Environmental costs and environmental impacts in a chemical industry

eLCC and LCA on two colorants

Stefan Bengtsson & Li Sjöborg
Product Stewardship & Sustainability
Akzo Nobel Surface Chemistry
April 2004

Preface

This report is the result of our master thesis work at Chalmers University of Technology in Gothenburg. The project was performed at Akzo Nobel Surface Chemistry Sweden and at the department of Environmental System Analysis (ESA) at Chalmers. Sverker Molander at ESA and Karin Sanne at Akzo Nobel have been the supervisors for this thesis work and we'd like to thank both of them for their support and their many good ideas. Additional thanks goes to the employees at Akzo Nobel Surface Chemistry Support Unit Sweden and to everyone we have been in contact with when collecting data to this thesis. Thank you!

Göteborg, May 2004

Stefan Bengtsson Li Sjöborg

Summary

As the awareness of environmental problems increases so does the demands and guidelines from legislations and customers that deal with the environmental problems of the industries products and manufacturing processes. For a large international chemical company such as Akzo Nobel these increasing demands lead to costs for administrative work, taxes, testing, additional staff and investments.

The aim of this study is to determine the properties of these “environmental costs” for the products of a chemical company.

The study has focused on the production of two colorants. A surfactant (Berol 09), used in the older colorant formulation, contains nonyl phenol ethoxylate, a substance with potentially toxic properties. The newer colorant formulation contains another surfactant (Bermodol SPS 2532) that was developed as an environmentally favorable alternative to the other surfactant. Both surfactants are manufactured at the Akzo Nobel plant in Stenungsund, Sweden. This substitution is studied both from a traditional LCA perspective and from a perspective of monetary environmental costs. An attempt is also made to develop a method that combines the LCA perspective and the perspective of environmental costs.

From an LCA perspective the newer colorant seems the better alternative. The substitution of surfactants leads to other changes in the formulation of the colorant. Among other things the formulation of the newer colorant contains more water and this affects the LCA results significantly.

The environmental costs are higher for the newer colorant. A large part of the difference between the colorants lies in the development cost of the new surfactant.

The environmental costs were approximately 5% of the sales price for both surfactants. As new legislations and increased tax rates lead to additional environmental costs they seem to remain an important issue for chemical companies.

Index

Figure Index

1 Introduction

1.1 Background

In the wake of modern industry the concept of environmental problems soon followed as the negative side effects of the industrial expansion became more and more pronounced. Awareness of environmental issues has increased enormously from the first complaints about fish deaths and damaged water reservoirs in the beginning of the last century.

The causes and effects of water pollution was discussed extensively in Sweden at the beginning of the nineteenth century but not until the beginning of the forties legislations on waste water treatment were put into effect. Up until then the general consensus was that the pollution of air and water was a natural consequence of the increased standard of living and that measures to protect the environment was tolerable, only if the economic investments in such measures were marginal. [Persson & Nilsson 1998]

During the sixties, after reports of the accumulation of toxic substances in birds of prey, extensive efforts were made to investigate and limit the effects of chemicals such as mercury and DDT and in 1967 the Swedish environmental agency, the first Swedish governmental institution whose sole responsibility was to work with environmental issues, was founded.

The environmental legislation that was accepted shortly thereafter was a first attempt to make a set of rules and regulations that governed all the different facets of environmental protection. The legislation prescribed how industries, counties and the general public should act towards the environment. Since then environmental legislations and restrictions have increased both in complexity and scope.

Environmental problems discussed today are of global concern and have possible impacts that far surpass what could be imagined fifty years ago. The greenhouse effect and concerns about toxic chemicals get the attention of both media and the general public. Lately there has been extensive discussion of the polluter pays principle that attempts to place the costs for emissions on the liable companies.

To meet the stricter demands of customers and legislations companies devote time and money to waste treatment and environmental improvements of their products. Costs associated with the time and work that companies spend on the environmental impact of their products and processes is not an extensively studied subject, but as the work associated with environmental issues increase so do the interest in the costs that this work causes.

