solutions for products. But do they take into account environmental impacts when they design a product and how do they integrate environmental aspects into product design?

Design for environment (DFE) is defined as *systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life cycle* (Ray and Guzzo, 1993). Application of DFE is becoming important for industries because major companies start to recognize the importance of environmental responsibility to their long-term success. They experience that DFE provides competitive advantage by reducing the costs of production and attracting new customers (Fiksel, 1996).

My thesis will investigate how to integrate environmental aspects into product design and development process and what kind of stakeholders should be involved in decision-making process. The investigation will be done by analyzing how a multinational company namely Alfa Laval is dealing with environmental issues, and what kind of strategy could be proposed in order to develop Life Cycle Design. Special focus will be given to the eco-benchmarking approach. This method will be investigated if it is an appropriate Life Cycle Design tool for Alfa Laval. The reason of choosing eco benchmarking approach (is described in section 4.5) was that Alfa Laval wants to check if this approach could be as the first step towards integration of environmental issues into product design.

1. 1 Alfa Laval and Alfa Nova

As a leading global provider of specialized products and engineering solutions, Alfa Laval is focusing on three key technologies: Centrifugal Separation, Heat Transfer and Fluid Handling. The company assists their customers in heating, cooling, separating and transporting products such as oil, water, chemicals, beverages, foodstuff, starch and pharmaceuticals. Alfa Laval is one of the best technology leaders in one of its core fields of expertise - heat transfer technology. The **AlfaNova** is the world's first plate heat exchanger made of 100% stainless steel. It's based on a revolutionary innovation in material design and manufacturing method, named and patented as AlfaFusion, which is utilized in the brazing process during manufacturing. It is extremely compact compared to its capacity to withstand temperature extremes and fatigue cycling in demanding heat transfer applications. It has also a very high resistance to corrosion. It has been proved to be the most hygienic heat exchanger. Mainly it is used in domestic hot water heater, process cooling, hydraulic oil cooling, chilled water, and refrigeration[1].

Alfa Nova - stainless steel heat exchanger

[1] Alfa Laval's materials

Alfa Laval believes that Alfa Nova is a *sustainable* and *green* product because it is made of one material that can be recycled; it is hygienic and compact, energy-efficient in consumption; has much wider scope of application than an ordinary brazed heat exchanger. However, Alfa Laval does not consider other environmental aspects in product development process. This is exactly the reason why this thesis is needed for Alfa Laval. This thesis explains what life cycle design of product is, why it is needed and how to consider all environmental aspects in product development. Therefore, eco-benchmarking approach will be described and proposed to apply for Alfa Nova as well as other products of Alfa Laval in order to find out the major environmental impact. Eco-benchmarking approach will be chosen in order to check if it is an appropriate method for Alfa Laval for integrating environmental issues into life cycle design of product.

1.2 Problem Definition

Many multinational companies lack a strategy for integrating environmental aspects into product design. For product life cycle design to be practiced successfully, it is important to adapt it to existing process of product development. Dr Joseph Fiksel claims in an interview for *the Journal of Sustainable Product Design* that it is important not only to understand how the process operates, but also to understand the whole culture of the product development community. He also argues that "product design developers tend to be arrogant, and are generally talented and creative individuals, with strong engineering skills. They tend to be suspicious of anyone who offers help, as well as anyone who seems to complicate their busy lives". (Charter, JSPD, 1998). Decision-making process of product development at Alfa Laval does not include enough stakeholders that could contribute to Life Cycle Design. It seems to be a new concept for managers that life cycle design can be incorporated into the product development process. They prefer to see environmental issues and life cycle design as a separated part of product development when the product has already been created (Interview results, see a list of interviews at the back of the references). Moreover, there are so many environmental aspects and indicators that it is complicated to build a strategy of life cycle design and incorporate it to existing product development process. Alfa Laval's employees see product development as a dynamics process that is changing all the time, and they think that it is very complicated to integrate life cycle design strategy to the dynamics of product development process. They are also confused at which stage life cycle design should be introduced for new and old products [Personal interview].

Alfa Laval just started to work on its environmental management system. It is a new issue for all Alfa Laval's employees. The company started a process of ISO 14001 certification in 2004 with a focus on four manufacturing sites. However, the company experiences a lack of competent people and 'know how' on how to integrate environmental issues into product development. Alfa Laval is one of global leaders in production of technology for the environment. Therefore, it is also important for Alfa Laval to design and produce products with less impact on the environment.

1.3 Scope and Structure of the Paper

The main objective of the thesis is to find an appropriate approach for Alfa Laval that will integrate environmental issues into product development process, and propose some recommendations for building a strategy for integration. For that purpose, interviews with stakeholders of Alfa Laval will be done in order to find the main factors that will be involved in the integration process of environmental issues into current product development process of Alfa Laval. The thesis will investigate if eco-benchmarking approach is an appropriate approach for the beginning stage of eco-design strategy for Alfa Laval.

The structure of the thesis includes five parts: 1) Introduction, 2) Background 3) Literature Review, 4) Analysis and 5) Conclusions and Recommendations. The thesis will be written in the way that will let a reader to understand the theoretical concept of life cycle design and its application in the real life situation. This thesis was planned to be a project thesis for implementation at Alfa Laval Group. My work will also contribute to the preparation process of Alfa Laval for ISO 14001 certification. Moreover, this thesis will be valuable 'guidelines' for Alfa Laval with theoretical and practical information related to product life cycle design and environmental issues in industries.

1.4 Research Questions

The main question: *How to integrate the life cycle design into the product design and development process at Alfa Laval?*

Seven sub research questions have been set:

1) What is operational Life Cycle Design for Alfa Laval's context?

To answer on this question theoretical framework of the literature survey will be used as well as interviewing the stakeholders of Alfa Laval. I will give a theoretical review about a concept of Life Cycle Thinking, Life Cycle Design and its tools.

2) What are the barriers of implementation of Life Cycle Design at Alfa Laval?

A list of common barriers will be formed in order to give an outline about the difficulties in integration the Life Cycle Design into Product Development at Alfa Laval. These key considerations will be drawn from my personal observation and discussions with the stakeholders of Alfa Laval.

3) What are the driving forces for life cycle design at Alfa Laval?

To answer on this question the results of interviewing of stakeholders of Alfa Laval will be shown in Causal Loop Diagram (CLD).

4) What are the stakeholders that are involved in product development and life cycle design process at Alfa Laval? How should they be involved (current and improved situation)?

Decision-making process in design of heat exchanger will be described as a current situation and projected version with incorporation of life cycle design will be proposed. The focus will be on all stakeholders and their role within life cycle design.

5) How should current product development process at Alfa Laval with integrated environmental issues look like? Environmental issues will be integrated in current product design and development process of Alfa Laval by two proposed versions.

6) What kind of approach is needed for beginning stage for life cycle design?

Several approaches will be discussed and compared. Eco-benchmarking approach (EBA) will be investigated and proposed as the first step for life cycle design for HE at Alfa Laval. The position of EBA in proposed Life Cycle Design process and the beginning phase of implementation of EBA will be presented.

7) What recommendations can be given to Alfa Laval Management in order to implement life cycle design, get benefits and avoid barriers?

The conclusions and recommendations for building life cycle design at Alfa Laval will be presented.

1.5 Limitations and Assumptions

The scope of the thesis is limited to the case study of one company. The empirical studies in this thesis are limited to the fact that there is a lack of environmental information, research and analysis within the company. This thesis is the first step for the life cycle design at Alfa Laval, therefore the eco-benchmarking approach will be investigated if it can be proposed as the beginning phase for the whole life cycle design of heat exchangers at Alfa Laval. Conclusions of this thesis are applicable to Alfa Laval only.

1.6 Methodology

This thesis can be defined as an *intrinsic case study* (Stake, 1994). An intrinsic case study is made in order to understand better the situation at Alfa Laval. The case study is an object to be studied because of my interest and an opportunity provided by Alfa Laval. The reason for choosing the case study approach is that I can be a part of the organization and I can study it from within. One may consider it as a strong aspect of my thesis research because the empirical data is collected not only from interviews but also by observation and closer understanding of the situation.

To answer on research questions that have been set, I collected information from two main sources. The first source was social research method – interviewing. Interviews give rich insights into people's experiences, opinions, aspirations, attitudes and feelings (May, 1997). I contacted different stakeholders (Alfa Laval employees, customers and competitors) in order to receive different view on need and use of product life cycle design. I mostly used semi-structured interview method (May, 1997). Questions were normally specified but from answers could appear new questions in order to fill the gaps or go deeper to the topic. All interviewees were related to stainless steel heat exchanger (its design, raw material supply, production, consumption, disposal stages) and product development process. Information was also gathered through telephone and e-mail. The second source was literature survey about theory and practice of life cycle design. This consists mainly of literature on the subject of a concept of life cycle thinking, life cycle design and life cycle design evaluation tools.

In the empirical part 'Analysis', seven research questions will be discussed. Analysis and proposal for change will be based on the interview results, my personal observation, and literature review. Moreover, I will use an adaptive learning method (Senge, 1990) in order to continually discover how to create a change in reality. I will analyze the whole picture of Alfa Laval by identifying internal and external driving forces, actors around product development process and Life Cycle Design, potential barriers of implementation of Life Cycle Design in order to propose a strategy to integrate Life Cycle Design at Alfa Laval. According to adaptive learning method, I continually discover new issues and possibilities at Alfa Laval through my personal experience being there, and reformulate the objectives of my thesis by using the mental models[2]. The company has a dynamic environment. It is changing continually. Therefore, I have chosen to be adaptive. Additionally, an eco-benchmarking approach will be investigated if it can be proposed as the beginning phase for life cycle design at Alfa Laval. The Delphi method[3] should be chosen in order to propose to create a group of experts for decision-making process. This group of experts should be facilitated by a person who is competent in the issues related to life cycle design in order to set environmental criteria for comparison of stainless steel heat exchanger with other heat exchangers. In the section 4.5 (Choosing Appropriate Life Cycle Design Tool for Alfa Laval), the implementation scopes, pre conditions and other criteria were the results of the interviews.

Systems Thinking will be used in order to show visually a cause and effect of the problems with a help of Causal Loop Diagrams. "System thinking is a science that deals with the organization of logics and integration of disciplines for understanding the patterns and relations of complex problems"(Haraldsson, 2004). Systems Thinking is known as a set of principles of theory of self-organization which involves a "systematic" or "holistic thinking". Systems Approach to Management allows to "identify, understand and manage interrelated processes as a system in order to contribute to the organization's effectiveness and efficiency in achieving its objectives" (Karl-Henrik Robérts, 2004).

1.7 Hypotheses

Life Cycle Design should be developed at Alfa Laval in order to integrate environmental aspects into current product design and development process of the company. It will demonstrate that Alfa Laval really follows its environmental business principles[4]. In order to build and implement Life Cycle Design, the following steps should be taken at Alfa Laval:

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[2] Mental models are assumptions, generalizations, or even pictures and images that influence how we understand the situation and how we take actions. It is an ability to have a "learningful" conversation where people expose their own thinking effectively and make that thinking open to the influence of others (Senge, 1990).

[3] The Delphi method is an exercise in group communication among a panel of geographically dispersed experts (Adler and Ziglio, 1996). This method is used in order to allow the experts to deal with a complex task or generate forecasts.

[4] See Environmental Business Principles of Alfa Laval at
http://www.alfalaval.com/scripts/WebObjects.dll/ecore.woa/wa/showNode?siteNodeID=4385&contentID=-1&languageID=1

1) understanding of concepts of life cycle thinking and life cycle design by the employees of Alfa Laval,
2) identification of internal and external driving forces of Life Cycle Design at Alfa Laval,
3) identification of barriers of implementation of Life Cycle Design at Alfa Laval,
4) building a model of integration of environmental aspects into current product design and development process at Alfa Laval,
5) eco benchmarking approach, as a relatively new tool of Life Cycle Design, should be chosen as an appropriate Life Cycle Design tool for Alfa Laval,
6) a competence team of environmental specialists among other competence teams should be build[5] in order to facilitate dynamics of life cycle design in product development process, and be a part of decision-making process about innovations and developments,
7) identification of stakeholders around Life Cycle Design at Alfa Laval.

2. BACKGROUND

2.1 Unsustainable Consumption and Production

The level of global consumption has expanded dramatically: growing as much as four-fold since 1960 and reaching 24$ trillion in 1998 (Robins, JSPD, 1999). In 1992, it was recognized by the Earth Summit that "the major cause of the continued deterioration of the global environment is the unsustainable pattern of consumption and production, particularly in the industrialized countries, aggravating poverty and imbalances" (UNCED, 1992). In the beginning of 90s, the society started to witness a growing consensus that something must be done about consumption and production. Sustainable consumption and production should be viewed in a strategic perspective where the task is "to create the conditions which will improve the capacity to choose, use and dispose goods and services sustainably" (Robins, JSPD, 1999). The workshop "Consumption in a Sustainable World" at Kabelvag showed that there are many bright examples of changing the action in policy, corporations and action of citizens towards sustainable development. But How should *We* start? The first step should be focused on the sustainability of goods and services produced by the multinational companies in emerging economies. According to the Third World Network, these multinational companies "are responsible for most of the world's resource extraction, pollution and generation of consumer culture" (Third World Network, 1997, Robins and Roberts, 1997). However, not only the multinational companies should be responsible for unsustainable production but also the consumers' choice and behavior can dramatically influence the producer culture.

2.2 Terminology

Design for environment (DFE) is defined as *systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life cycle* (Ray and Guzzo, 1993).In the end, it should lead to sustainable production and consumption that can be achieved together with a number of other measures that are very important, for example, legislation. ***Life Cycle Design*** integrates environmental issues into product development by considering all product life cycle stages: raw material acquisition, manufacturing, use, distribution and disposal (Keoleian, Koch, Menerey, 1995).
There are many other terms that relate to the life cycle design: eco-design, design for the environment, life cycle design, and environmentally conscious design and production (Brezet and Van Hemel, 1997). ***The product life cycle*** is a model that contains and describes all the processes that are necessary for the extraction and processing of raw materials, production, distribution, consumption and disposal of the product (Figure 1). ***Environmental***

[5]As a successful example can be mentioned IBM Centre of Competence which is supported by IBM's Engineering Center for Environmentally Conscious Products (ECECP) at Research Triangle Park, North Carolina. The ECECP is a center of competence for DfE activities and a resource for division of environmental specialists, product development and procurement engineers, suppliers and product recycling centers. IBM's Competence Center manages the Product Environment Profiles in order to monitor and document the environmental characteristics of products (IBM, Product Stewardship, 2004 [online]).

impact is the material influence on the environment. ***Environmental criteria*** are product-oriented and production process- oriented solution strategies that lead to less environment damaging products (Bakker, 1995).

Environmental impact is any change to the environment which can be adverse or beneficial. This change comes from activities, products or services of the company. It is important to notice that environmental impact can be positive. For example, production of heating (for district heating purposes) harms the environment, but the overall impact is less than if all households have their own boiler (Brorson and Larsson, 1999). ***Eco-benchmarking approach*** is a method that integrates environmental aspects into product design. This method is based on the assessment of five focal areas: energy, material and weight, packaging, potentially harmful substances, and recyclability (Boks and Stevels, 2003). Eco-benchmarking approach is chosen to be checked if it is an appropriate method for start phase of life cycle design.

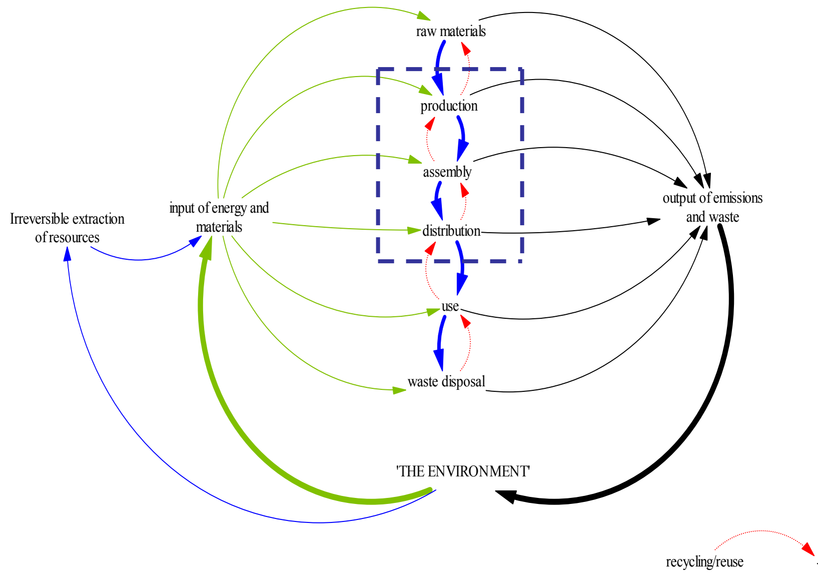

Figure 1: Flow Chart of Materials: *Adapted Life Cycle Concept*
(Source: Bakker, 1995)

2.3 Model of Thesis Problem

Using my advantage to be within Alfa Laval, I observed the situation and sketched a problem. The broad problem can be visually displayed in the figure 1. The figure shows the life cycle concept that involves all the processes in decision-making process in the company from the extraction and processing of raw materials, production, distribution, consumption and to disposal of the product. A dark blue striped box shows the stages of the product that Alfa Laval is concerned about the most. It is mainly production and distribution. Alfa Laval usually has good communications with the stakeholders of these stages in product development. But, unfortunately, there is not enough information as well as communication with the suppliers of raw material about their environmental programs and performance; about the customers' demands towards environment and environmental impact of the product in consumption stage; about product end-of-life stage, and etc (personal interview). It should be noted that I adapted the Life Cycle Design concept of Bakker (1995) by dividing 'the environment' into two types of resources: irreversible extraction of resources and reversible extraction of resources (the last term is included in 'the environment'). 'The environment' illustrates all the natural capital together with input of emissions and waste. It is important to mention here about the biggest ecological concern in the society: growing irreversible extraction of resources which may lead to the end of these resources. Moreover, pollution and emissions dominate in 'the environment'. Therefore, industries should be aware of material flow in life cycle concept and future risks of availability of resources.

The information flow and communication circle about the environment[6] is very limited. It is only within Alfa Laval itself or sometimes there is no information at all. The communication loop is not even closed because information may go from one direction but it can end up nowhere (without any feedback) (Figure 2). This situation appears not only at Alfa Laval but also in many other

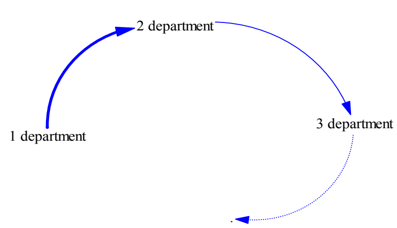

Figure 2: Flow Chart: *Communication flow cycle at Alfa Laval*

[6] Here I talk about information such as environmental reports, environmental performance, 'conservation of environment' as one of the business principles at Alfa Laval, environmental certification and other activities related to environment

multinational companies (Polonsky, Rosenberger III, Ottman, JSPD, 1998).