In 1997 SCB (Statistics Sweden) performed a study of how large the environmental costs were for different branches in the Swedish industry. In this study the environmental protection costs for the chemical industries were 0,61% of the total costs and the environmental protection investments were 3% of the total investments.[SCB 1997]

The chemical industry's work with environmental issues is even more important than in industries in general and chemical products with environmen tally hazardous properties are one of the main environmental concerns in the chemical industry. One way to improve the environmental properties of a product that contains a hazardous chemical is to try to substitute the chemical with another chemical that can fill a similar function in the product without the hazardous properties of the first.

1.2 Case Study

The study of such a substitution has been performed at Akzo Nobel in Stenungsund. Akzo Nobel is an international company active in the areas of pharmaceuticals, coatings and chemicals.[Akzo Nobel 2004]

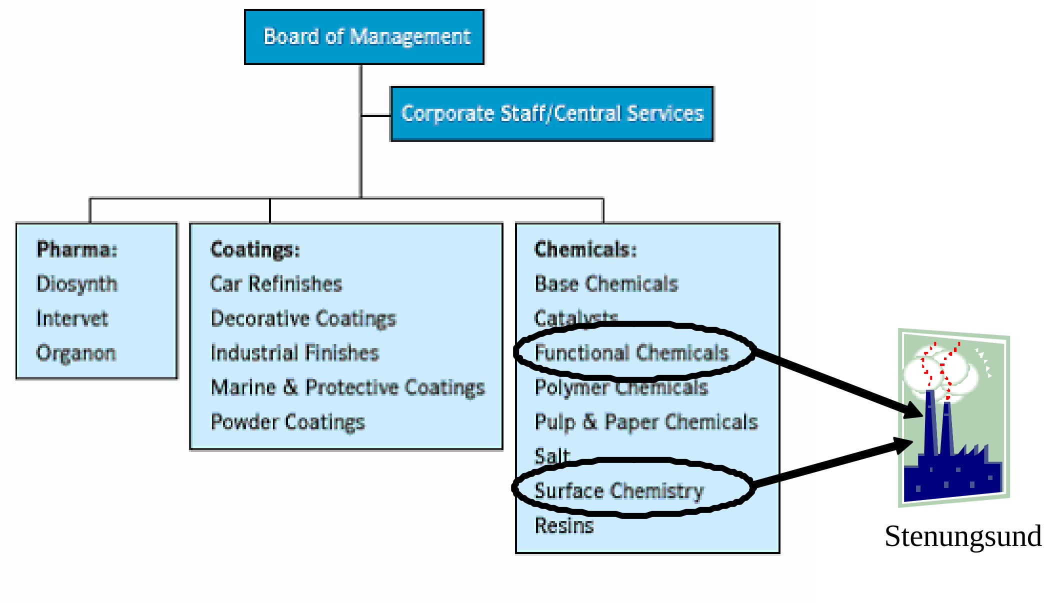

Figure 1. An overview of Akzo Nobel's organization, the subunits active at the site in Stenungsund are indicated.

At the plant in Stenungsund two business units of Akzo Nobel are active: Functional Chemicals and Surface Chemistry. The Surface Chemistry business unit is further divided into sub business units. Two of these sub business units are included in this study: Cellulosic Specialties and Surfactants Europe.

The chemicals involved in the substitution, Berol 09 and Bermodol SPS 2532 are used as surfactants in iron-oxide yellow colorants in water based indoor paint. Bermodol SPS 2532 was developed by Cellulosic Specialties and both surfactants are produced by Surfactants Europe at the site in Stenungsund.

The surfactants are needed to keep the colorant, a mix of pigment, water and glycol as a homogenous solution. A small amount of the colorant is added to paint, by the paint retailer, in order to provide the customer with a paint of specific color and strength..

Berol 09 is a high volume product with a multitude of different applications in various areas such as paint and detergents and as a spermicide. Bermodol SPS 2532 on the other hand is a specialized low volume product that is used exclusively as an alternative to Berol 09 as a surfactant in specific colorants.

Nonyl phenol ethoxylate, a major constituent of Berol 09, has been the topic of several years of discussions and studies of its environmental performance and possible estrogen-like activity. [Svennberg 1995] In a study performed on fish cells, nonyl phenol was found to have a relative effect of 0,000009 of estrogen's effect. [Jobling & Sumpter 1993]
Discussions of the future legislation on nonyl phenol ethoxylate breached the subject of a possible ban on the use of nonyl phenol ethoxylate in several applications, among them paint. [Munk 2003]

Thus SVEFF, Association of Swedish Paint Manufacturers, agreed to voluntarily cut the use of nonyl phenol ethoxylate in paint on the Swedish market by 90% till 2000 [Colorant Manufacturer 2003]. In 1991 Cellulosic Specialties began the work on an alternate surfactant for use in colorants for water based paint. One of the results of that development work, Bermodol SPS 2532, was developed in association with the Colorant Manufacturer and production of Bermodol SPS 2532 began in 1995.

Since the properties of the two surfactants are different several changes have to be made to the recipe of the colorant, shown in Figure 2. It is not a simple substitution of 1 kg of Bermodol SPS 2532 for each 1 kg of Berol 09. In the studied case, an iron oxide yellow colorant, the amounts of surfactant, water and glycol are altered significantly. These changes in turn give rise to the need of additional changes. The new colorant contains small amounts of pesticides and fungicides that are needed as the larger water content otherwise would make the colorant viable for microorganisms. Not only the amount, but also the sort of glycol used in the new colorant is different. Polyethylene glycol is used in the new colorant to give it a longer drying time.

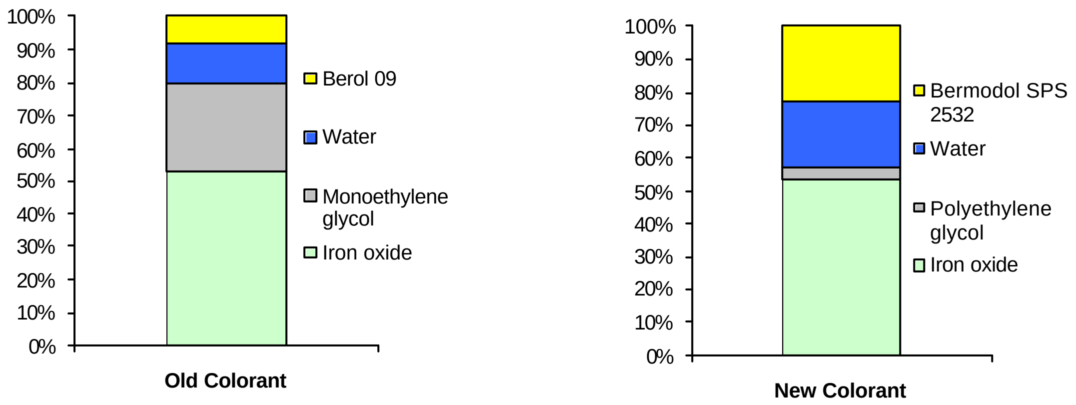

Figure 2. Approximate composition of the iron oxide yellow colorants that are studied in the project. The colorant containing Berol 09 will from here on be referred to as Old Colorant while the colorant containing Bermodol SPS 2532 will be referred to as New Colorant.

1.3 Environmental costs

Environmental taxes and fees are used as economic incitements to reward behavior that minimizes the impact on the environment. However, taxes and fees are not the only way that the environmental impact of products and processes affect the economy of a company. A chemical company carries costs such as for example: costs for testing of new products, wages for additional staff that work with environmental issues, investments made to reduce the emissions from their production plants, waste management cost for residues from their production and development costs for new environmentally favorable products.

Understanding and investigating these costs are important, both to the companies that carry them and to the authorities in charge of the environmental taxes and fees.

The concept of environmental costs in this study is referring to monetary costs carried by the producing companies, in this case costs carried by Akzo Nobel in Stenungsund, Sweden and the colorant manufacturer exclusively. Since there is no global definition of what costs should be considered environmental costs the following criteria has been used in this report to distinguish between environmental and other costs.

Any cost that could be related to the environmental impacts of a product or a manufacturing process is an environmental cost. Additionally, any costs that arise due to general environmental work in a company are also environmental costs.

This criterion unfortunately only provides rather vague guidelines whether or a specific cost should be considered environmental or not especially since the term “environmental impact” differs in meaning depending on the context in which it is used. In this report “environmental impacts” includes emissions to air, water and ground, use of non-renewable natural resources, release of substances with toxic properties. Impacts on the working environment is however not included.