The reason is that only recently the companies started to pay attention on the environment. Different driving forces will be described and discussed in thesis that really pushed the companies to go towards the environmental awareness.

Another important aspect of the problem is *attitude* of Alfa Laval's working team towards product life cycle design. This attitude can be formulated in the statement: "We know that we produce environmentally-friendly products that really help to solve environmental problems. Why do we need life cycle design of these products?" This statement exists at Alfa Laval. The reason of such statements can be found in a lack of knowledge about life cycle design and environmental coordination. Moreover, a decision-making process in product development does not include environmental aspects and impact because of a lack of Competence Team of environmental specialists and overall awareness and knowledge of decision-makers.

More specifically, the problem can be illustrated in the figure 3 where, with a help of a causal loop diagram, the reasons of the problems are shown. A Causal Loop Diagram (CLD) is presented in order to understand a problem and show a solution. The Causal Loop Diagram concept was firstly discovered in sixties by Jay Forester (1961) and further developed by Rosnay (1979), Richardson and Puch (1981), Senge (1990) and Sterman (2000). The CLD's are used in order to understand the behavior of the problem and develop the strategies to solve it or counteract the behavior. "CLDs describe the reality through causalities between variables and how they form a dynamic circular influence" (Haraldsson, 2004). The CLD describes the perpetuations of change through a system. It is complementary to a flow diagram which describes the perpetuation of mass, energy or information through a system.

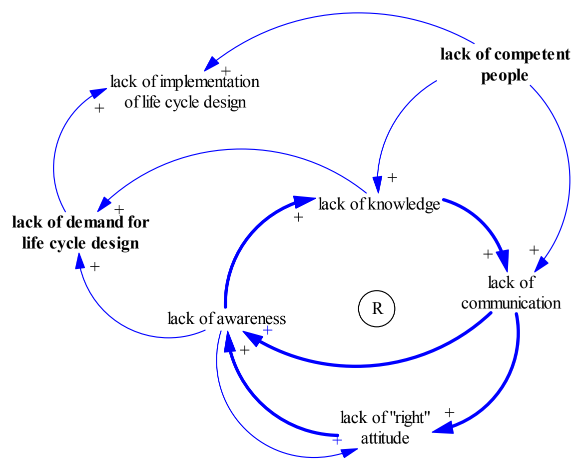

Figure 3: CLD : *Initial Model of Thesis Problem*

The main question of this CLD is: Why life cycle design is not implemented at Alfa Laval? You can "read" from the CLD that the main reasons are: lack of knowledge about environmental issues - lack of communication – lack of the "right" attitude towards environment – lack of awareness about environmental issues – lack of competent people. All these reasons lead to the lack of demand for life cycle design. Due to this, there is no implementation of life cycle design at Alfa Laval. It should be noted that this CLD illustrates a problem within Alfa Laval, not taking into account external factors which will be analyzed in chapter 'Analysis'.

2. LITERATURE REVIEW

This chapter provides a theoretical framework for the empirical part of the thesis. The literature review is divided into six main parts. The first part provides the concept of life cycle thinking (with an explanation and examples of application) as the first step that should be integrated in a company (Section 3.1). The second part of literature review is dedicated to life cycle design concept, its goals, principles and process (Section 3.2).Next part is focused on Integrated Life Cycle Management. It summarizes life cycle thinking and life cycle design concept in order to give a framework that includes all decisions and actions taken by different stakeholders who determine the environmental profile and sustainability of the product system (Section 3.3). One section is dedicated to the essence of Stakeholders Management for Life Cycle Design. It explains three levels of stakeholders that are involved in product life cycle design (Section 3.4).

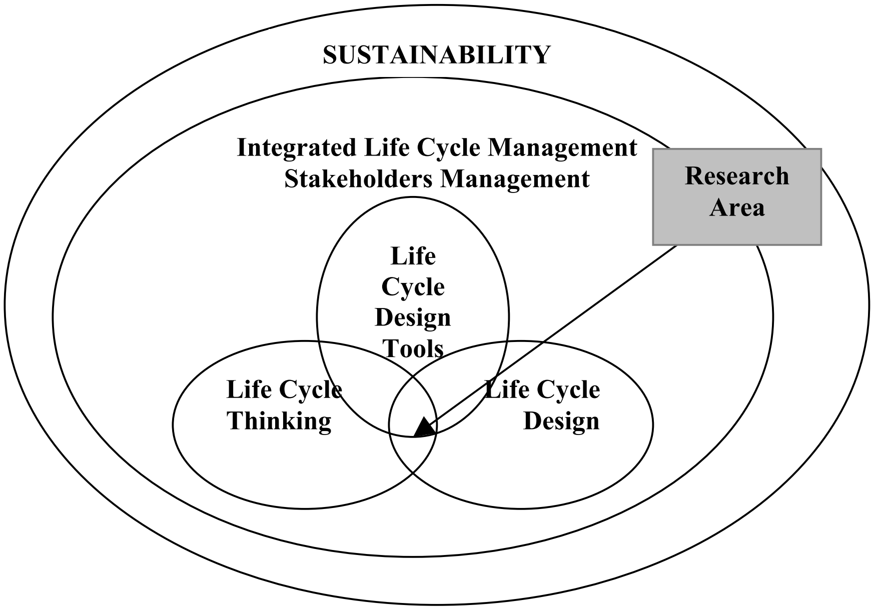

Figure 4: *Literature Concept Map*

The next part explains connection between life cycle thinking and life cycle design and sustainability. In this part I also argue about the use of sustainability concept in product design (Section 3.5). In Section 3.6, six selected life cycle design tools, methodologies, databases, approaches and application of them are described. In this chapter I also concentrate more on eco-benchmarking approach because this approach will be applied to Alfa Laval's stainless steel heat exchanger in the empirical part of the thesis in order to check if this method is appropriate for Alfa Laval as a start phase of life cycle design. A relationship between these six theoretical parts is shown in Figure 4.

3.1 Life Cycle Thinking

Before beginning to introduce life cycle thinking, I want to mention that life cycle thinking should be accepted and integrated by a company and its stakeholders in order to launch a life cycle design process. It means that the stakeholders and, especially, the employees of a company should understand the essence of life cycle concept because 'successful' implementation of life cycle design demands awareness and participation of a wide range of stakeholders. Therefore, life cycle thinking will be introduced as an initial step towards integration of environmental aspects into life cycle design.

Before discussing the essence of life cycle thinking, it is important to define it. The only formal definition that I could find was at UNEP web pages. According to Executive Director of UNEP Klaus Toepfer (2004), "Life cycle thinking implies that everyone in the whole chain of a product's life cycle, from cradle to grave, has a responsibility and a role to play, taking into account all the relevant external effects. The impacts of all life cycle stages need to be considered comprehensively when taking informed decisions on production and consumption patterns, policies and management strategies" (Klaus Toepfer, Executive Director, UNEP, CIRAIG, 2004). From Toepfer's statement one may conclude that life cycle thinking has two main ideas. First of all, life cycle thinking should be integrated into all activities, strategies and policies within a company. Secondly, it demands commitment and participation of all stakeholders during product life cycle (interdisciplinary teamwork of multistakeholders).

However, many multinational companies use life cycle thinking concept only as the basis of environmental activities. For example, NOKIA believes that life cycle thinking strategy is a "circular process that begins and ends with the use of raw materials in the most efficient way" (NOKIA, 2004). NOKIA's aim is to reduce adverse environmental effects during product's life cycle (see figure 5).

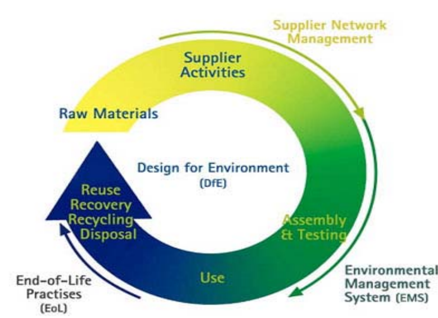

Figure 5: Life Cycle Thinking Concept of NOKIA, Source:: http://nokia-asia.com/nokia/0,8764,27261,00.html

The Life Cycle Initiative was launched by UNEP with the mission to “develop and disseminate practical tools for evaluating the opportunities, risks, and trade-offs, associated with products over their whole life cycle” (UNEP, 2004).
UNEP Life Cycle Initiative has the goal to foster life cycle thinking around the world by developing an international life cycle management framework. The Malmö Declaration was the start for UNEP to launch the Life Cycle Initiative in 28 April, 2002. Moreover, life cycle thinking was such an important issue that the Malmö Declaration was reinforced at the World Summit on Sustainable Development in September 2002 (UNEP, 2004).
According to EICTA[7], Life Cycle Thinking method is the most appropriate method for European companies. Life Cycle thinking tools check if product design complies with the criteria that have been set on energy use, packaging, end of life issues and hazardous substances in the early stage of the product design. Due to this, the problems can be identified and solved already in the early stage of product design which will lead to no delays in time. The practice showed that Life Cycle thinking tools, for example such as ECMA-341[8], are already used in many multinational companies in Europe and showed good results (EICTA, 2003).

In conclusion, life cycle thinking is the essence of life cycle design (Behrendt, Jasch, Peneda, van Weenen, 1997). It must be considered, understood and accepted by a company before starting to elaborate life cycle design.

3.2 Life Cycle Design

This section provides a brief introduction into life cycle design; however, a more complete explanation of life cycle design principles, goals and processes will be described after this section. As it has been defined before, Life Cycle Design (more recent name of life cycle design, which one may meet in a recent literature, is eco design (Kirkels, Noort, Nunen, Schjindel, 2004)) integrates environmental issues into product development by considering all product life cycle stages: raw material acquisition, manufacturing, use, distribution and disposal (Keoleian, Koch, Menerey, 1995). It is the product development by applying environmental criteria in order to reduce the environmental impacts during all the stages of the product life cycle (Bakker, 1995) (see Figure 1.1). According to Keoleian, Koch, Menerey(1995), this product development process should consider the product system that contains three main elements: product, process, and distribution. These elements are interconnected and have a key role in life cycle design process. According to Keoleian, Koch, Menerey (1995), Life cycle design has requirements which should be developed through a team-oriented process which involves as many stakeholders as possible. In order to succeed a design strategy, Product Life Cycle Design Team[9] should understand the relationship between environmental, performance, cost, cultural, and legal requirements of the product system.

Life Cycle Design Goals

According to Behrendt (1997), the main goal of life cycle design is to reduce the total *environmental burden*[10] from product development by finding sustainable solutions for the needs of society. The second main goal of life cycle design is to achieve sustainable development[11] which consists of the following main elements: sustainable

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7 EICTA - European Information, Communications and Consumer Electronics Technology Industry Association - combines 43 major multinational companies as direct members and 29 national associations from 19 European countries. EICTA altogether represents more than 10,000 companies all over Europe with more than 1.5 million employees (EICTA Position paper, 2003).
8 ECMA – 341 is a standard for environmental design consideration for electronic products (www.ecma.ch)
9 Product Life Cycle Design Team involves chosen stakeholders (external and internal) of the product together with Competence Team of environmental specialists at Alfa Laval
10 Environmental burden has two impact categories: resource depletion and ecological and human health effects (Keoleian, Koch, Menerey, 1995)
11 Sustainable development meets the needs of the present generation without compromising the ability of future generation to fulfill their needs (WCED, 1987)

resource use[12], pollution prevention, maintenance of ecosystem structure and function, and environmental equity (Keoleian, Koch, Menerey, 1995; Miller, 2001). Another goal of life cycle design is to promote sustainable resource use. Depletion of nonrenewable resources and overuse of renewable resources limit their availability to future and future generations. There can be no product development without available resources. Moreover, life cycle design is focused on promotion of pollution prevention strategy that minimizes raw material losses and reduces long-term liabilities. Life cycle design protects ecological and human health. According to EPA's Science Advisory Board, the biodiversity and species loss are among the most severe risks to human health and the environment (EPA, 2004). Finally, life cycle design strategy promotes environmental equity[13].

In conclusion, it should be noted that life cycle design is based on the fundamental idea that a manufacturer should prevent and reduce energy and material input and output, as well as material diversity and the use of hazardous waste. Negative environmental impact should be prevented or reduced during all life cycle stages.

Life Cycle Design Principles

According to the Life Cycle Design Guidance Manual (EPA 600/R-92/226), there are three main principles for guiding environmental improvement of product systems in life cycle design: 1) Systems analysis of the product life cycle; 2) multicriteria analysis for identifying and evaluating environmental, performance, cost, cultural, and legal requirements; 3) multistakeholder participation and cross-functional teamwork throughout design. A systematic approach is needed in order to understand interrelationships between social needs, industrial systems that provide goods and services, political and regulatory systems, and ecological systems that have been influenced by human action. In multicriteria analysis, specification of requirements is very essential. There should be not only environmental requirements, but also social, economic and legal requirements. In order to set the requirements that reflect the needs of different stakeholders (suppliers, manufacturers, consumers, resource recovery, waste managers, etc.), interdisciplinary teamwork of multistakeholders is needed.

It is important to underline that interdisciplinary teamwork of multistakeholders is essential in life cycle design. In my opinion, interdisciplinary cooperation in a complex problem or task (I claim here that product life cycle design is a complex task), that include different aspects, demands active participation and involvement of different specialists in order to succeed effective implementation of product life cycle design. I believe that life cycle design will be completely implemented and facilitated only by a Life Cycle Team which consists of different specialists.

Life Cycle Design Process

After building an interdisciplinary multistakeholder life cycle team, understanding and integration of life cycle thinking, and development of life cycle design goals and principles, life cycle design process should be elaborated. Koeleian and Menerey (1993), have elaborated and offered a useful plan to build Life Cycle Design Process (see Figure 6) that consists of six main steps: 1) Developing of Life Cycle Framework and Goals , 2) Building Life Cycle Team and Elaborating Strategies and Policies (Integration of Life Cycle Thinking idea), 3) Analyzing needs of Stakeholders (Stakeholders Management), 4) Setting Life Cycle Design Requirements, 5) Developing Product Design, 6) Implementing Product Design.

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[12] Conservation of resources, minimization of depletion of non-renewable resources, etc.

[13] "The concept of environmental equity implies that some populations, particularly minorities and those of low income are disproportionately exposed to environmental injustices. The major concern of environmental equity is expressed in the idea that minority and low-income residential neighborhoods are most proximate to elevated concentrations of environmental hazards such as waste treatment facilities, waste dumps, incinerators, landfills, and other industrial and commercial toxic release sites" (EPA,2004).

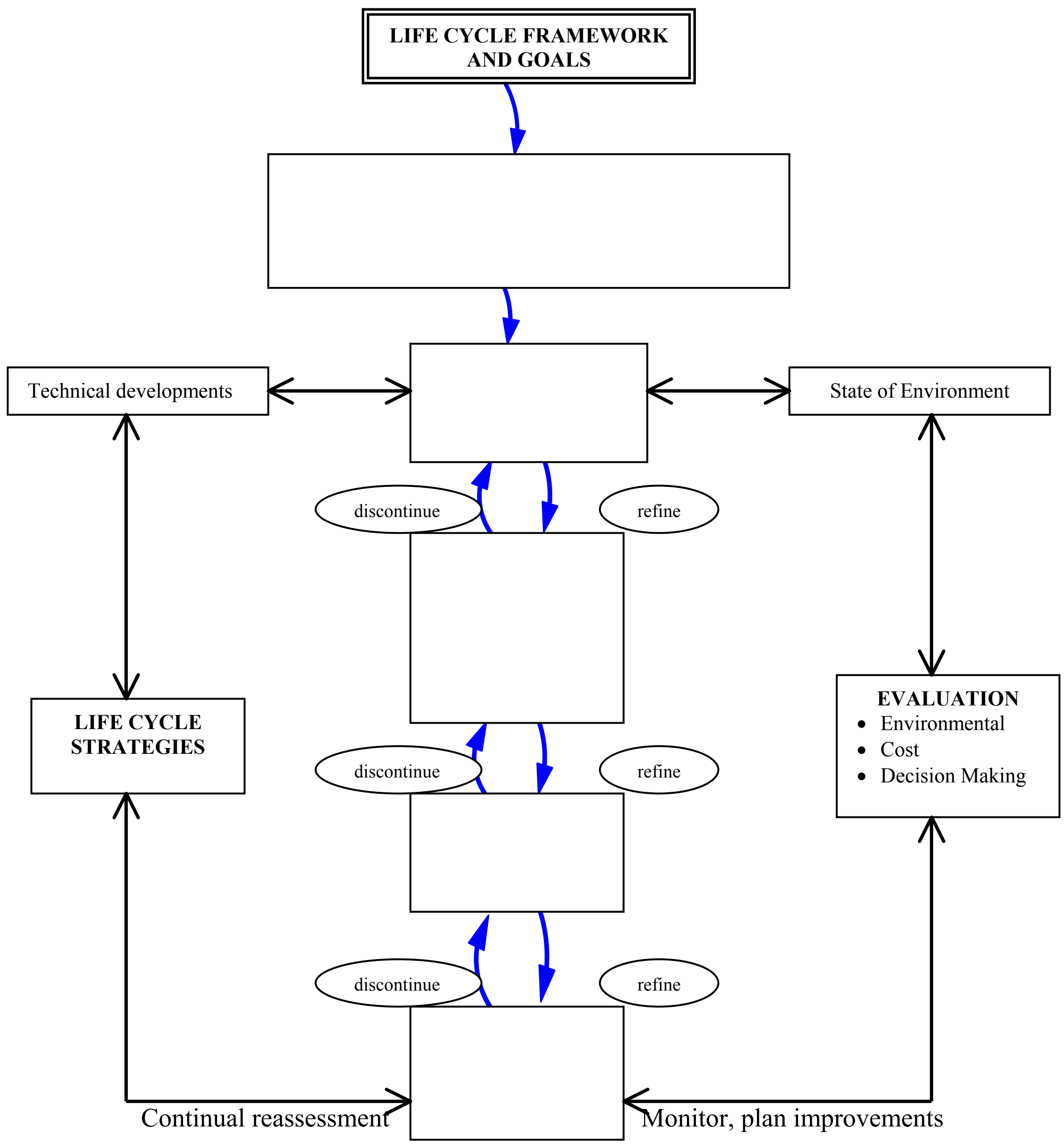

Figure 6: Flow Chart: *Life Cycle Design Process*, Source: (Keoleian, Menerey, EPA)

As Figure 6 shows, product development is a complex system. In the diagram life cycle goals are very important, therefore they are located at the top. Management influences all the stages of life cycle design process. Concurrent design and life cycle quality provide models for life cycle design. Moreover, measures of success, life cycle team coordination, and policy, strategy are needed in order to support all life cycle design process with design projects.

According to Gregory Koeleian and Dan Menerey, a typical design project begins with a needs analysis that identifies customers' needs and ideas of a company. Here I also add that not only customers' needs and interests should be analyzed but also other stakeholders' needs and interests (suppliers, government, competitors, consumer and environmental organizations). After identification and analysis of the needs, the project team formulates the requirements. Requirements can be set with a use of Requirements Matrix that allows project team to study the interactions between life cycle requirements. Matrices are effective for organizing data and evaluating it later. After development of requirements, project team evaluates conceptual, preliminary and detailed design. Before implementation, a detailed design is compared to benchmark products. All the weaknesses, minor problems and unclearness can still be corrected. After formal approval of a detailed design, it can be implemented. Implementation includes production, distribution, marketing and labeling.