In some cases there are no problems to determine whether a cost is environmental or not. The tax on carbon dioxide is definitely an environmental cost and wages to employees in the public relations department most often are not environmental costs.
In other cases the distinction becomes more complicated. Investments that are partly motivated by environmental concerns, and wage to personnel in charge of among other things the environmental department of a company, could be considered environmental costs, but to what extent is not always obvious.

The environmental costs are further discussed in chapter 2.7, in chapter 2.8 a list of possible environmental costs in a chemical industry is presented.

1.4 Aim

The aim of the project is to study the environmental impact and environmental costs of the colorants in a way that allows comparisons with environmental impact data from an LCA. A comparison of the environmental costs for the two colorants and a comparison between the environmental costs and the environmental impacts will be performed.

Since experience from studies on environmental costs is limited, the actual size of the environmental costs and the process of collecting environmental cost data are also valuable to study.

2 Methods and concepts used

2.1 *Life Cycle Assessment (LCA) in general*

Life Cycle Assessment (LCA) is a method that attempts to account for the various environmental impacts that are associated with a product throughout its life cycle. For a full scale LCA, the life cycle considered consists of data from the products cradle, the extraction of natural resources, to its grave, the final step of waste management for the product. Strictly speaking what's considered is not a product but rather a particular function of a product or a service. If the product of interest is a plastic, a function co uld be for example its use in plastic bags.