However, there are several barriers that can limit life cycle design process:

8) lack of data for determining life cycle impacts,
9) lack of motivation within a company,
10) reduction of total impacts may increase local impacts (Keoleian, Menerey, EPA, 1993).

Unless life cycle goals are embraced by development teams, true life cycle design is impossible
(Koeleian, Menerey, EPA, 1993)

3.3 Integrated Life Cycle Management

Before continuing a theoretical discussion on Life Cycle Design, Integrated Life Cycle Management should be explained. One may notice by looking at the second step of Life Cycle Design Process diagram (see Figure 6) a concept of Integrated Life Cycle Management (ILCM). As David Cohan (Fiksel, 1996) defined, ILCM is "a comprehensive and flexible life cycle framework for making planning, design, and operating decisions, explicitly considering costs and other fundamental business metrics together with environmental, health, and safety factors"(Cohan: Fiksel, 1996). That means that ILCM includes all decisions and actions taken by different stakeholders which determine the environmental profile and sustainability of the product system (Keoleian, Menerey, EPA, 1993). According to Keoleian, Koch and Menerey (1997), Integrated Life Cycle Management can be influenced by external and internal factors (see Figure 7).

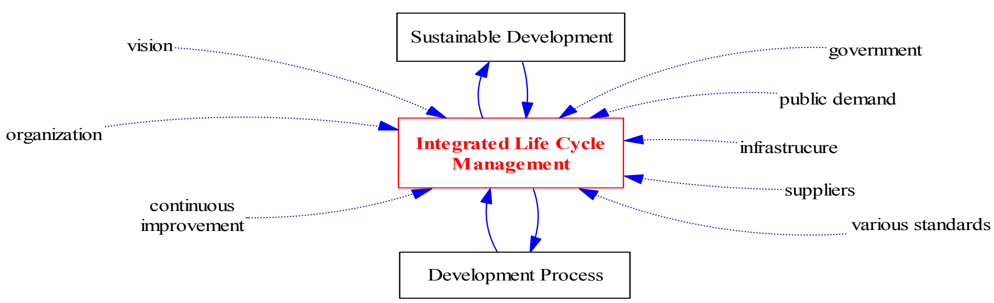

Figure 7: Flow Chart: *Internal and External Factors Influencing the Development Process,* Source: (Keoleian, Koch, Menerey,EPA, 1997)

Internal factors are illustrated on the left side of Figure 7. And external factors, such as government, public demand, infrastructure, suppliers' demand and standards, are on the right side of the figure. The factors influence the product development team's *ability* to effectively address environmental issues through design. The concept of sustainable developments is located at the top, which means that all the elements of Figure 7 are influenced or interconnected to the principles of sustainable development.

It is important to notice that some internal and external factors are the stakeholders of a company. For example, suppliers, government, society, organization, etc. (see Figure 7). Therefore, it is essential for a company to organize a good Stakeholders Management.

3.4 Stakeholders for Life Cycle Design

In order to succeed the implementation of Life Cycle Design, involvement of different stakeholders is essential. According to Behrendt, Jasch, Peneda and van Weenen (1997), stakeholders, who are involved in life cycle design, can be divided into three levels according to the importance of their involvement (see Figure 8).

The most important stakeholders of life cycle design are in a Design Team. Design Team elaborates and facilitates Life Cycle Design process. Usually it consists of designers, constructors, product managers, sales and marketing managers, and environmental and safety experts. The successful introduction of LCD depends on the commitment of product managers (Keoleian, Menerey, 1993). They should control that product projects are applied in the environmental requirements. Marketing managers define market and environmental characteristics of a product by analyzing environmental performance, price levels and customer profiles.

In the second level, the stakeholders of the whole product chain (production, operation, distribution, supply, packaging, etc.) are involved. Especially good cooperation with suppliers in environmental programs is important because it enables a company to have environmentally certified materials and components. In the third level, customers, government, stockholders, environmental organizations can play a role of a driving force towards implementation of life cycle design.

However, in my opinion, there can not be the same common picture of stakeholders for Life Cycle Design for all companies. Each company should identify, prioritize, and involve stakeholders in Life Cycle Design process individually and according to the company's Life Cycle Design goals. For example, I can argue that a group of big customers and suppliers should be named not as external stakeholders but as a part of a Design Team. Big customers and suppliers should be involved in Life Cycle Design decision making process (Johansson, 2001). According to McAloone (1998), the supplier network can provide important information in choosing environmental alternatives of materials, components and process. The customers are the one that can contribute in identification and determination of environmental criteria and profile of a product.

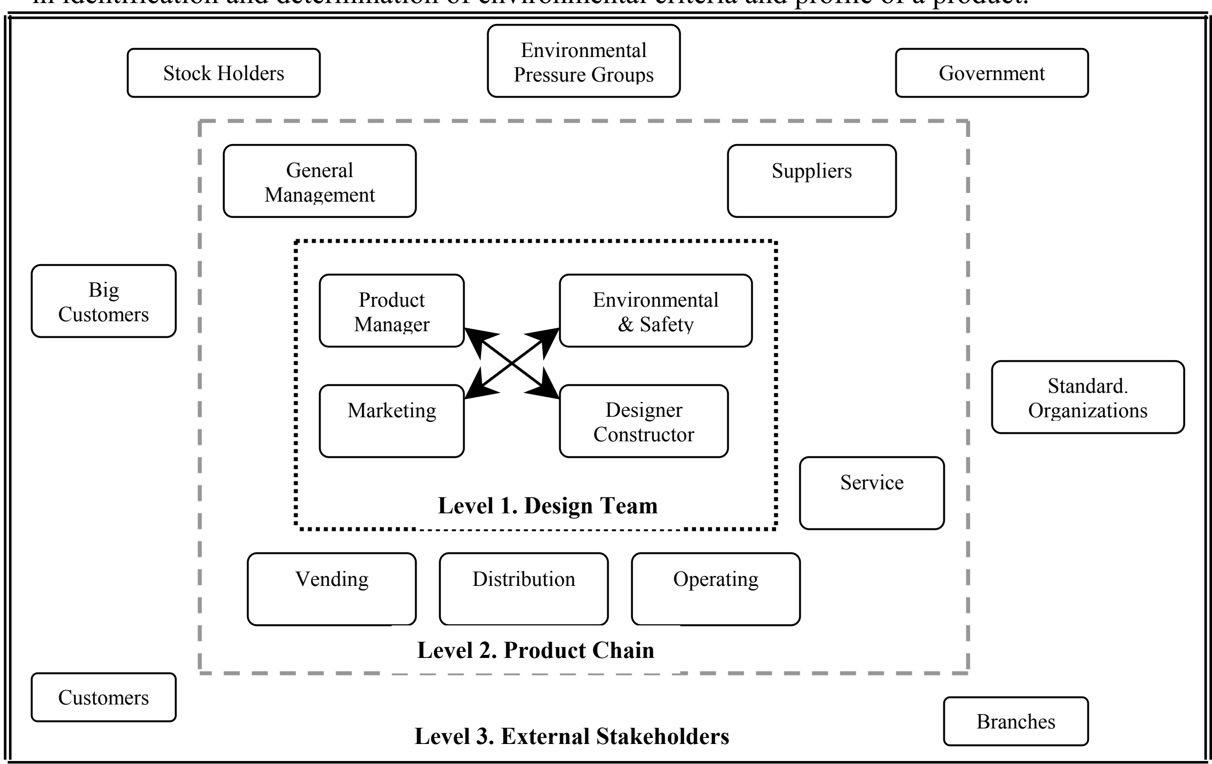

Figure 8: *Stakeholders for Life Cycle Design*, Source: Behrendt, Jasch, Peneda, van Weenen, 1997

3.5 Product Life Cycle Design and Sustainability

One may notice that the concept of sustainable development is shown and mentioned almost in all sources and is illustrated in many figures, diagrams and pictures. Now the companies started to be more interested in "sustainable" strategies than in "environmental" strategies [personal interview]. However, not always the industries understand the essence of the concept of sustainable development.

Before discussing Life Cycle Design and Sustainability, I would like to introduce a figure (Figure 9), which was elaborated by Yale School of Forestry and Environmental Studies, which illustrates the way of achieving sustainable development by implementing a strategy of sustainable production or "sustainable business". I have chosen this Figure (Figure 9) because it clearly illustrates the place of Life cycle thinking, Life Cycle Design (it is named as Environmental Conscious Design & Manufacturing at the Figure), Single Product Lifetime, Society, and Sustainable Development. Starting from a single product and going forward to industrial parks with multiple manufacturers to the whole society can be a strategy or one of potential solutions how to start a journey towards sustainable development. However, there are many other ways to achieve sustainable development.

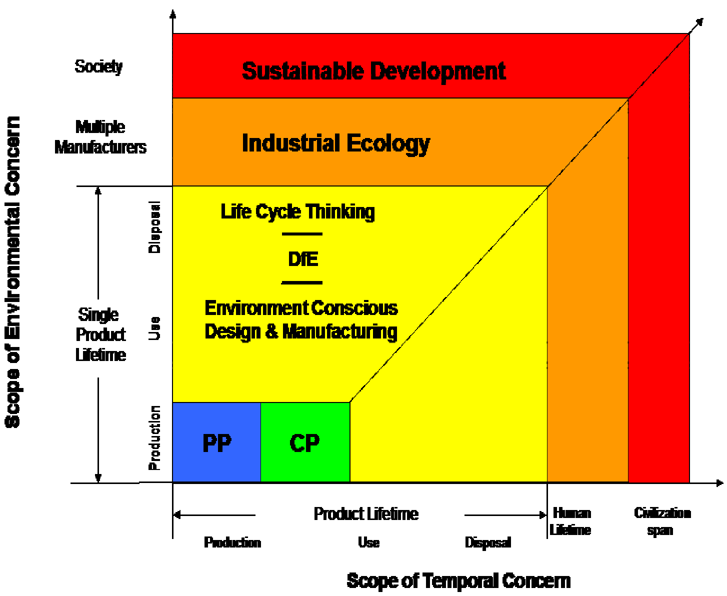

Figure 9: *Moving Towards Sustainability*, Source: WasteWise Update, US EPA, EPA530-N-00-002, March, 2000
Abbreviations in Figure 1.8: PP-Pollution Prevention, CP – Control of Pollution, DfE – Design for Environment

The transition from a linear to a sustainable will probably not happen for some years. It will need many radical changes in society. If we follow the history of development of sustainable development in production or business sector, we can see that it started with the *'end-of-pipe' thinking*. Industry, policymakers, society looked at the effects of pollution after it has been created. Policymakers started to push industries to manage better the pollution they created (for example, cleaning wastewater, installing filters, etc.). After several decades, industry and government started to realize that it is both economically and environmentally beneficial to *prevent pollution* by designing *eco-efficient products and processes* (eco-efficiency). Now pollution prevention is still the first environmental strategy for many companies. However, more and more industries started to integrate the concept of *sustainable development* considering not only economic and environmental dimensions but also *society and social needs*.

Now the companies started to think how not only to prevent pollution but also save natural resources for future generations. However, one may criticize the industries for putting the word 'sustainable' for everything without a real understanding and explanation what it is and how to achieve it. I was trying to find out the meaning of the concept *sustainable product design* in many sources where they mention this concept. However, there was no clear definition or explanation. Due to this, one may argue that perhaps nobody knows what sustainable product design is and how to achieve it.

3.6 Approaches, Tools, Databases, Methodologies for Life Cycle Design

This section provides a brief theoretical descriptive analysis of tools, approaches, databases, and methodologies for Life Cycle Design. A framework Design for Environment and Five Life Cycle Design tools, such as Eco Design Strategy Wheel, Eco Indicators, Life Cycle Assessment, MET matrix, and Eco Benchmarking Approach, are shortly introduced at the beginning of this section. In order to show a comparison between the tools, I have chosen to build a table with criteria for Life Cycle Design tools (see part Analysis). In the thesis part 'Analysis', eco-benchmarking approach is proposed as an appropriate tool for start phase of Life Cycle Design of stainless steel heat exchanger at Alfa Laval.

Design for Environment

It is important to clarify a term *Design for Environment* before discussing Life Cycle Design tools because one may be confused by understanding from literature sources that Design for Environment is one of Life Cycle Design tools. Design for Environment is not a tool but is a framework that includes Life Cycle Design tools. According to Ray and Guazzo (1993), ***Design for environment*** (DFE) is defined as systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life cycle (Ray and Guzzo, 1993). This concept was created in 1992 by a number of electronic firms that were attempting to build environmental awareness in product development. The American Electronics Association was a first initiator of DFE (AEA, 1992). After that, this concept started to be used widely by many industries that wanted to integrate environmental awareness into product design.

Gertsakis, Lewis and Ryan (1997) defined 15 strategies of "design for environment" (eco design or Life cycle design as synonyms) concept: design for resource conservation, design for environmentally preferred materials, design for cleaner production, design for efficient distribution, design for energy efficiency, design for water conservation, design for minimal consumption, design for low-impact use, design for durability, design for re-manufacture, design for re-use, design for disassembly, design for recycling, design for degradability, design for safe disposal. Moreover, Simon (2000) provides a concept of DFX, where X can be any environmental criteria. It depends on a company and designers to choose these criteria. It should be noted that the concept of design for environment covers whole life cycle of a product. Therefore, different "design for environment" strategies and tools apply to different life cycle phases.

Bakker (1995) describes a method of "design for environmental efficiency". In the Dutch manual for environment oriented product development (Bakker (1995): Brezet et al, 1994) it is called as 'product analysis', and Wenzel (1992) defines it as "rationalization of product function and product structure" (Wenzel, 1992). The purpose of this method is to improve efficiency and effectiveness of product's functions, and reduce the environmental impact of the product. This method is based on existing design approaches, like for example value analysis (or value engineering), which objective is to increase the value of the product for the purchaser and reduce the costs for its producer. This method can be used in detailed design stage (see Figure 6 Life Cycle Design process) in order to improve negative side-effects (Bakker, 1995).

Limitations: However, one may notice from elaborated strategies of DFE that mostly these tools are related to end-of-life and production phases. Additionally, DFE is still a concept which has a variety of tools.

Eco Design Strategy Wheel

The Eco Design Strategy Wheel is an element of the Sustainable Value software which was developed by Delft University of Technology in the Netherlands. This tool is used in order to improve environmental performance of a product by prioritizing 7 environmental strategies: selection of low-impact materials, reduction of materials use, optimization of techniques, optimization of distribution system, reduction of impact during use, optimization of initial life time, optimization of end-of-life system (See Figure 10). According to the statement at Delft University, the Eco Design Strategy Wheel is a "graphical representation of all possible Eco design strategies throughout the lifetime of a product" (TUDelft, EcoQuest, 2004). According to Bakker (1995), the eco-wheel can be used in order to: 1) generate ideas, 2) select between strategies, 3) make environmental 'product portfolio'.

Limitations: It can be mostly used as a general framework or a starting point to identify the needs and generate the ideas of life cycle design strategy. The Eco Design Strategy Wheel usually does not describe the resulting separate

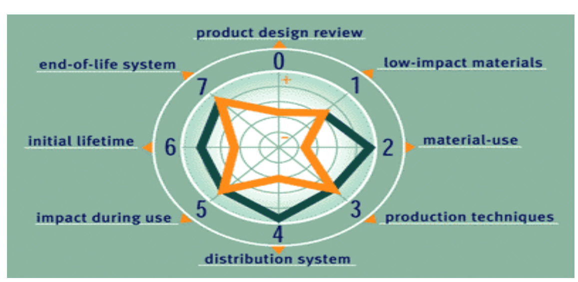

Figure 10: *Eco Design Strategy Wheel* ,Source:,*http://www.io.tudelft.nl/research/dfs/ecoquest/welkom/Entry.html*

environmental effects (Brezet and van Hemel, 1997).

Eco Indicators

Before discussing *Eco Indicator 99* tool, it should be mentioned about development of this tool. In 1993, the Netherlands started a project "Eco Indicator" in order to develop an *environmental indexing*[14] procedure for product development. This project was done in cooperation with Dutch industries and research groups from Switzerland and Scandinavia. According to Bakker (1995), the valuation in this project was divided into two parts: normalization and evaluation. In normalization, the aggregated data per impact category is related to the level of environmental impact of an average European per year. This gives the relative magnitude of different environmental impacts. The evaluation part has been calculated for each environmental impact reduction factor by the *Institute of Public Health and Environmental Protection* in the Netherlands.

According to PRé Consultants (life cycle specialists), Eco Indicator 99 scores or factors are based on the methodology which transforms inventory data into damage scores which can be aggregated. The methodology is used for calculation of indicator values for a large amount of processes and materials that are used constantly. This method has been successfully used in Philips for calculating several hundred scores for specific materials for products, mostly batteries and electronics (Godkoop and Spriensma, 2000). At the beginning I was confused if eco indicators can be an alternative to LCA methodology. Later I clarified that eco indicators are used for materials databases to give the values. For example, Idemat is a database which uses "EcoIndicator 95/99" values, and can be used as a tool assisting eco design[15].

Limitations: According to Godkoop and Spriensma (2000), Eco Indicator is mainly an indicator for (toxic) emissions. However, it has been improved during last years, and some companies use it as the main strategy for design or as supporting tool for the main strategy.

Life Cycle Assessment

Life Cycle Assessment (LCA) has been recognized and internationally accepted as one of the most 'popular' life cycle design techniques for evaluating environmental performance [personal interview][16]. However, this approach has also been often criticized by many life cycle specialists (Godkoop and Spriensma, 2000).The initiator and creator of LCA method is the Society of Environmental Toxicology and Chemistry (SETAC). The first manual of LCA method was published in 1992 providing a work of three Dutch institutes[17] (SETAC report, 1997).

A complete definition was given by SETAC (1991):

"A LCA is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and develop opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing of raw materials; manufacturing, transportation and distribution, reuse, maintenance; recycling, and final disposal."

LCA method has four main components: 1) goal definition and scoping, 2) inventory analysis, 3) classification, 4) valuation. After establishing a goal, scope, functional units, and a procedure of quality assurance of the study,

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[14] "Environmental index" is "a final and aggregated assessment of the environmental impact based on the classification procedure" (Bakker (1995): Ryding (1994))

[15] Interview with Casper Boks, Assistant Prof. , Applied Eco Design, Delft University of Technology

[16] It is a common phrase that I have heard from many employees at Alfa Laval

[17] Centruum voor Milieukunde Leiden, Netherlands Organization for Applied Scientific Research and Bureau Brand & Grondstoffen

inventory analysis is made of the environmental interventions[18] during the product life cycle. The result is called 'inventory table'. In the classification phase, the data from inventory analysis are formed in a number of environmental impact categories. The result of the classification phase is called 'environmental profile', which contains environmental effects of a product. The evaluation interpreters and aggregates classification data into 'environmental index' (SETAC (1997) and Bakker (1995)).