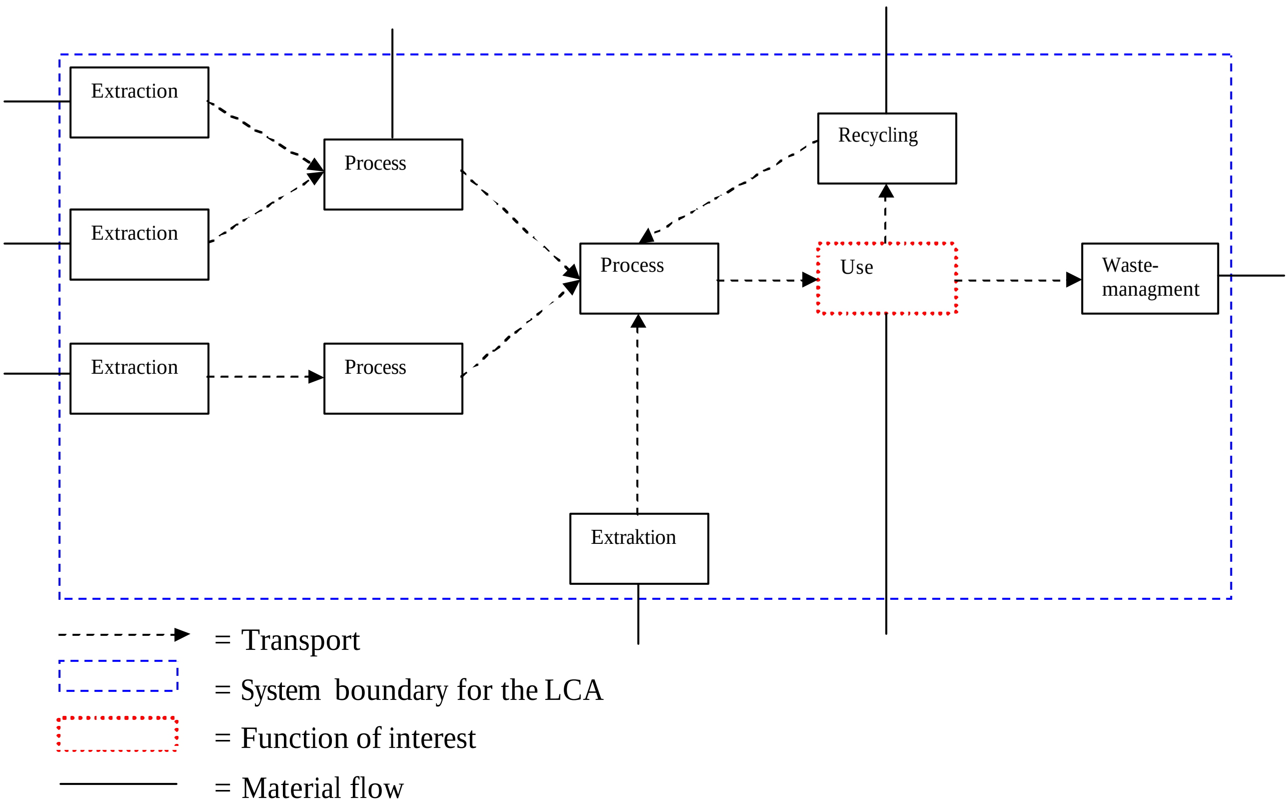

Figure 3. Flowchart of a simplified LCA

The arrows that cross the system borders represent material flows that may or may not have environmental impacts. Typically there are lots of different emissions and resource uses caused by any process in the life cycle, in the figure above represented by the material flows that cross the system boundaries. The data accounted for when the LCA is summarized is the material flows that cross the system boundaries.

2.2 LCA Procedure

2.2.1 Goal and Scope definition

The first step of the LCA is to define the goal and scope of the study. The goal definition includes the intended applications of the study, the reason for carrying it out and whom the results are intended for[ISO 1997]

The scope of the study includes specifications of the modeling such as the choice of a functional unit that relates the environmental impact to the function of a product. Other modeling decisions to be considered are the system boundaries: Decisions on what processes to include in the study, what environmental impacts should be considered, if site specific or site generic data should be used and if marginal or average data is more appropriate.

2.2.2 Inventory Analysis

When these decisions have been made a system model has to be constructed based on the choices made in the goal and scope definition. This system model consists of a flowchart of a technical system that includes the examined processes in the system and consists of all the environmentally relevant flows (defined in the scope definition) needed to produce one functional unit. Once this model is constructed, data is collected for all the processes that are included in the system. Collection of this data is usually the main part of the work on a Life Cycle Assessment. When sufficient data is collected, resource use and emissions can be related to the production of a functional unit.

2.2.3 Impact Assessment

The aim of the Life Cyde Impact assessment is to indicate the environmental impact of the emissions and resource use derived from the inventory analysis. [Baumann & Tillman 2003] The first step of the impact assessment, the classification, consists of sorting the parameters from the inventory analysis depending on what sort of environmental impact they give rise to. Once this is done the second step, characterization, quantifies the relative contribution of the emissions and resource uses to the different environmental impact categories.

Thus, for example, different air emissions are categorized, aggregated and weighted in CO_2 equivalents to determine the contribution from the production of one functional unit to the GWP (Global Warming Potential).

Sometimes the results are aggregated even further into a single environmental impact indicator. There are several different methods for this, such as for example EPS (Environmental Priority Strategy).

2.3 *Life Cycle Costing (LCC) in general*

LCC is a method for evaluating the total cost that a product will cause during its entire life cycle, from its development and production to the end of its useful life.[Woodward 1997] One of the purposes of an LCC is to provide information on how the future costs of the product will affect the economy of the purchaser. With this information a company can make important strategic decisions about their products. They can decide what products to keep as they are in their portfolio and which ones they should improve in order to be more competitive on the market.

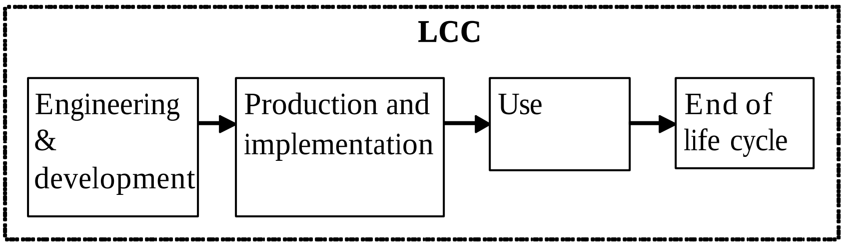

Figure 4. Schematic model of the different phases where costs are studied for an LCC

Figure 4 shows an aggregated model of the costs that are included in a LCC. **Engineering and development** includes the costs of the pre-production phase as for example investments, costs of design, planning. **Production and implementation** bears the costs of materials, labor and other costs that are related to the production process. The costs for **the use phase** include costs in the actual use of the product the size of the costs depend on the expected life time and the possible number of shutdowns of the product. **End of life cycle** includes the costs for destruction, recycling and other costs related to the end of a products life.