Limitations: The results of LCA studies are often hard to interpret because LCA results contain a number of different environmental flows. The implementation of a LCA study takes too much time to be useful for designers (Godkoop and Spriensma, 2000). Additionally, LCA study often does not include involvement of different stakeholders groups that can provide good information sources (SETAC report, 1997). LCA is also an expensive technique. Many variables of LCA or their values are not known or uncertain in the early phase of a LCA study (Life Cycle Design '98: Luttropp and Persson: Baraf, 1998). However, with development of software and databases it is possible to manage quicker and cheaper LCA studies.

One may be still confused by naming LCA as a tool of Life Cycle Design. LCA is a methodology that includes a method, a database, and a user interface[19].

MET matrix

According to the sources in Bakker's book (1995), the MET matrix is a result of the Eco Design demonstration program (Eindrapportage Eco Design programma, TNO Productcentrum, Delft, 1994). The MET matrix's goal is to identify environmental "hot spots" within product life cycle and find the ways for environmental improvement of product and its processes. The MET matrix is based on the inventory analysis of the LCA methodology. It has three groups of environmental interventions: **M**aterial cycle (aspects that are related to a product's materials), **E**nergy consumption (in production and use stages), **T**oxic emissions (during different life cycle stages of a product) (MET matrix). Brezet (1994), in his manual, provides an example of qualitative MET matrix for a copier (see Table 1.).

	Material Cycle	**Energy Consumption**	**Toxic emissions**
PRODUCTION	• depletion of raw materials • recycling of production wastes	• energy contents of the materials • process energy	• fire retardants
USE	• consumption of paper • toner waste	• energy consumption • energy during transport	• emissions of ozone
DISPOSAL	• recycling of the machine		• selenium drum

Table 1: *Qualitative MET matrix for a copier,* Source: Brezet et al, 1994

Once The MET matrix is ready, environmental effects should be prioritized and improvement options should be identified.

Limitations: It is still hard to decide environmental priorities from MET matrix. In this case, LCA study can be applied.

Eco Benchmarking Approach

The objective of this section is to present an eco benchmarking approach. An eco benchmarking approach (or environmental benchmark method as it is mentioned in some literature sources) will be described by several key points: 1) how it was developed and by whom, 2) how it is defined, 3) what is the procedure of beginning of implementation, 4) what is a methodology, 5) example of a company that uses this method, 6) what are benefits, 7) what are limitations.

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[18] Environmental interventions can be, for example, such as the use of raw materials, emissions, production of noise, energy consumption in production process, etc.

[19] Casper Boks, Assistant Prof. , Applied Eco Design, Delft University of Technology

The eco benchmarking approach was developed and practiced in cooperation of the Design for Sustainability Lab of Delft University of Technology and the Environmental Competence Center of Philips Consumer Electronics in Eindhoven, The Netherlands since 1997 (Boks and Stevels, 2003). First of all, it is important to define a term *benchmarking.* According to Watson (1993), benchmarking means " a continuous search for and application of significantly better practices that lead to superior performance". It is a method for improvement of a product and its performance. It is one of the tools that is used by companies that become a leader in the market. According to ISO/TR 14062:2002,"environmental benchmarking is the measurement of properties of a product that are related to environmental impacts during its lifecycle. The measurements can be compared to a baseline of a previous product or a competitor's product, both with similar functionality".

Hee-jeong Yim and Kun-mo Lee (2002) identified in their study six procedures and activities that should be done as the beginning of implementation of eco benchmarking approach (Table 2). The eco benchmarking methodology process is illustrated in Figure 11, which is mentioned in paper of Boks and Stevels (2003).

WHY	Organization's benchmarking objective
WHEN	Time required for implementation of benchmarking
WHAT	Benchmarking target strategy, what kind of products will be benchmarked
WHO	Benchmarking partners that will be involved
WHERE	Benchmarking source and background information[20]
HOW	Benchmarking implementation method and its results[21]

Table 2, *Starting Procedures and Activities of Eco Benchmarking*, Source: adapted from Hee-jeong Yim and Kun-mo Lee (2002)

The figure shows that eco benchmarking is an integrated approach of three procedures: 1) the actual benchmark procedure, 2) the link to eco design, 3) the exploitation of the results in the market. The description of eco benchmarking methodology that is given here is based on a publication by Boks and Stevels (2003).

The actual benchmark procedure includes four stages: the choice of products, the system definition, comparing and validation of chosen products, the review of results. In the stage of choosing products that will be benchmarked, Philips named the selected products as Green Flagships. These Green Flagships were compared with 3-4 competitors' products. All products in the benchmarking procedure should have similar characteristics in the following areas: functionality, commercial availability, price/performance ration, size, and product generation.

Assessing benchmark issues and defining system includes five focal areas of energy, materials, packaging and transport, potentially harmful substances and recyclability. However, particular areas of a specific product can be also added. *Comparison and validation of products* is done according to established criteria of five focal areas. In order to validate environmental performance of a product, LCA method can be used.

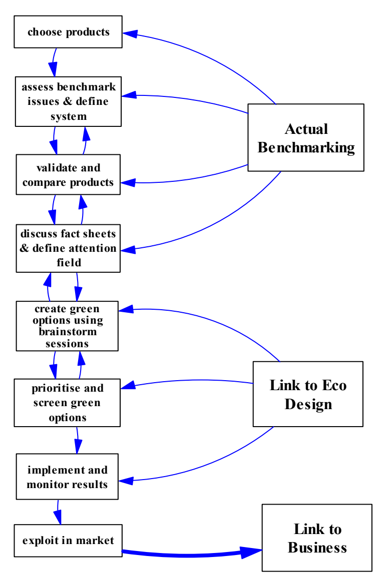


Figure 11, Flow Chart: *The Environmental Benchmark method*, Source: Boks and Stevels, 2003: Ram and Salemink, 1998

[20] It includes the following aspects: 1) what the focal areas of eco benchmarking are, 2) what functional units and system boundaries are, 3) what kind of information sources will be used

[21] It includes the following aspects: 1) how to compare the outcomes of eco benchmarking, 2) how to prioritize improvement options from the results, 3) how to implement established targets for improvement

Benefits: In terms of eco design and eco benchmarking method, learning from competitors or alternative products can give a very good input in designing or redesigning products. Moreover, comparing and analyzing five focal areas can identify good alternative technological solutions, such as alternative materials, alternative energy sources, alternative logistic systems, etc. Additionally, from results of eco benchmarking approach is possible to make a *prioritization of green options* (Boks and Stevels, 2003).

Philips Environmental Competence Centre performed and reported over 100 benchmark studies[22] of a wide range of consumer electronic products (cellular phones, TV sets, monitors, audio sets, DVDs, CDRs, etc.). Benchmark studies and reports gave a valuable database of information. Moreover, benchmark studies constituted to improvement of product performance, cost reductions, and overall environmental awareness within Philips (Boks and Stevels, 2003).

Limitations: One of limitations of eco benchmarking is data collection about the alternative products of competitors. It is not always easy to get all information which is required for the approach.

4. ANALYSIS

The main question of this thesis is "How to integrate the life cycle design into the product development process at Alfa Laval?" In order to answer on this question, a description of situation at Alfa Laval was introduced in section 'Model of Thesis Problem', and a theoretical framework for analysis was provided in a chapter of literature review. This chapter analyzes important aspects in integration of life cycle design into product development at Alfa Laval. The following questions (which are research questions from 2 till 6 of the thesis) will be answered in this chapter:

1) What are internal and external driving forces of implementation of Life Cycle Design at Alfa Laval?
2) What are barriers in implementation of Life Cycle Design at Alfa Laval?
3) What are the actors around current product development at Alfa Laval and proposed Life Cycle Design process?
4) What is current process of product design and development at Alfa Laval? And how should it look like after integration of environmental aspects?
5) What is appropriate Life Cycle Design tool for Alfa Laval?
6) What is the first step of implementation of eco benchmarking approach at Alfa Laval?

4.1 Internal and External Driving Forces for Life Cycle Design at Alfa Laval

In this section, the model (causal loop diagram) of external and internal driving forces for life cycle design at Alfa Laval is introduced. This model (Figure 12) answers on two questions:
1) What are the internal (within the company) driving forces in order to integrate life cycle design into product development process at Alfa Laval?
2) What are the external driving forces for integration of life cycle design into product development process at Alfa Laval?

The main *variables*[23] in the model are: knowledge, communication, awareness and attitude. It is important to describe these variables in order to understand what it means by knowledge, communication, awareness, and attitude:

1) 'knowledge' in the model means a knowledge about environmental issues in a company (such as environmental management system, life cycle concept, product life cycle design, sustainability, green products, benefits of successful eco design and environmental management practices, etc.),
2) 'communications' means a communication about environmental issues within Alfa Laval – exchange of information,

[22] Casper Boks, Assistant Prof. , Applied Eco Design, Delft University of Technology
[23] key words that are connected, these variables come from the first CLD, see Figure 3. Figure 3 was developed in Figure 12

3) 'awareness' means when Alfa Laval's employees are aware of the essence of environmental issues and product eco design,
4) 'attitude' means an attitude towards environment and environmental issues within Alfa Laval. Attitude could negative, positive or indifferent.

According to the model (causal loop diagram), knowledge, communication, attitude, and awareness about environmental aspects at Alfa Laval are the key internal driving forces that will lead to demand for life cycle design within the company. The secondary main variables are: Competence Team (a team of environmental specialists) and demand for life cycle design. It means that building the Competence Team of environmental specialists at Alfa Laval will lead to the knowledge about environmental aspects which will be communicated to all the employees raising environmental awareness and creating a positive attitude towards environment. This will raise a demand for integrating the life cycle design into product development process with a help of internal driving forces. Moreover, four external driving factors, such as customers' demand, legislation and standards, competition and commercial benefits, increase a demand for life cycle design at Alfa Laval. It is very important to consider and analyze external and internal driving forces[24] because a demand and interest for life cycle design of product should come not only outside but also from Alfa Laval itself. This model was named as "Model of Solution" because, after my observation and research about the situation at Alfa Laval, I found out the main missing elements that should be integrated **first** in order to prepare the company for elaborating life cycle design and integrating it into the product development process at Alfa Laval. These missing elements are a lack of knowledge about environmental issues that leads to the lack of communication, awareness and positive attitude towards product life cycle design.

According to the results from the interviews with Alfa Laval's employees, the main driving force for environmental activities at Alfa Laval is commitment and motivation of Top Management. If there is no interest and awareness of Top Management, environmental aspects and life cycle design will not be implemented. Top Management is influenced by all external driving forces of life cycle design: customer's demands, legislation and standards, competition, commercial benefits, shareholders.

In conclusion, it should be noted that successful life cycle design projects require commitment from all employees and all levels of management. Environmental management system by coordination of a Competence Team should support environmental improvement through a number of key elements: environmental policy, goals, environmental communication strategy, environmental training and seminars, a strategic plan, good management and coordination of human resources, etc.

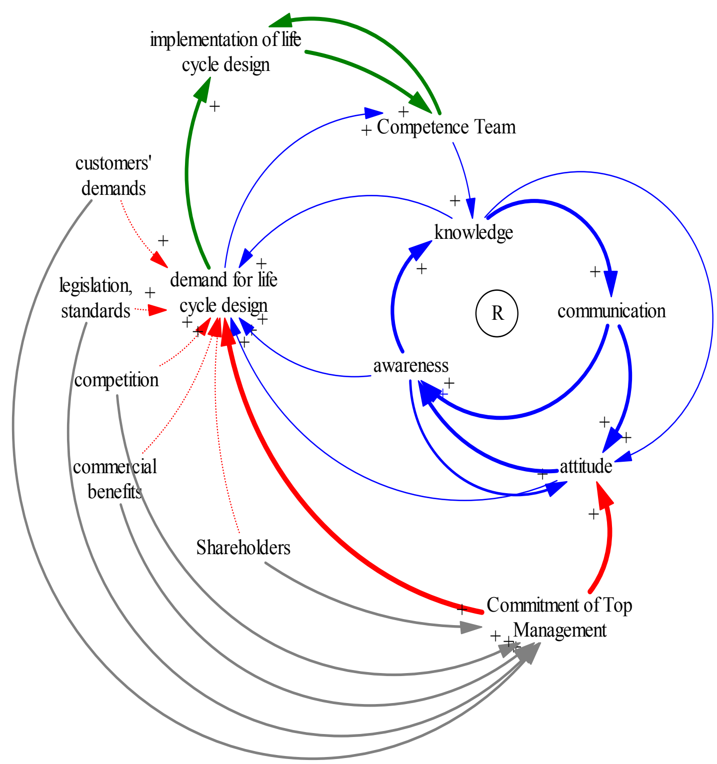


Figure 12: CLD: *Internal and External Driving Forces of integration of life cycle design at Alfa Laval*

[24] Internal and external driving forces for integration of life cycle design into product development process were elaborated and concluded with Alfa Laval's stakeholders

Additionally, environmental management system and a Competence Team should also provide access to accurate information about environmental impacts not only on a local level (as it is at Alfa Laval) but also on international level (for example, Global Reporting).
Moreover, environmental management team (a Competence Team) should be able to communicate effectively Alfa Laval's' environmental expectations and objective to the multiple stakeholders (suppliers, customers, government, environmental organizations, etc.).

4.2 Barriers in Implementation of Life Cycle Design at Alfa Laval

In this section, I summarized common barriers to implementation of Life Cycle Design at Alfa Laval. My formulation of common barriers is based on literature review and interviews with stakeholders of Alfa Laval. These barriers should be taken into account during the implementation of Life Cycle Design.

- **Insufficient Motivation Barriers**

An insufficient motivation barrier within Alfa Laval is probably one of the biggest problems for Life Cycle Design implementation in the company [personal interview]. The motivation of senior board to Life Cycle Design issues is important and necessary (Gertsakis, Lewis, Ryan, 1997). The greater the interest and stronger motivation from managing directors and chief executives, the better and easier is the process of integration of environmental issues into product development. If senior board is aware of the goals of product life cycle design and admits the benefits from integration, then this strong commitment can become the most important driving force for successful implementation of Product Life Cycle Design (Puraji and Wright, 1999). For example, senior board can provide enough resources for implementation of Life Cycle Design.

- **Leadership and Coordination Barriers**

Strong leadership and coordination both in environmental issues and Life Cycle Design is the next important issue to improve at Alfa Laval [personal observation]. Without good managing of coordination of Life Cycle Design Strategy, individuals at Alfa Laval will not be encouraged to actively participate in the implementation process. Coordination of the process should be established at early stages of implementation.

- **Cost Barriers**

Integrating environmental issues into product development and building Life Cycle Design seems to require environmental investments which are usually very expensive. For example, a process of ISO 14001 certification, Life Cycle Assessment studies, external environmental consultancy, environmental investigations and analysis are considered to be expensive activities [personal interview and literature sources]. On the other hand, many environmental investments that are resource efficient may bring tangible financial returns in reasonable payback periods (Hawken and Lovins, 1999). However, sometime it is difficult to measure the benefits from these investments.

- **Skills and Knowledge Barriers**

I discovered during my investigations at Alfa Laval, that there is a lack of knowledge about environmental issues. Interviewing the employees of Alfa Laval, I realized that not all of them understand the essence of environmental management and life cycle design. At the same time, some of Alfa Laval's customers (for example, Tetra Pak) and some competitors know more about environmental issues [results from personal interviews]. Therefore, even if environmental objectives are established in the company, a problem could arise from a lack of knowledge and competence about environmental management and life cycle design (Ritzen, 2000). A lack of competent human resources is one of the key problems at Alfa Laval, which leads to the lack of knowledge, information and communication about Life Cycle Design (see Model of Thesis problem, p. 8-9). This results in a "wrong" attitude towards environmental issues.

- **Insufficient Internal and External Communication with Stakeholders**

During my research period at Alfa Laval, I observed that there is no sufficient communication between the employees at Alfa Laval related to Life Cycle Design issues. It took much time for my research to make clear who is responsible for what and find the ‘right’ people to get needed information. Internal communication system is rather weak in terms that there is no interdisciplinary cooperation between different departments in environmental issues [personal interview with Communication department]. Information about customers and suppliers (for example, related to Alfa Nova) is not summarized or not easily accessible, what **does** create the barriers in research or business projects, especially in the projects of environmental investigations. For example, several efforts were taken and much time was spent to find Alfa Laval’s suppliers of stainless steel. However, after some time some good specialists that contributed to my thesis project were discovered. This indicates that there **are** valuable human resources at Alfa Laval, just good management and coordination of them is needed in order to succeed an environmental study.

- **Insufficient External Pressure**

According to my interview with Vice President of Human Resources at Alfa Laval, there is insufficient external pressure from the customers to start Life Cycle Design. What is the main driving force to invest? The answer is customers’ demands. But if customers do not ask for Life Cycle design and environmentally conscious products, will a company start producing ‘green’ products? Perhaps the answer is “no”. This is the reason why some of Alfa Laval’s employees are rather skeptical to invest in integration of environmental issues into product design and development process. The company’s position in a supply chain management is not so close to the end users as, for example, Tetra Pak’s position. Therefore, at present, the customers do not demand directly environmental information about Alfa Laval’s products. However, because of an overall environmental concern, a concept of sustainable development, and a concept of supply chain management, the customers, retailers, suppliers, shareholders, and other stakeholders can start demanding environmental certification, information about environmental performance of its products, etc. Due to the future concern, Alfa Laval started to integrate environmental issues slowly because of a lack of external pressure at the moment.

This list of barriers is not completed. I mentioned the most important barriers toward implementation of Life Cycle Design at Alfa Laval. Moreover, this list of key considerations will be a basis of the analysis of the case study.

4.3 Alfa Laval’s Stakeholders: Network of Actors around the Product Development and Eco-Design of the Product

The complexities of environmental issues require that developers and designers of new ‘green’ products should research, involve and learn from stakeholders. The stakeholders often have information that can really help in product life cycle design process in order to develop less environmentally harmful products (Polonsky, Rosenberger III, Ottman, JSPD, 1998).

In figure 13, a simple model of network of actors around the Product Development at Alfa Laval is shown. Some elements of this network model are an adaptation from Selderijk et al (1991). It is essential to distinguish ‘players’ (those actively involved in product development process) and ‘stakeholders’ (those that are not actively involved in product development process) (Bakker, 1995). In Alfa Laval’s case the players that are involved in product development are mainly the company itself. Other actors are stakeholders that are not involved in product development process

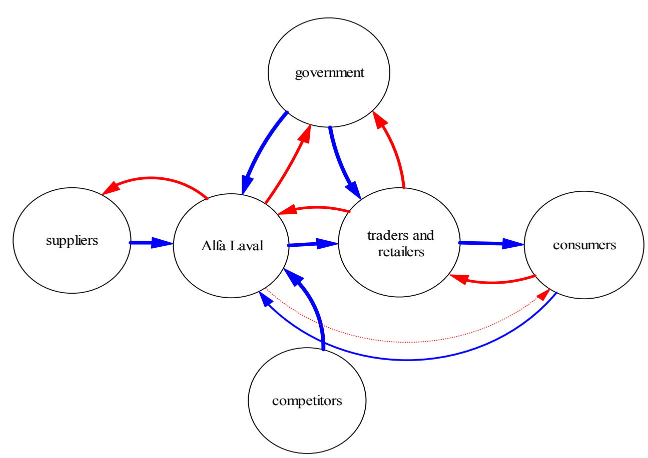


Figure 13: Flow Chart: *A model of network of actors around product development process at Alfa Laval*

directly: suppliers, trade and retail, customers, competitors and government.
The blue arrows show the communication flow about environmental issues at Alfa Laval. Red arrows show the communication flow that is missing at Alfa Laval and is very essential in product development process (Ulrich and Eppinger, 2000).

- **Customers**

The results of product development process should satisfy the customer's needs. Then the product will be successful on the market. Therefore, the customer is the most important stakeholder for Alfa Laval who has a direct influence on the product development process. Usually the product is developed or redesigned according to the demands of the customers [personal interview]. Identifying customer's needs is an integral phase in product development process and is very closely related to concept generation, concept selection, competitive benchmarking, and the establishment of product specifications (Ulrich, Eppinger, 2000). More and more Alfa Laval's customers started to demand information about environmental performance of heat exchangers: harmful substances, energy consumption in usage phase, and other environmental impact. For example, food and beverage producers are very interested in environmental impact of heat exchangers when they use them [personal interview at Tetra Pak]. It became common that customers demand that their suppliers should have ISO 14000 certificate[25] or participate in EMAS (Barthel, 1999). Therefore, it is necessary to present environmental information about the products. As it is illustrated in Figure 1.4, Alfa Laval should have a direct communication channel about environmental aspects of heat exchangers with the customers in life cycle design process. Communication with different stakeholders is an effective way to elaborate or enlarge environmental criteria for the products (Colman, 2004). Construction companies in Sweden that started to build "environmentally friendly" green houses demand that all the materials, equipment and appliances they use for building a house and putting to the house should have an eco-label [personal interview]. Higher life style standards create more demand for eco-products. The positive attitude towards environment of Alfa Laval can play a very important role and influence customers' attentions towards the issue, and vice verse. (Henriques and Sadorsky, 1999). Market demand for environmentally responsible products has forced companies to consider the environment as a core business issues. Product design strategies that reduce environmental impacts and costs will provide the greatest potential for producers to meet rising consumer expectations (Keoleian, Koch, Menerey, 1995).

- **Suppliers**

The environmental performance of the product is closely connected to the materials and energy flows that characterize its life cycle. Automobiles and computers are assembled from many different elements and usually are manufactured by one set of suppliers and recovered or recycled by other suppliers (Fiksel, 1996). Therefore, it is essential in life cycle design of the product to set supplier selection criteria and analyze the role of different suppliers. In order to fulfill the principles of life cycle design, it is necessary to have environmental information about raw materials the company receive and *the way the suppliers extract* these materials for the company. Now the current trend is that suppliers are also becoming co-makers. They supply the manufacturer new technological possibility or develop products or components themselves (Bakker, 1995). Nowadays major multinational companies, for example Renault, include not only product developers in eco-design process but also all component and material suppliers. Renault's strategy vis-à-vis its suppliers is based on long-term relationships. The strategy involves the suppliers in the project at a very early stage of development (Renault's Performance, 2002). In case of stainless steel heat exchanger at Alfa Laval, it is necessary to include in eco-design process only the suppliers of stainless steel. Stainless steel suppliers are needed in order to elaborate the end-of-life phase in the product life cycle of Alfa Nova. Alfa Nova is produced from one material - stainless steel. It is 'easy' to

[25] Personal interview with Karin Alenius (responsible for environmental investigations at Alfa Laval), she mentioned about one department at Alfa Laval that could not sell marine diesels because customers required ISO 14001 certification

recycle (Alfa Laval's brochures). But is it possible to recycle used Alfa Nova? Does it go for by-products? Can Alfa Laval's suppliers of stainless steel take a responsibility to recycle old Alfa Nova? Supply Chain Management is really a powerful instrument to influence the companies to improve their environmental performance. Effective and open communication with suppliers or substantial influence on their activities can reduce the environmental burden of many product systems (Keoleian, Koch, Menerey, 1995).

- **Traders and Retailers**

The intermediate trade can demand information about the products they buy from manufacturers. Moreover, the intermediate trade can make a choice between different alternatives of the products in order to build up an assortment (Bakker, 1995). In the case of Alfa Laval, for example, Tetra Pak AB is considered as the intermediate trade of Alfa Nova. For instance, Tetra Pak AB provides "integrated processing, packaging, and distribution line and plant solutions for food manufacturing. Tetra Pak's customers get multi-product solutions from a single source, with matching equipment at every stage" (Tetra Pak Ltd [online]). It means that Tetra Pak buys Alfa Nova from Alfa Laval in order to integrate it to the system and provide to its customers. Therefore, it is very important for Tetra Pak to have environmental information about Alfa Nova because Tetra Pak works closer to the end-users of the product who started to demand environmental information about all products from Tetra Pak. For example, Skåne Mejeri (personal interview at Tetra Pak]. Moreover, Tetra Pak AB has a continuous Design for Environment process and program where the company is concentrated on Supply Chain Management.

- **Environmental and Consumer Organizations, Government**

Environmental, consumer organizations, and government can influence product development and eco-design of the product directly and indirectly (Bakker, 1995). Government can influence directly by legislation. In the United States, Europe or Japan, producers are aware of increasing regulations towards developing cleaner processes. For example, German packaging law excludes from the German market the products which packaging cannot be eliminated, reused, or recycled.In the United States, pollution prevention plans is a requirement for many medium-sized and large enterprises (Cattanach, Holdreith, Reinke, Sibik,1995, p.65). Environmental and consumer organizations usually demand environmental information more than the intermediate trade and customers.

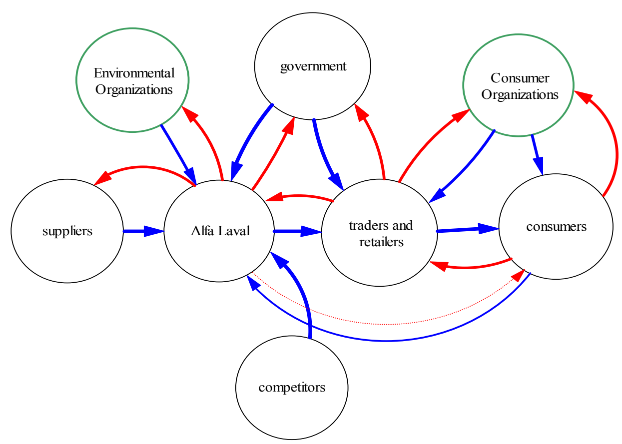


Figure 14: Flow Chart: *An Extended model of network of actors including environmental and consumer organizations around product development process at Alfa Laval*

In the case of chemicals in the United States, Environmental Protection Agency wanted to increase information to users of Toxics Release Inventory (TRI) chemicals[26] by expanding Material Safety Data Sheets to include environmental hazards[27] , or demanding manufacturers to provide "product stewardship" information to their customers (Hanson, 1990). In Europe, requirements about providing a "product environmental profile"[28] to the customers are being explored (U.S. Congress, Office of Technology Assessment, 1992, p.96). Additionally,

[26] The Toxics Release Inventory (TRI) is a publicly available Environmental protection Agency database that contains information on toxic chemical releases and other waste management activities reported annually by certain covered industry groups as well as federal facilities [online].

[27] Required by US Occupational Safety and Health Administration

[28] A product profile is a qualitative description of the life-cycle environmental impacts of a product, intended to use by professional buyers, rather than individual consumers (U.S. Congress, Office of Technology Assessment, 1992)

consumer organizations are interested in product testing which results are published. Product test results can influence consumer behavior, manufacturer motivation to improve environmental performance of the products, and retailer's strategy to promote the product (Bakker, 1995). Cooperation with environmental organizations may result not only in partnership but also in technology development (Fineman and Clarke, 1996; Hartman and Stafford, 1997). For example, the Danish Railway cooperated with O_2 organization[29] to design more environmentally friendly and cost-effective S-trains. Another example is Foron, German company, that cooperated with Greenpeace to produce the Greenfreeze line of refrigerators (Polonsky, Rosenberger III, Ottman, JSPD, 1998).

- **Competitors**

Competition is an important motivator for change in the company (see Figure 12 and 14). If competitors take environmental issues seriously, this can influence the company as well to produce greener products. At the same time, if competitors do not consider environmental issues, then the company has a comparative advantage in greening its products and having a reputation of environmentally friendly company with sustainable products. One of Alfa Laval's competitors believes that "eco-design of heat exchanger is needed to achieve sustainable energy systems for the society"[personal interview].

- **Alfa Laval as a Manufacturer**

Poor internal and external communication within a company are the biggest barriers to "*selling* 'eco-design' (internally) or 'eco-products' (externally)" (Charter and Belmane, JSPD, 1999). Generally, product eco-design has been an isolated activity within a company. Mostly companies try to elaborate the environmental design for production phase: reduce energy consumption in production, reduce amount of emissions, etc. [personal interview]. However, the companies should also consider use phase, distribution phase and disposal phase (see Figure 1). For example, in the case of Kambrook kettle of Axis, only after when researchers and designers observed *how the customers used* the kettle, they started to define the strategies for significant environmental improvements (Sweatman and Gerstakis, 1997). Alfa Laval is the main 'player' who should facilitate the process of eco-design of heat exchanger by communicating with its stakeholders and integrating eco-design of heat exchanger to the product development process. According to Conny Bakker (1995), the manufacturer can have strategic and reactive reasons to invest in the eco-design of its products. Strategic reasons could be the company's corporate image. Reactive reasons can be competition or pressure from the stakeholders (Bakker, 1995).

- **Consultancy and Academic Support**

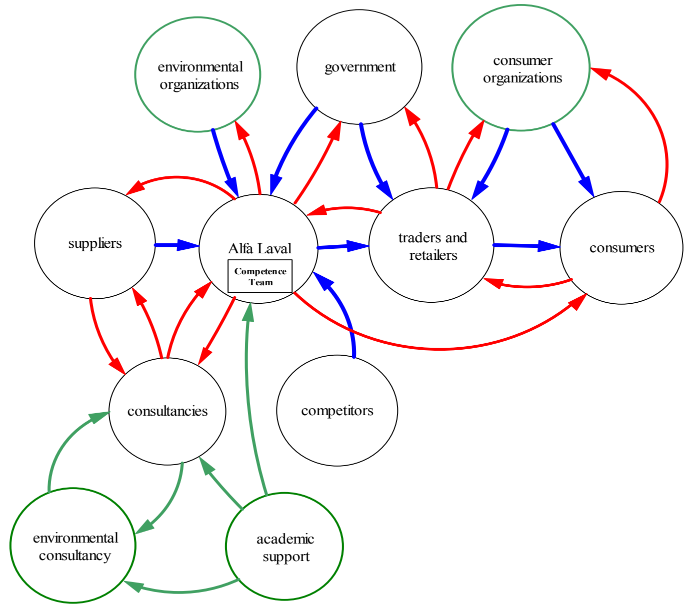
In Figure 15, an extended model is shown. In this model all the necessary stakeholders for life cycle design process are involved. This paragraph will discuss the role of consultancies and academic support in Life Cycle Design process.

A company can use both external and internal environmental consultants in eco-design process. External environmental consultant works on client contracts in the following areas: water pollution, land and air contamination, environmental impact assessment, environmental audit, waste management, environmental policy, ecological/land management, noise and vibration management, and environmental management (AGCAS, 2004).

Design process decisions should not be taken in isolation but in cooperation with all eco-design consultants (external and internal).Industrial designers after the training in environmental design usually become internal environmental consultants in product eco-design process (Gangemi, Malanga, Ranzo, 2000).A company can also establish a Competence Team of environmental experts that will develop and facilitate product eco-design process from the beginning till the end. This Competence Team should be interdisciplinary which means that the Team should involve different specialists.

[29] A non-profit international network of ecological design professionals

For example, Environmentally Conscious Products Program at IBM is supported by its Engineering Center for Environmentally Conscious Products which is a Centre of Competence for *Design for Environment* activities. The Centre has a huge division of environmental specialists, product development and procurement engineers, suppliers and product recycling centers (IBM Environment, 2004). The Centre works with Product Environmental profiles processes, monitors and documents environmental characteristics of the products. Additionally, The Competence Team or Centre usually cooperates with academies and research centers to develop new approaches for improvement of environmental performance of products. However, for small and medium-sized companies the role of internal industrial designer in eco-design process is very essential.



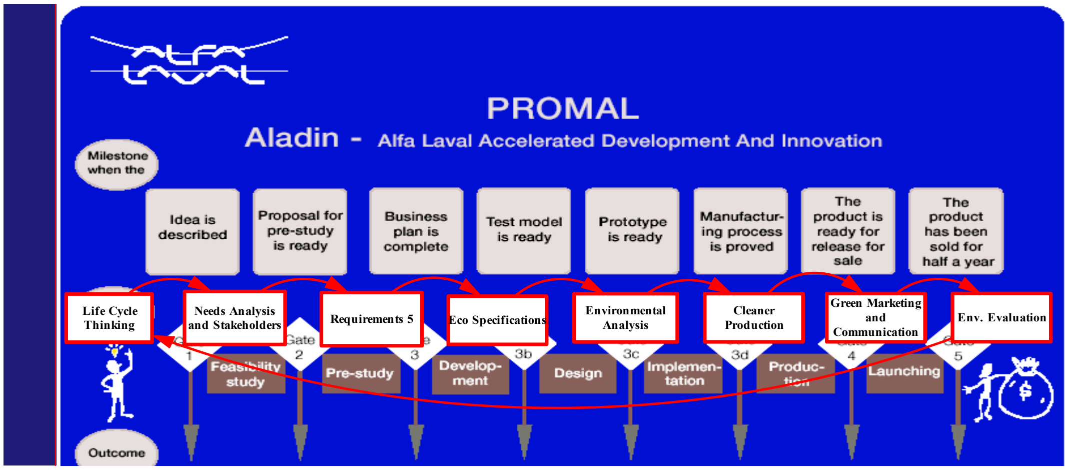
15 Figure: Flow Chart: *An extended model of network of actors including consultancy and academic support in product development and life cycle design process for Alfa Laval*

4.4 Product design and development process at Alfa Laval before and after integration of environmental aspects

In the first section of this chapter 'Analysis', I identified internal and external driving forces of Life Cycle Design at Alfa Laval. It was followed by a list of possible barriers of integration of Life Cycle Design at Alfa Laval. After, I discussed and analyzed actors and their role in product design and development process at Alfa Laval. This section presents a current process of product design & development at Alfa Laval. Here I integrate environmental aspects into current product development at Alfa Laval or implement Life Cycle Design (with another word). In Figure 16, which is a current product design and development process at Alfa Laval, one can see that all these steps in red boxes are possible actions related to the integration of environmental aspects. To make this process of integration more standardized, I propose to conduct it in accordance to ISO/TR 14062:2002 standard (Swedish Standard Institute, 2002). To make this process of integration more oriented on the needs and opportunities of Alfa Laval, and more diversified, I also use some elements of Koeleian and Menerey (1993) Life Cycle Design Process (see Figure 6) Major and important environmental issues, which are related to the case of Alfa Laval, will be showed and analyzed in a very condense way in this section. However, it should be noted that it is my personal proposal that I elaborated according to ISO/TR 14062:2002 standard, Koeleian and Menerey (1993) Life Cycle Design Process, my interview results and personal observation at Alfa Laval.

- **Current product design and development process at Alfa Laval**

Figure 16 shows a current product development process at Alfa Laval which is called 'Aladin' (**A**lfa **L**aval **A**ccelerated **D**evelopment and **In**novation). Its objective is that product development must create the highest possible value to customer as well as Alfa Laval in the shortest possible time. A development project has a responsibly project manager and project team members. The manager and the group are responsible for the project from start till launch. They always have full overview of the aims and tasks, which must be reached for the next gate meeting. They also know the criteria according to which the steering committee evaluates the project. When a phase is finished, the project manager presents the results to the steering committee. The total steering committee has the necessary knowledge in product development, marketing, sales, economics and production. Their task is to estimate advice and decide regarding the project. The steering committee has the authority on the spot to decide further action of the project. If their decision is "GO", the project manager will have resources and authority to continue until the next gate meeting within the agreed timeframe (internal documents about Aladin of Alfa Laval, 2004).



Source: Figure 16 ,**PROMAL *Alfa Laval Accelerated Development and Innovation Process***, internal materials of Alfa Laval, 2004

There are seven phases of product development at Alfa Laval: feasibility study phase, pre-study phase, development phase, design phase, implementation phase, production phase and launching phase (See Figure 15). Each phase has its inputs and outputs. Each phase starts and finishes with a gate meeting, in which the steering committee decides if the project can go to the next phase. I will propose to integrate environmental considerations into all seven phases.

According to my interview results with R&D managers at Alfa Laval, I found out that product development team at Alfa Laval does consider some environmental aspects in product development process. For instance, when they have a possibility to choose from two different materials for rubber gaskets, they choose the one that is the most environmental-friendly. Another example is that Alfa Laval is trying to produce more compact heat exchangers in order to save a material use. However, product development team at Alfa Laval does not have any strategy, plan or coordination for considering environmental aspects in development process. They do realize that Alfa Laval needs to integrate environmental issues in product development; however, they admit that it is rather difficult. The biggest barrier that they foresee is a lack of knowledge and competent people that know about environmental issues in general. Another barrier is the state of technology they use. The first step that should be done, according to their opinion, is to get knowledge about environmental impact of the products, and what happens to them when they become a scrap. And it should be done as soon as possible, according to opinion of specialists from research and development department. In addition, Alfa Laval's product development team thinks that it was a strong demand from legislation and/or customers towards integration of environmental issues into product development. Unfortunately, they admit that they do not have enough knowledge to start this process [personal interview with employees from research and development department at Alfa Laval].

- **Integrating environmental aspects into product design and development at Alfa Laval**

As I mentioned before, integration of environmental aspects into product design and development at Alfa Laval is recommended to be based on ISO/TR 14062:2002 standard and some elements of Koeleian and Menerey (1993) of Life Cycle Design Process. A Technical Report ISO 14062 describes concepts and current practices related to the integration of environmental aspects into product design and development process. It contains clear guidelines for integration of environmental issues into product development for a company that just started to develop environmental management system. Life Cycle Design Process of Koeleian and Menerey (1993) is well-structured and contains important environmental aspects that should be considered in case of Alfa Laval, in my opinion.

Product design and development process varies between different products and organizations. Therefore, it is not recommended to integrate environmental issues according to one standard. This process of integration should be elaborated individually within a company. The aim of this section is to describe shortly the main important environmental aspects that should be considered during seven phases of product design and development at Alfa Laval. I propose two ways of integration of environmental aspects into current product design and development process at Alfa Laval: “high priority” way and “low priority” way (see appendix II). It could be also named as a long term proposal and a short term proposal (what could be implemented immediately).

In the phases, the beginning stage and the end stage of product design and development process are the most important. In the beginning stage, designers and decision-makers can decide if they choose a “high priority” way or a “low priority” way of consideration of environmental aspects. It should be decided during the step “Needs Analysis”, where the needs of Alfa Laval and customers related to Life Cycle Design should be identified. If there is a *commercial potential* for investing in Product Life Cycle Design, then designers may choose the “high priority” way. If there is no commercial potential and no high demand from customers and other stakeholders for Life Cycle Design, then, designers may choose the “low priority” way.

The final phase of Life Cycle design process is environmental evaluation of product performance. The main outcome of this phase is a document “Environmental Product Profile” which contains environmental information about a product. A standard of this document should be elaborated by Alfa Laval’s specialists according to the environmental legal requirements. Usually Environmental Product profiles contain negative and positive environmental impact of a product. The document can have several environmental key areas such as energy consumption, waste and emissions, recyclability, materials, harmful substances, transportation, packaging, etc. This document can be used as valuable environmental information for Alfa Laval, for the customers, suppliers, government, and other stakeholders. Moreover, Environmental Product profiles can be used in a decision-making process about a new product where designers and other decision-makers may look at negative environmental impact of an existing product, and consider this negative impact when they create and develop a new product. This may lead to eco innovation and success!

Coming back to the proposed Life Cycle Design process, each phase of Alfa Laval’s product design and development process is analyzed by four main questions: 1) When should it be done? (a name of phase), 2) What should be done? (what kind of aspects and activities), 3) Who should do it (what kind of specialists)? 4) How should it be done? (what kind of tools, approaches, activities, etc.). Moreover, the expected outcome for each gate meeting from each environmental activity will be defined. I selected these questions in order to simplify my explanation of integration of different environmental issues. These questions come as a result of interviews that I conducted during my research project. NB! It should be noted that the explanation is condensed and general, and it is not applied to any specific product of Alfa Laval.

The beginning stage of Life Cycle Design

The beginning stage of Life Cycle Design process (see Figure 17) in the proposed version is the Life Cycle Thinking concept. It is proposed to start with integrating this concept to the stakeholders that are related to product design and development process.

1) Life Cycle Thinking should be explained and integrated at Alfa Laval. It is the first step that should be done. The impacts of all life cycle stages need to be considered comprehensively when taking informed decisions on production and consumption patterns, policies and management strategies. Moreover, Life Cycle thinking should be taken into account during generation if ideas and creation of new products.

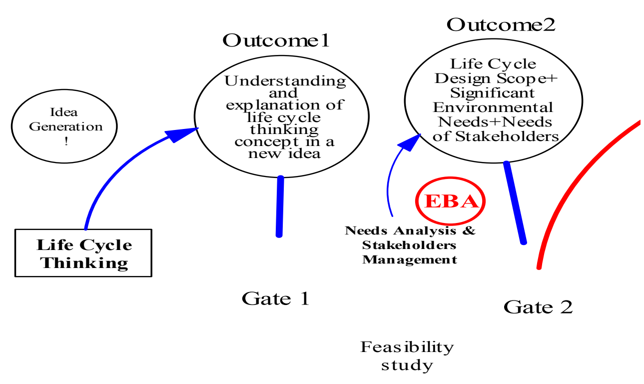


Figure 17: Flow Chart: *The Beginning Stage of Life Cycle Design Process at Alfa Laval*

It may also lead to the innovation of eco products. If a company considers the product's entire life cycle, it can help to focus not only on the environmental impacts of a product itself, but also on the system in which the product performs.

WHAT: Life Cycle Thinking
WHEN: at the early stage of a development project (during generation of ideas) [before feasibility study]
WHO: Competence Team of environmental specialists or Environmental Coordinator
HOW: via training, seminars, guidelines, principles
OUTCOME/RESULTS for the gate meeting: life cycle thinking should be explained and understood by design team for the gate meeting 1

2) A new development project should clearly identify Alfa Laval's and its customer's needs. Design is usually focused on meeting these needs. It should be noted that at this step a company should determine a scope of life cycle design project. It is essential to listen and communicate to the stakeholders that can bring the ideas and help to define significant environmental aspects that should be included in the design project.

WHAT: Needs Analysis and Stakeholders Management (Communication)
WHEN: Feasibility study phase
WHO: Environmental Coordinator
HOW: communicate with Alfa Laval's stakeholders and identify significant environmental needs. Here eco benchmarking approach can be applied. Team work
OUTCOME/RESULTS for gate meeting: life cycle design scope, significant environmental needs, needs of stakeholders in terms of environmental issues should be defined for the gate meeting 2.

This stage is the most important stage in Life Cycle Design process. At this stage, designers and decision-makers should decide if they will follow the "high priority" way or the "low priority" way in order to consider environmental aspects in product design and development process. Therefore, in the needs analysis it is important to analyze customer's demands and legislation related to environment. If there is a high demand and commercial potential, then Alfa Laval can follow the "high priority" way. If there is no very high demand and commercial potential, then the company can implement the "light" version. Environmental opportunities and related cost-benefit analysis should be conducted and discussed.

The "high priority" way of Life Cycle Design

First, I will describe the "high priority" version. I identified five areas of environmental issues that should be integrated in product development process at Alfa Laval in the "high priority" version: 1) 5 Requirements, 2) Identification of Environmental Specifications of a Product, 3) Environmental Analysis, 4) Practices of Cleaner production, 5) Green Marketing and Communication (see Figure 18).

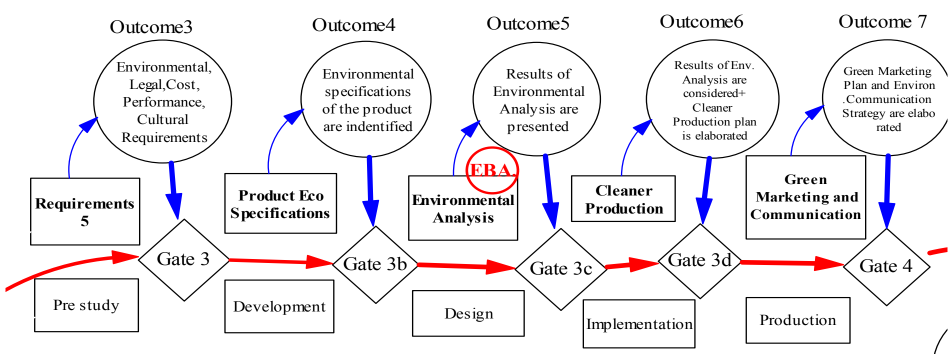


Figure 18: Flow Chart: *The "High Priority" version of Life Cycle Design Process at Alfa Laval*

1) When the company makes a decision to implement the "high priority" version of Life Cycle Design, a formulation of 5 groups of requirements (environmental, legal, cost, cultural, and performance) related to environmental issues is essential in product development process. To define requirements may be the most critical phase of design. Requirements define the expected outcome. According to Keoleian and Menerey (1993), environmental requirements should minimize raw materials consumption, energy consumption, waste generation, health and safety risks, and ecological degradation. Legal requirements include local, state, and international environmental, health, and safety regulations and mandatory requirements. Cost requirements need to reflect market possibilities, and should help to designers add value to the product system. Cultural requirements define the shape, form, color, texture, and image that a product projects. The choice of them has direct environmental consequences. Successful cultural requirements promote an awareness of how it reduces environmental impacts. Performance requirements are functional requirements. Designers need to offer a high level of performance in order to satisfy the customer's needs. However, not always better performance is good for environment. Innovative technology may increase performance and decrease environmental impacts; however, it can also increase consumption, which may again generate a negative environmental impact.

WHAT: Identification of 5 Groups of Requirements

WHEN: Pre-study phase

WHO: Environmental Coordinator

HOW: Building a Matrix of Requirements, data collection, team work

OUTCOME/RESULTS for the gate meeting: five groups of requirements should be identified for the gate meeting 3

2) After building a matrix of requirements, it is time to identify environmental specifications of a new product via conceptual and detailed design. Design team together with Environmental Coordinator elaborates product design specifications. Environmental coordinator facilitates a process of identification of environmental specifications of a product using data, analysis and other information that was collected during previous stages. Project-specific priorities are discussed and environmental specifications are chosen.

WHAT: Identification of Environmental Specifications

WHEN: Development and Design phase

WHO: Environmental coordinator with design team members

HOW: team work, brainstorming

OUTCOME/RESULTS for the gate meeting: environmental specifications of a product should be identified for the gate meeting 3b

3) After identification of environmental specifications, environmental coordinator has to conduct environmental analysis of a product in order to distinguish positive and negative environmental impacts of a product according to selected environmental specifications. Different Life Cycle Design tools, methodologies, databases, approaches can be applied (for example, eco benchmarking approach). The results of analysis can still influence and/or change the environmental specifications of a product. Therefore, environmental analysis should be conducted before implementation phase.

WHAT: Environmental Analysis

WHEN: Design phase

WHO: Environmental coordinator

HOW: data collection and analysis (depends on the chosen Life Cycle Design tool, methodology, etc. (see section 3) I propose eco benchmarking approach, which will be described after this section)

OUTCOME/RESULTS for the gate meeting: environmental analysis should be conducted for the gate meeting 3c

4) In the phase of implementation, the production process is being tested in the 0-series for correct production equipment and correct production material, i.e. drawings, item lists etc. All documents (drawings, specifications etc) are still preliminary. Therefore, the results of environmental analysis can still be considered.

In this stage, a production unit has to start to integrate cleaner production[30] practices (it was failed to find out if cleaner production practices are started at Alfa Laval) or use existing cleaner production methods.

WHAT: Cleaner Production practices

WHEN: Implementation phase and Production phase

WHO: Environmental coordinator, production unit, design team

HOW: team work, brainstorming, seminars,

OUTCOME/RESULTS for the gate meeting: results from environmental analysis should be taken into account and a plant with cleaner production goals should be elaborated for the gate meeting 3d

5) Environmental Communication Strategy and Green Marketing are needed in order to assist in promotion of the product. Green Marketing should concentrate on the environmental aspects of the product. Marketing specialists together with Environmental Coordinator should create "green" image of a product by using the results of environmental analysis and experience, and knowledge of Environmental Coordinator who followed the whole life cycle design process from the beginning to the end. Environmental Communication Strategy should be elaborated in order to have a continuous communication about environmental aspects of the product with Alfa Laval's stakeholders, particularly with the customers. It should be noted, that collection of environmental data and information is crucial because it might be needed to provide the information to different stakeholders.

WHAT: Environmental Communication Strategy and Green Marketing

WHEN: Production and Launching phase

WHO: Environmental Coordinator, Sales and Marketing specialists, Communication specialists

HOW: by creating a green image for the product, promoting the product in the market, communicating with Alfa Laval's stakeholders about environmental aspects of the product, collecting environmental information

OUTCOME/RESULTS for the gate meeting: Environmental Communication Strategy and Green Marketing plan should be elaborated and in force for the gate meeting 4

The "low priority" way of Life Cycle Design

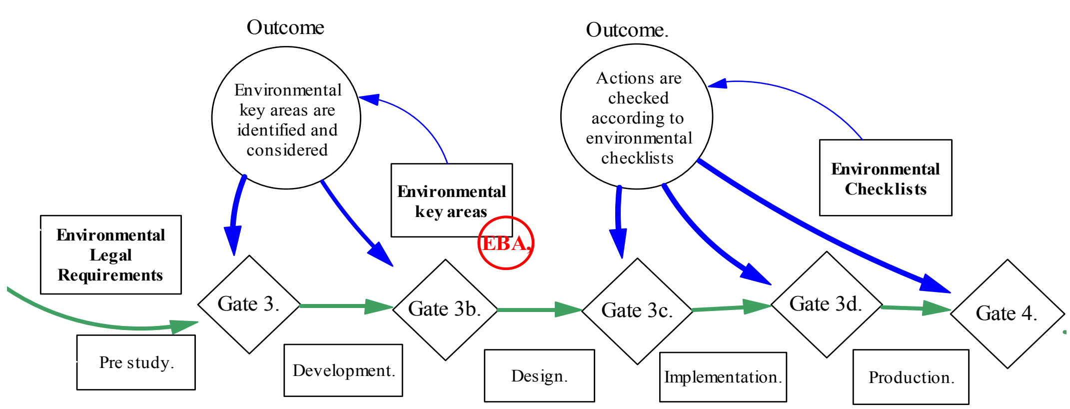


Figure 19: Flow Chart: *The "Low Priority" version of Life Cycle Design Process at Alfa Laval*

If the company, after "Needs Analysis", makes a decision that there is no demand and commercial potential for life cycle design, then "low priority" way of life cycle design can be implemented (see Figure 19). The "low

[30] "Cleaner Production is the continuous application of an preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society" (UNEP, 2003).

priority" way differs from the "high priority" way in terms of that there will not be large environmental investments and detailed environmental analysis of a product. Only legal environmental requirements will be considered. For collecting environmental information, environmental key areas will be identified. For instance, it can be 7 focal areas: energy, materials, packaging, harmful substances, transportation, waste, recyclability. Eco benchmarking approach can be used for identifying environmental key areas. Design, implementation and production activities can be checked according to environmental checklists. Environmental checklists can be used as an aid to memory in order to remember different environmental criteria during the whole life cycle design process. For example, a checklist about solid waste and toxic emissions may consist of the following questions (Bakker, 1995): 1) Is the use of priority substances avoided? 2) Are there options for the product's disposal other than landfill or incineration? 3) Are the toxic substances that are emitted during the product's life cycle minimized in comparison to the products with the same functionality? Environmental checklists should be developed individually by a company according to the needs, goals and interests of a company and a particular goal of life cycle design process.

1) When the company makes a decision to implement the "low priority" version of Life Cycle Design, legal environmental requirements about life cycle design practices and a particular product should be considered.

WHAT: Identification of Legal Environmental Requirements about the product and life cycle design process

WHEN: Pre study phase

WHO: Environmental Coordinator

HOW: checking appropriate legal environmental regulations and creating a checklist

OUTCOME/RESULTS for the gate meeting**:** a checklist with legal environmental aspects that should be developed for the gate meeting 3.

2) After identification of legal environmental requirements, environmental key areas in life cycle design process should be identified. Eco benchmarking approach can be used as one of options in order to collect environmental information about a product. Eco checklists should be created according to environmental key areas.

WHAT: identification of environmental key areas and collection of environmental information

WHEN: development phase

WHO: Environmental Coordinator together with development project members

HOW: for example, eco benchmarking approach

OUTCOME/RESULTS for the gate meeting: environmental checklists are developed for the gate meeting 3c

3) In the phase of Design, Implementation and Production, elaborated environmental checklists with environmental key areas should be used.

WHAT: use of environmental checklists

WHEN: Design, Implementation and Production phase

WHO: Environmental Coordinator with a project manager controls the process

HOW: according to elaborated environmental checklists

OUTCOME/RESULTS for the gate meeting: environmental information about how life cycle design process has been conducted and what kind of environmental key areas have been considered.

Adaptive Feedback in Life Cycle Design

One of the most important issues in proposed Life Cycle Design process is the adaptive feedback between the meeting gates (see Figure 20). If we look at the meeting gates, it is clear that certain requirements should be met. But what happens if these particular requirements are not met or are not completely fulfilled?

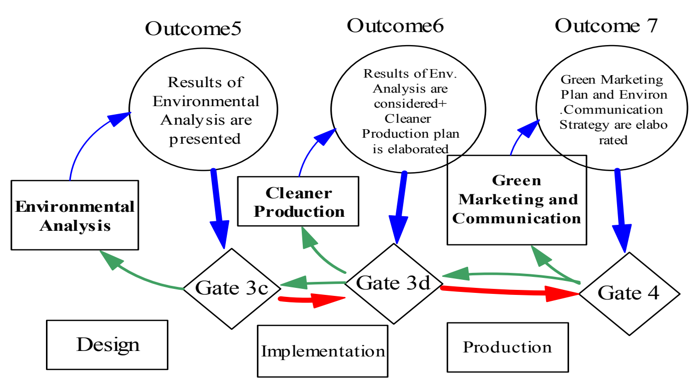


Figure 20: Flow Chart: *Adaptive Feedback in Life Cycle Design Process*

Therefore, the adaptive feedback should be explained. Figure 20 shows a fragment from “high priority” version of Life Cycle Design Process where the adaptive feedback is shown with “green” arrows. In the gate meeting 3d, Cleaner production Plan should be elaborated. If the plan is not satisfactory elaborated, then the process comes back to the stage before (“Cleaner production”) in order to improve failed Cleaner production Plan. Moreover, there is also the adaptive feedback from one gate to another gate, if designers need to reconsider previous decisions.

The final stage of Life Cycle Design

When the product is produced and launched on the market, Environmental Coordinator can conduct an overall environmental evaluation of the product and its performance in order to identify positive and negative environmental impacts of the product. This information can be used internally for Alfa Laval’s employees in order to redesign the product or improve its performance.
Moreover, the company can also set the targets in and its performance for the future (idea of eco inno

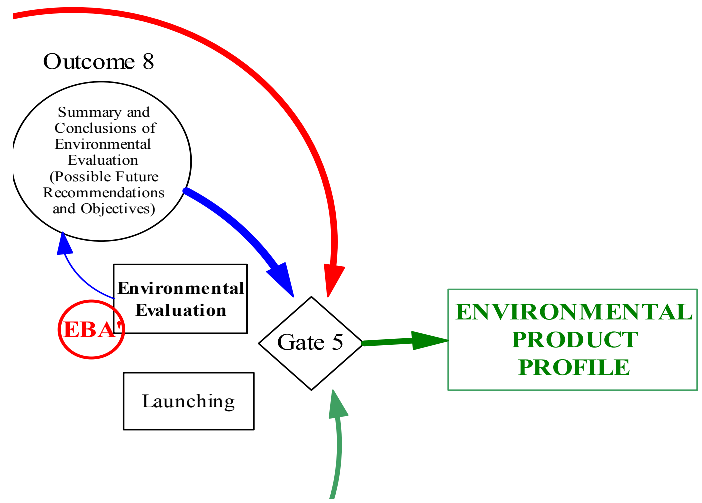


Figure 21: Flow Chart: *The Final Stage of Life Cycle Design Process at Alfa Laval*

WHAT: Environmental Evaluation of the product and its performance
WHEN: Launching phase and after the launching phase
WHO: Environmental Coordinator
HOW: Life Cycle Design Evaluation Tools, Methodologies, Approaches, Databases, Software tools, etc. I propose to use eco benchmarking approach (see section 3)
OUTCOME/RESULTS for the gate meeting: Environmental Evaluation should be conducted and results should be summarized in a ***Environmental Product Profile*** for the gate meeting 5

To sum up, I would like to stress that not only a diversity and complexity of Life Cycle Design and environmental aspects is crucial to consider in order to succeed the integration process but also the role and position of environmental coordinator is very important in life cycle design process. First of all, environmental coordinator of life cycle design process should have good communication, leadership, facilitation, and coordination skills. Moreover, this person should have knowledge in many different disciplines: environmental science, management, marketing, communications, product development, industrial design, engineering and technology, production and materials, etc. Environmental coordinator should be able to communicate and work in a team with different specialists. Therefore, he or she should have a strong and ambitious personality.

Integration of environmental issues into product design and development process does not happen quickly. It takes time to train people to consider and work with environmental aspects every day. Once it has been achieved, the company will be used to work with environmental issues and will be able to develop the skills and experience. Moreover, the gained knowledge and experience in life cycle design may lead to unique environmental innovations as well as enlargement of the market, and development of business.

4.5 Choosing Appropriate Life Cycle Design Tool for Alfa Laval

Alfa Laval's design and development team mentioned during the interviews that the first step of implementation of Life Cycle design at Alfa Laval should be the environmental evaluation of existing products. They are willing to know about positive and negative impacts of their products. Therefore, this section will compare Eco Benchmarking approach (because it was proposed by Alfa Laval) with alternative Life Cycle Design tools, methodologies, approaches, databases that have been described in a literature review in order to identify if eco benchmarking approach is the most appropriate Life Cycle Design tool for Alfa Laval. Eco benchmarking approach will be compared according to six aspects: 1) Objective of the tool, 2) Time needed for implementation, 3) Implementation costs , 4) Human Resources needed, 5)Collection of data needed, 6) Limitations. These six aspects have been asked most often by Alfa Laval's employees (designers, product managers, marketing specialists) during my interviews (see a list of interviews at the end). Some of them will work with these issues in the future. The most common questions about eco benchmarking were: 1) What is this? 2) When and how much time does it take? 3) How much does it cost? 4) Who can do it? 5) What kind of data is needed? 6) Are there limitations?

First of all, it is important to identify the needs and possibilities of Alfa Laval (results of interviews and my personal observation) in implementation of Life Cycle Design approach, tool, methodology or database:

Short Term Implementation Scope: is to compare environmental performance of stainless steel heat exchanger with two other heat exchangers in the same application within the whole product life cycle in order to find negative environmental "hot spots" and positive environmental characteristics of stainless steel heat exchanger.

Long Term Implementation Scope: to find an appropriate method and use it for evaluating environmental performance of Alfa Laval's products and communicating them to the customers.

Pre conditions: The implementation should not require hiring environmental experts or external consultancy. However, a short training can be arranged and financed. Alfa Laval is intending to use existing human resources for implementation of a project. Cooperation with university is supported.

Expected time for implementation: Alfa Laval expects to have results within 1-2 months

Available Financial Resources: no or very low

Human Resources for implementation: one full-time employee from Alfa Laval who will be available only part time for this project

Available data for research: data needs to be collected within an amount of time (no previous study was made)

Expected Results: to evaluate environmental performance of stainless steel heat exchanger and identify environmental advantages and disadvantages of the product in comparison to two alternative heat exchangers with the same function. The results are expected to be communicated to the customers through a report.

In Table 3 **eco benchmarking approach** has been compared to three alternatives (Eco Design Strategy Wheel, Life Cycle Assessment, MET matrix) by six aspects. These three alternatives were chosen as the most practiced, well-known, and well-described in the literature and periodicals. Eco Indicators are not included in the table because they can not be compared to other tools, databases, and methodologies due to the fact that they are used to assist life cycle design. **NB It should be noted that I have made some assumptions according to the literature sources. Therefore, this evaluation of tools is subjective.**

	Alternative 1	Alternative 2	Alternative 3
	Eco Design Strategy Wheel	**Life Cycle Assessment**	**MET matrix**
Objective	Worse than EB	Almost the same as EB	almost the same as EB
Time needed	almost the same as EB	Worse than EB	almost the same as EB
Implementation Costs	almost the same as EB	Worse than EB	almost the same as EB
Human Resources needed	almost the same as EB	Worse than EB	almost the same as EB
Data needed	Better than EB	Worse than EB	Better than EB
Limitations	Worse than EB	Worse than EB	Better than EB

Table 3: *Alternatives of Eco Benchmarking Approach*

Table 3 shows if objective, time needed, implementation costs, human resources needed, data needed, limitations of alternatives are better, worse or almost the same as in eco benchmarking (EB) approach. This comparison is supported by the following qualitative analysis:

1. Objective: More or less all alternatives have the same objective like eco benchmarking approach to evaluate environmental performance of a product. However, Alfa Laval needs to identify and compare environmental advantages and disadvantages of products. In this case, an Eco Design Strategy Wheel does not show a detailed analysis of positive and negative environmental impacts. It just identifies a strategy in order to improve environmental performance of a product.

2. Time needed: Alfa Laval expects to have results during 1-2 months. It is possible to get the results by implementing eco benchmarking approach, eco design strategy wheel, and MET matrix. However, LCA studies and eco indicators will take longer time. It should be noted that Alfa Laval wants to compare stainless steel heat exchanger with two other heat exchangers. It means that three studies should be done.

3. Implementation costs: It should be noted that in comparison to eco benchmarking approach, LCA studies and Eco Indicators are very expensive alternatives. However, MET matrix and Eco Design Strategy Wheel may have approximately the same implementation costs like eco benchmarking approach. Alfa Laval expects to have very low implementation costs.

4. Human Resources needed: Eco Benchmarking approach, Eco Design Strategy Wheel, and MET matrix may require a commitment of only one part time employee during the project, which fits to Alfa Laval's possibilities. However, LCA studies, Eco Indicators may require a commitment of one full time employee, and, in some cases, even external consultancy.

5. Data needed: Data, analysis and calculations depend on an approach and criteria. It is different from one method to another. Products are different, and they have different environmental aspects to be benchmarked. Therefore, a company should determine what kind of aspects should be benchmarked. That makes an eco benchmarking approach a flexible tool for each individual product. LCA methodology and Eco Indicator method are standard tool packages with elaborated software that, in some cases, cannot be readily applied to all products. In case of Alfa Laval, a company needs to have a flexible and simple approach (that can determine different environmental characteristics of each individual product) that could be applied to other Alfa Laval's products in future. This approach should not require a complicated and time consuming data collection. Often in LCA study, data collection is a rather complicated process.

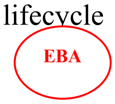
6. Limitations: Limitations are also different in all Life Cycle Design tools, methodologies, approaches, databases. It should be noted, however, that eco design strategy wheel usually does not describe the resulting separate environmental aspects. LCA studies' results are very difficult to interpret. In eco benchmarking approach it is not always easy to get information for comparison, and determine the aspects that should be benchmarked. However, an eco benchmarking approach is easier tool for identifying environmental advantages and disadvantages of a product than LCA and MET matrix. Moreover, it is easy to read the results of an eco benchmarking approach and use them for further studies.

In summary, I can conclude that eco benchmarking approach fits to the needs, possibilities, and demands of the research scope of Alfa Laval. MET matrix meets almost all Alfa Laval's conditions. However, like in Eco Design Strategy Wheel, it does not identify environmental priorities and shortcomings of a product in comparison to alternative products with the same functionality. Moreover, eco benchmarking approach is a new tool in life cycle design, and was proved by Philips to be effective for their purposes.

Eco Benchmarking Approach in product design and development process at Alfa Laval

It should be noted that choosing the right Life Cycle Design tool may be the most important step in Life Cycle Design process because it evaluates the environmental performance of a product. It is also important to be able easily to interpret the results of environmental evaluation. Therefore, this section will give an outline about how and when in proposed Life Cycle Design process for Alfa Laval is possible to apply eco benchmarking approach.

In the Figure 1.1 (in appendix II) ***Proposed version of integrating environmental aspects into product design and development at Alfa Laval***, one may notice that I propose to apply eco benchmarking approach (EBA) in three places: at the beginning of life cycle design process, in the middle, and at the end of lifecycle design process. There could be different objectives of eco benchmarking approach in life cycle design:



1) First of all, an eco benchmarking approach can be used in "Needs Analysis" in order to identify environmental aspects of a product that will be created. For example, Alfa Laval came to the idea to develop another type of heat exchanger. In the 'Needs Analysis', three existing heat exchangers of Alfa Laval (for example, cooper brazed heat exchanger, nickel brazed heat exchanger and stainless steel heat exchanger)with the same functionality can be analyzed using an eco benchmarking approach. Significant environmental aspects and negative and positive environmental impact will be identified in eco benchmarking approach. The results will help to make decisions about what kind of environmental aspects should be considered in developing a new heat exchanger in order to reduce a negative environmental impact from three existing heat exchangers. For example, it can make designers think about a new (more sustainable) transportation system (better than existing) that creates less environmental impact to the environment, or it can assist in choosing more environmentally friendly materials and components. It can make think about end-of-life stage and recyclability, etc.

2) The second option for eco benchmarking approach that I propose is to apply it in the middle of life cycle design process. When eco specifications of the product have already been developed, environmental analysis with a help of eco benchmarking approach may be applied in order to distinguish positive and negative environmental impacts of a newly developed and designed product according to selected environmental specifications. The environmental performance of the product may be compared with two alternative products with the same functionality. If the eco benchmarking approach has already been applied in "Needs Analysis", then to repeat it in the middle of life cycle design will be quicker and easier. The results of environmental analysis are important for environmental documentation. Additionally, the results may influence the implementation and production plan (for example, practices of cleaner production can be developed). Finally, the results of environmental analysis can be used in Green Marking and Environmental Communication Strategy in order to create "green" image for the product which will be used in promotion of the product at the market.

3) The third option for application of eco benchmarking approach at Alfa Laval is to use it at the end of life cycle design. When a product is developed, designed, implemented, produced and, launched in the market, it can

be evaluated in order to summarize the overall environmental performance of the final, already existing in the market, product. Therefore, eco benchmarking approach can also be used as the final evaluation of the product in order to summarize all resulted environmental aspects (negative and positive environmental impact). As it was proposed in my version, the results of this final environmental evaluation can be illustrated in *a Product Environmental Profile*, which can be used internally by Alfa Laval and externally for other stakeholders (government, customers, suppliers, traders and retailers, academies, etc.) NB! It should be noted that Alfa Laval can use Product Environmental Profiles in a decision-making process of life cycle design of a new product. Designers and decision-makers may take in consideration environmental aspects (negative and positive) of existing products in order to include them when they create a new product. It may lead to eco innovation!

There is one more opportunity for Alfa Laval related to the application of eco benchmarking approach. According to my interview results with employees from R&D department at Alfa Laval, they are missing knowledge and information about environmental impacts of existing products at Alfa Laval. They wish to learn about it. Therefore, eco benchmarking approach may be applied as a Life Cycle Design tool in order to evaluate environmental impact of existing products of Alfa Laval. The results of such evaluation can be used for environmental databases with Product Environmental Profiles. Moreover, they can be used in decision-making process about development of new products.

The beginning phase of eco benchmarking approach

In this section I will propose the beginning phase of implementation of eco benchmarking approach for stainless steel heat exchanger at Alfa Laval.

If we look at the chapter "Literature Review" (p.12), there is a theoretical framework with starting procedures and activities of eco benchmarking (Table 2). Therefore, I will describe six starting steps of eco benchmarking for Alfa Laval in this section. The methodology of eco benchmarking approach is based on the UNEP Eco Design Manual draft, which was elaborated by Delft University of Technology, and will be published in 2005.

Why (the objective of eco benchmarking):

Short Term Objective: is to compare environmental performance of stainless steel heat exchanger with two other heat exchangers in the same application within the whole product life cycle in order to find negative environmental "hot spots" and positive environmental characteristics of stainless steel heat exchanger.

Long Term Objective: to find an appropriate method and use it for evaluating environmental performance of Alfa Laval's products and communicating them to the customers.

When (time required for implementation):
Within 2 months.

What (what kind of products should be benchmarked):
Stainless steel heat exchanger, cooper brazed heat exchanger, nickel brazed heat exchanger

Who (human resources needed for implementation):
One full-time *competent* (it means already trained) employee from Alfa Laval who will be available only part time for this project + a board of specialists (Competence Team) by using the Delphi Method. I propose to use the Delphi Method in order to build a Competence Team that will participate in implementation of en eco benchmarking approach. According to Adler and Ziglio (1996), the Delphi Method "is an exercise in group communication among a panel of geographically dispersed experts". This method allows experts to deal with a complex problem or task in order to conduct evaluations or generate forecasts. I have chosen this method because its technique is rather straightforward. A competent person, who knows eco benchmarking methodology

and the Delphi method, will facilitate all the process by sending a series of questionnaires by email or via internet systems to a chosen Competence Team. A competence person will also summarize the answers and make conclusions which could be presented and discussed in a final meeting or can be sent by email to a Competence Team. Additionally, another point of the Delphi method is that the group of interaction is anonymous, what might be important in terms of sending confidential information for analysis and proposing some forecasts, ideas, etc. However, it was not the reason of my proposal to choose this methodology. According to my personal observation, employees of Alfa Laval are in business trips most of the time, therefore, it creates difficulties in terms of time to have all the experts in one meeting. Due to this, the Delphi method can simplify the application of the eco benchmarking approach at Alfa Laval. The most important results from the Delphi method are: 1) availability and involvement of different experts for evaluation, 2) reliable and creative exploration of ideas, 3) production of suitable information for eco benchmarking approach and decision-making process and 4) saving time.

Where (eco benchmarking sources and background information):
Eco benchmarking focal areas and aspects of these focal areas, functional units and systems boundaries should be determined by a competent person and Competence Team using the Delphi methodology. I propose a preliminary matrix with focal areas and life cycle phases for eco benchmarking of heat exchangers at Alfa Laval.

According to the methodology of the eco benchmarking approach, five focal areas should be considered in evaluation of environmental performance of a product: Energy, Materials application, Packaging and Transportation, Potentially Harmful Substances, and Durability/Recyclability. I propose to build a matrix where five focal areas are correlated to six life cycle phases (see Table 4).

Life Cycle phases

Focal Area	**Raw Materials**	**Production**	**Assembly**	**Distribution**	**Consumption**	**End of Life**
Energy						
Materials						
Packaging						
Potentially Harmful Substances						
Recyclability/Durability						

Table 4: ***Proposed matrix for eco benchmarking approach for Alfa Laval***

How (eco benchmarking implementation methods and its results: (1) how to compare the outcomes of eco benchmarking, 2) how to prioritize improvement options from the results, 3) how to implement established targets for improvement):

The eco benchmarking implementation method can also be conducted by the Delphi method (communicating with a group of experts). Experts can propose how to select the priorities for improvement from the results and set the targets. However, as it was described before, the results of the eco benchmarking approach will be used for environmental information about a product (Environmental Product Profile).

Recommendations: According to Philips Consumer Electronics (Enthoorn and Stevels, 2000)[the company that is successfully using eco benchmarking approach] the focus should be more on business aspects that on technicalities when conducting an eco benchmarking approach. A company should focus on those environmental aspects that can be influenced by the company itself rather than a holistic perspective of life cycle analysis. Focal areas and functional units, as well as system boundaries can be elaborated individually according to the needs of the company and the particular product.

5. Conclusions and Recommendations

The main question of this thesis was "How to integrate the life cycle design into the product development process at Alfa Laval?" In order to answer on thesis question, a research project was divided into five research sections. First of all, the essence of Life Cycle Design was presented in the literature review by answering theoretically on three questions: What is Life Cycle Design? What are the actors around Life Cycle Design? What are the tools, methodologies, approaches, databases of Life Cycle Design?

After that, en empirical part was started by analyzing ad discussing the internal and external driving forces for Life Cycle Design at Alfa Laval. During the empirical part, I learned about a dynamic environmental of Alfa Laval, which made me be adaptive and come back to my research questions and methodologies in order to reformulate and reconstruct them. My next step was identifying the barriers of implementation of Life Cycle Design at Alfa Laval. I learned a lot about the people, organizational structure, the vision, and environmental commitment of Alfa Laval. It was followed by describing and analyzing the actors and their roles around Life Cycle Design at Alfa Laval.

After identifying the driving forces, barriers, and actors of Life Cycle Design at Alfa Laval, I looked at Alfa Laval's current process of product design and development, and proposed a version with "high priority" way and "low priority" way of integration of environmental aspects. Next step was choosing an appropriate Life Cycle Design tool (Eco Benchmarking approach) for evaluation of environmental performance of Alfa Laval's products. Eco Benchmarking approach was positioned in proposed Life Cycle Design process as evaluation tool. Finally, I described a beginning phase of implementation of eco benchmarking approach for heat exchangers at Alfa Laval.

The hypotheses of this thesis have been proved to be correct and applicable to Alfa Laval's case.

My conclusions will be followed by a summary of the findings from my research project and critical discussion that provides learned lessons and recommendations.

5.1 About External and Internal Driving forces for Life Cycle Design at Alfa Laval

First of all, according to the findings of the analysis of driving forces of Life Cycle Design at Alfa Laval, I understood that it should be not only external driving forces, such as customer's demands or/and legislation, etc., but also internal motivation and understanding of the essence of Life Cycle Design within Alfa Laval that will lead to the successful implementation. The most important external driving forces are customer's demand and legislation that motivates Alfa Laval to work towards integration of Life Cycle Design. At the same time, internal driving forces, such as knowledge and communication flow about environmental issues, overall awareness and the right attitude towards environment are the key issues to meet the external demand. Regarding Alfa Laval's current situation, the company is on the right track. Alfa Laval started to research on how to integrate environmental issues by analyzing the current situation, opportunities and barriers via communication and education.

5.2 About Implementation Barriers of Life Cycle Design at Alfa Laval

Six main implementation barriers were identified where insufficient external pressures and a level of importance to integrate environment issues lead to the insufficient motivation within Alfa Laval to invest more resources on Life Cycle Design. Due to this, the process of integration of Life Cycle Design is moving forward rather slowly. However, there is a big potential of Alfa Laval to make it be implemented because of a dynamic environment of the organization which is becoming more positive and used to the environmental ideas and issues. At the end of my thesis period, I discovered and learned that the attitude towards environment at Alfa Laval is changeable and is not a new concept anymore. My interview results were rather different from the time I started my thesis project by the time I finished. At the beginning, environmental issues and Life Cycle Design were a new concept and 'untouched' subject. However, at the end of my project, I found out that the level of awareness about the need and benefits from Life Cycle Design raised within Alfa Laval. Alfa Laval's employees are ready to be trained in environmental issues and integrate them step by step into their business activities.

5.3 About Actors around Life Cycle Design at Alfa Laval

Regarding actors around Life Cycle Design, I looked at a simple standard supply chain management in order to describe a current situation of stakeholders at Alfa Laval that are involved in integrating environmental aspects in product development process of Alfa Laval. I focused on communication flow between Alfa Laval's stakeholders in exchanging environmental information. After that, I proposed a version of what kind of stakeholders should be involved in Life Cycle Design process at Alfa Laval, and how they can contribute to integration of environmental aspects. My main proposal was to build a strong dual communication flow between all the stakeholders in order to find out the needs and interests of the stakeholders regarding what kind of environmental aspects should be considered in Life Cycle Design of Alfa Laval, and what kind of environmental information should be produced. My finding was that in order to implement Life Cycle Design successfully, Alfa Laval should communicate not only with the customers, suppliers and authorities, but also with academies and environmental and consumer organizations. These stakeholders can bring good ideas and cooperation in producing environmentally-friendly products. Moreover, they communicate with the society and can assist in promoting a good image of Alfa Laval as a 'green' company by a rather low cost. Finally, according to Life Cycle Design principles, interdisciplinary teamwork of multi stakeholders is essential in life cycle design. Interdisciplinary cooperation in a complex problem or task like Life Cycle Design, that include different aspects, demands active participation and involvement of different specialists in order to succeed effective implementation of product life cycle design.

5.4 About Integration of Environmental Aspects into Product Development Process at Alfa Laval

After analyzing different actors around Life Cycle Design, I integrated environmental aspects [such as Life Cycle Thinking concept, Needs Analysis, Stakeholders Management, Environmental Requirements, Product Eco Specifications, Environmental Analysis, Green Marketing and Communication, Environmental Evaluation ,and Environmental Product profile] into all the stages of current product design and development process at Alfa Laval. I elaborated a "high priority" (ideal) version and a "low priority" (beginning) version of Life Cycle Design for Alfa Laval describing all the steps that should be taken. I would recommend to start with implementation of a "light" version and elaboration of the beginning stage and the final stage (Environmental Product profile) of proposed Life Cycle Design process. Once it has been achieved, the company will be used to work with environmental issues and will be able to develop the skills and experience in order to improve the process.

5.5 About Eco Benchmarking Approach as Life Cycle Design Tool for Alfa Laval

My final step was to analyze different Life Cycle Design tools, methodologies and databases in order to propose an appropriate Life Cycle Design tool for environmental evaluation of existing products of Alfa Laval. Eco benchmarking approach was proposed to be an appropriate evaluation tool for Alfa Laval. This approach can be used in three different stages of proposed Life Cycle Design process. Additionally, this approach can be used I order to evaluate environmental impact of existing products of Alfa Laval.

6. Suggestions for Future Research

The thesis proposes a general version of integration of environmental aspects into product design and development process at Alfa Laval. However, it has not been able to show environmental aspects in every stage of product development process in details. Therefore, it is suggested to elaborate environmental aspects in details at every stage of Alfa Laval's product design and development process. Moreover, it is suggested to start implementation of Life Cycle Design.

Another research area could be environmental information of products. It will be more demands from legislation to provide environmental information about products in the future. Therefore, it is important to research what kind of environmental information is required for different stakeholders of Alfa Laval. Additionally, an Environmental Product Profile should be elaborated in order to show environmental impact of Alfa Laval's products. Hence, it is important to analyze a Supply Chain Management of different Alfa Laval's products.

Due to the fact that Alfa Laval jus started to build environmental management system, it can be another research area. It is suggested to elaborate a strategy how to integrate environmental issues into Alfa Laval in order not to have environmental management system as a separated activity but incorporated into Alfa Laval's every day's business activities.

Another area of great research is eco innovations. It is a 'hot' issue between high tech companies to develop environmental technology nowadays. Due to the fact that Alfa Laval is one of the best companies in producing environmental technology, it could be of a big interest to research what kind of factors are important in eco innovation. This issue is suggested to be research during the implementation of Life Cycle Design at Alfa Laval.

REFERENCES

BOOKS, REPORTS, ARTICLES

Adler, M., and E. Ziglio (1996), *Gazing into the Oracle: The Delphi Method and Its Application to Social Policy and Public Health*, London, Jessica Kingsley Publishers

AEA (1992) – American Electronics Association, *The Hows and Whys of Design for Environment,* Washington, DC, November

Alfa Laval (2004)*, Alfa Laval Accelerated Development and Innovation Manual- Aladin,* Alfa Laval internal documents

Bakker, C. (1995), *Environmental Information for Industrial Designers*, Technische Universiteit Delft

Barthel, M. (1999), *Greening the Supply Chain*, British Standards Institution

Behrendt S., Jasch Chr., Peneda M.C., H. van Weenen (1997), *Life Cycle Design: A Manual for Small and Medium-Sized Enterprises*, Institut fur Zukunftsstudien und Technologiebewertung, Springer

Boks, C. and Stevels, A (2003), *Theory and Practice of environmental benchmarking in a major consumer electronics company*. Emeral Internationa Journal. Benchmarking, Vol.10 N 2, p.120-135

Brezet, J. C. et al (1994), *PROMISE Handleiding voor Milieugerichte Produkt Ontwikkeling,* SDU Uitgeverij, Den Haag

Brezet, H. and Van Hemel, C. (1997), *Eco Design: A Promising Approach to sustainable production and consumption*, Delft University of Technology, UNEP, p.37

Brorson T. and Larsson G. (1999), *Environmental Management*, EMS AB, Stockholm, p.34

Cattanach R.E., Holdreith J.M., Reinke D.P., Sibik L.K. (1995), *The Handbook of Environmentally Conscious Manufacturing: From Design&Production to Labeling&Recycling.* Richard D. IRWIN, INC.

Charter M. (1999), *Editorial part*, The Journal of Sustainable Product Design, July 1999, p.5-6

Charter, M. (1998), *The Journal of Sustainable Product Design*, interview with Dr Joseph Fiksel, April 1998, p.49-52

Charter M., Belmane I. (1999), *Integrated Product Policy and eco-product development*, Journal for Sustainable Product Design, UK, July, 1999

Colman R. (2004), *Satisfied Stakeholders*, CMA Management, 78, 1, ABI/INFORM Global p.22, March 2004

Fiksel, J. (1996), *Design for Environment: Creating Eco-Efficient Products   Processes,* McGraw-Hill

Fineman, S. and Clarke K. (1996), *Green Stakeholders: Industry Interpretations and Response,* Journal of Management Studies, Vol. 33, No. 6

Gangemi V., Malanga R., Ranzo P. (2000), *Environmental Management of the Design Process. Managing Multidisciplinary Design: the role of environmental consultancy.* Pergamon, Renewable Energy 19, p.277-284

Gertsakis J., Lewis H., Ryan C.(1997), *A Guide to EcoReDesig: Improving the environmental performance of manufactured products.* Centre for Design at RMIT, Melbourne

Goedkoop M., Spriensma R. (2000), *The Eco Indicator 99: A damage oriented method for Life Cycle Impact Assessment*, Methodology report, 2nd Edition, Pre Consultants B.V., Amersfoort, 17 April, 2000

Hanson D. (1990), *EPA Develops Product Stewardship, Hazard Communication Regulations,* Chemical and Engineering News, N 19, November, 1990

Haraldsson H. V. (2004), *Introduction to System Thinking and Causal Loop Diagrams*, Report 1:2004, Department of Chemical Engineering, Lund University

Hartman C., Stafford E. (1997), *Green Alliances: Building New Business with Environmental Groups,* Long Range Planning, Vol.30, No.2

Hawken P. (1999), Lovins A. & Lovins H., *A Road Map of Green Capitalism,* Harvard Business Review, May-June

Hee-jeong Yim, Kun-mo Lee (2002), *Environmental Benchmarking Methodology for the Identification of Key Environmental Aspects of a Product*, Department of Environmental Engineering, Ajou University, Suwon, Korea

Henriques, I and P. Sadorsky (1999), *The Relationship Between Environmental Commitment and Managerial Perceptions of Stakeholder Importance,* Academy of Management Journal 42(1), p.87-99

ISO 14040:1997 (E), *Environmental management Systems,* Life Cycle Assessment, Principles and Framework, 1997

ISO/TR 14062:2002, *Environmental Management – Integrating Environmental Aspects into Product Design and Development*, Swedish Standards Institute, October 2002

Johansson G. (2001), *Success Factors for Integration of EcoDesign in Product Development – A Review of State-of-the-art,* International Graduate School of management and Industrial Engineering, Department of Mechanical Engineering, Linkoping University

Keoleian G. A., Menrey Dan (1993), *Life Cycle Design Guidance Manual: Environmental Requirements and The Product System*, US Environmental Protection Agency, EPA600/R-92/226, January

Keoleian G. A., Koch Jonathan E., Menerey Dan (1995), *Life Cycle Design Framework and Demonstration Projects*, Environmental Protection Agency, EPA/600/R-95/107, July

Luttropp C., Persson J-G. (1998), *Life Cycle Design '98*, Department of machine Design/Engineering Design at the Royal Institute of Technology – KTH, Stockholm

May, T. (1997), *Social Research: Issues, Methods and Processes,* Open University Press, Buckingham, Philadelphia, p. 109-111

McAloone T. (1998), *Industry Experiences of Environmentally Conscious Design Integration: An Exploratory Study*, Phd Thesis, School of Industrial and Manufacturing Science, The CIM Institute, Cranfield University, Cranfield

Miller (2004), *Living in the environment: principles connections and solutions*. International Student Edition, ed 13. Books&Cole-Thomson Learning. Canada.

Polonsky, M.J., Rosenberger III, P.J., Ottman J.A. (1998), *Developing green products: learning from stakeholders.* The Journal of Sustainable Product Design, p.7-21, April

Puraji D., Wright G. (1999), *Management of Environmental New Product Development,* from: Charter M., Plonsky M., *Greener marketing – A Global Perspective on Greener Marketing Practice*, Greenleaf Publishing Ltd., Sheffield

Ram B., Salemink S. (1998), *Environmental Benchmark Methods: Comparison of Consumer Products with Competitors for determination of Green Flagship Products,* Philips Consumer Electronics internal document code AB17-G98-5051-035/2

Ray, D. L. with Guzzo Lou (1993), *Environmental Overkill; Whatever Happened to Common Sense?* Harper Collins, New York

Ritzen S. (2000), *Integrating Environmental Aspects into Product Development – Proactive Measures,* Phd Thesis, Department of Machine Design, Royal Institute of Technology, Stockholm

Robert, Karl-Henrik (2004), *Strategic Leadership Towards Sustainability*, Blekinge Institute of Technology, Karlskrona

Robins, N.(1999), *Making Sustainability Bite: Transforming Global Consumption Patters*, The Journal of Sustainable Product Design, July

Ryding, S. O. (1994), *International Experiences of Environmentally-Sound product Development Based on Life Cycle Assessment,* Final Report, Swedish Waste Resource Council, Stockholm

Senge P. M. (1990), *The Fifth Discipline: The Art &Practice of the Learning Organization*, Century Business, USA

SETAC report of *SETAC Life Cycle Impact Assessment*, Impact Assessment Workgroup, Society of Environmental Toxicology and Chemistry LCA Advisory Group, 1997

Simon M. (2000), *Environmental Priorities in Strategic Product Development*, Business Staregy and Environment, Volume 9

Stake R. E. (1994), *Case Studies. In N.K. Denzin & Y.S. Lincoln: Handbook of Qualitative Research,* Thousand Oaks, CA, Sage Publications

Sweatman A., Gerstakis L. (1997), *Mainstream appliance meets eco-design,* The Journal of Sustainable Product Design, July

Ulrich K. T., Eppinger Steven D. (2000), *Product Design and Development*, Irwin McGraw/Hill

UNCED (1992), Agenda 21, Rio de Janeiro, UN

U.S. Congress, Office of Technology Assessment, *Green Products by Design: Choices for a Cleaner Environment,* OTA-E-541, Washington, DC, U.S. Government Printing Office, October, 1992, p.96

US Environmental protection Agency – EPA, *Moving Towards Sustainability*, WasteWise Update, US EPA, EPA530-N-00-002, March, 2000

Watson G. (1993), *Strategic Benchmarking: How to rate your company's performance against the world'sbest,* New York, Wiley

Wenzel H. (1992), *Procedure of Eco Design of Industrial Products*, paper of the Danish program for Environmental Design for Industrial Products, Technical University of Denmark

World Commission on Environment and Development (WCED), *Our Common Future*, Oxford University Press, 1987, p.43

INTERNET SOURCES

AGCAS, *Environmental consultant,*[online], http://www.prospects.ac.uk/downloads/occprofiles/profile_pdfs/R4_Environmental_consultant.pdf [August, 2004]

ATEEC – Advanced Technology Environmental Education Centre, *Environmental Equity and Human Resources*, [online], http://www.ateec.org/publ/critical_issues/ci-environ.cfm , [online, August, 2004]

CIRAIG – Interuniversity Research Center for Life Cycle Assessment, Interpretation and Management of products, services and processes, *What is Life Cycle "Thinking"?*, [online], http://www.polymtl.ca/ciraig/ciraig_eng.html , [online, September, 2004]

EICTA - European Information, Communications and Consumer Electronics Technology Industry Association, *European Commission proposal for aDirective of the European Parliament and of the Council On establishing a framework for the setting of Eco-design Requirements for Energy-Using Products and amending Council Directive 92/42/EEC*, EICTA Position Paper, Brussels, December 8, 2003, [online, September, 2004], http://www.euractiv.com/ndbtext/infosoc/eictapositionpaperoneup.pdf

IBM Product Stewardship (2004), [Online] http://www.ibm.com/ibm/environment/annual2000/product.shtml [2004, August]

Kirkels A.F., van Noort D.A.A., van Nunen H., van Schjindel P.P.A.J., *Ecodesign and Life Cycle Assessment in education at Eindhoven University of Technology*, http://www.tue.nl/tdo/docs/Eco%20Design%20and%20LCA%20in%20education%20at%20TUe.pdf [online, September, 2004]

NOKIA – Nokia Asia Pacific, *Life Cycle Thinking*, [online], http://nokia-asia.com/nokia/0,8764,27261,00.html , [online, September, 2004]

Pre Consultants – Life Cycle specialists, *Eco Indicator 99, http://www.pre.nl/eco-indicator99/eco-indicator_application.htm ,* [online, September, 2004]

Renault's Performance 3 in 2002, [online], http://www.renault.com/docs/finance_gb/re2002_08_Performance2002.pdf, [2004, August]

Robins Nick and Sarah Roberts, *Upshifting? Sustainable Consumption and the South,* International Institute for Environment and Development, London, September 1998, [online], http://www.iied.org/smg/pubs/up-draft.doc [online, August, 2004]

Tetra Pak Ltd. *Environment*, [online], http://www.tetrapak.com/environment, [2004, August]

TUDelft – Delft University of Technology, EcoQuest – website +software tool for electronic industries, http://www.io.tudelft.nl/research/dfs/ecoquest/welkom/Entry.html , [online, September, 2004]

UNEP, Production and Consumption Branch, Sustainable Consumption, *Life Cycle Thinking as a Solution*, [online], http://www.uneptie.org/pc/sustain/lcinitiative/background.htm , [online, September, 2004]

UNEP, *Production and Consumption Branch*, http://www.uneptie.org/pc/cp/understanding_cp/home.htm [online, October, 2004]

U.S. Environmental Protection Agency*, Toxics Release Inventory Program,* [online], *http://www.epa.gov/tri/index.htm,* [2004, August]

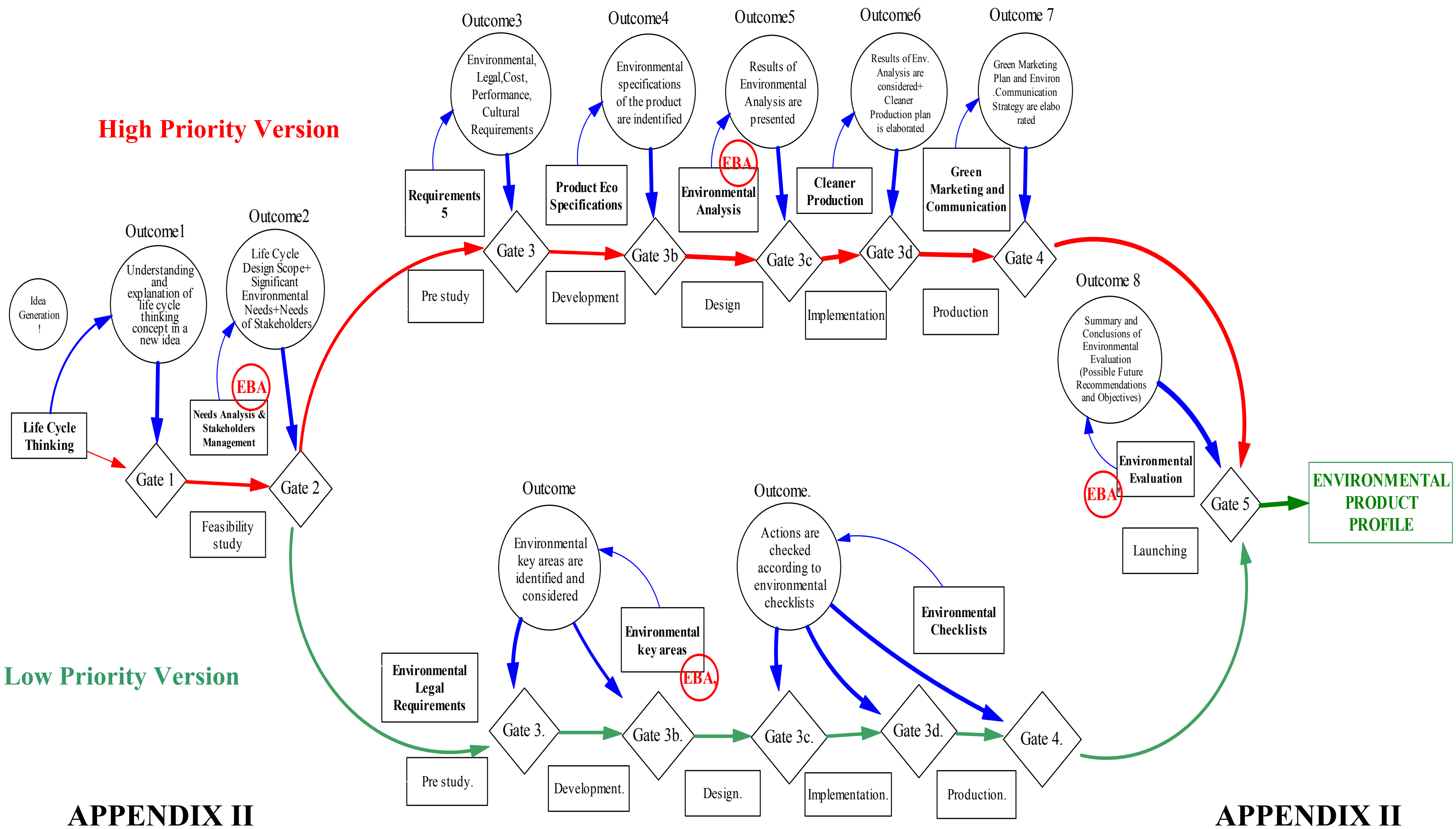
U.S. Environmental protection Agency, *Biodiversity*, [online], http://oaspub.epa.gov/webi/meta_first_new2.try_these_first , [online, August, 2004]

APPENDIX I

Interviewees of Research project:

Product Management	R&D	Marketing & Sales	Purchasing	Environmental Coordination and Analysis	Production	Communication	Quality	Customers of Alfa Laval
5[31]	5	2	2	2	2	2	1	3

[31] Number of people from a particular department



APPENDIX II

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