The costs that are included in the LCC depend on the studied product. For example in house-building, engineering and development is where the architects and construction engineers are setting up the plans of the house. Production and implementation is when the house is actually being built. Use costs is the maintenance costs of the house. And finally, the end of life cycle is when the house no longer can be used and is demolished.

2.4 Environmental LCC (eLCC)

A regular LCC considers all costs that arise in the different life cycle phases of the product. In this study only the environmental costs included in the standard LCC are of interest and an environmental cost LCC has been developed for this purpose. The eLCC will only consider the costs that are associated with activities related to the product's environmental impact. Both the environmental impact of the product and the impact of its production will be considered. Also, the initial phase of the production might include a feasibility study of the environmental impact of the product and its manufacturing and should therefore be considered as a relevant cost. Among other costs are environmental taxes, insurances and investments done in order to improve the products environmental impact. A schematic illustration of an Environmental LCC is shown in Figure 5. More specifically the costs considered in an eLCC in a chemical industry will be described in the chapter on possible environmental costs 2.8.

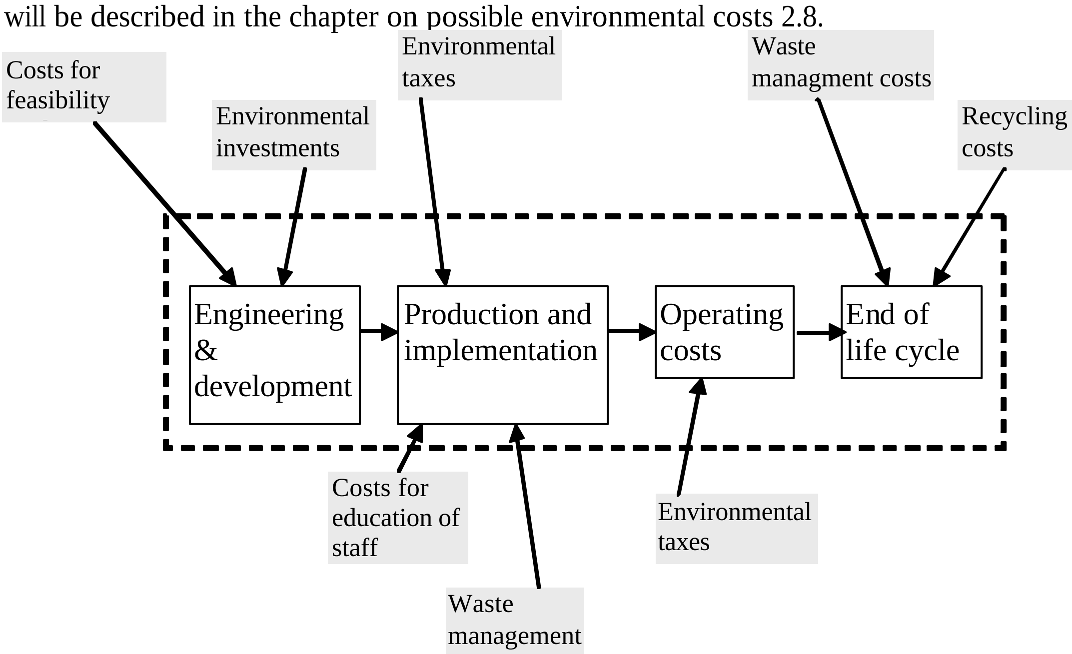

Figure 5. Examples of costs that cold be included in an environmental cost LCC (eLCC)

2.5 The eLCC procedure

As no standardized procedure on the LCC has yet been developed there are neither any standard on the eLCC procedure as the eLCC method has been developed just for the purpose of this study. Since the eLCC study will be performed in combination with an LCA study the eLCC procedure will be based on the LCA procedure with some alterations to be more suitable for the study of environmental costs. The procedure of this specific study is described below.

The first step is to identify possible environmental costs; the costs are general environmental costs for the chemical industry. The environmental costs could however, to some extent, be applicable on other industries. The identified costs will be discussed briefly in order to clarify why a specific cost is considered an environmental cost. The costs will also be grouped depending on where in the products life cycle they originate.

In order to limit the scope of this study there is a need for defining the boundaries of the study. The boundaries define what processes will be part of the study and which ones will not. An explanation of what is included in the expression environmental cost will also be presented. A functional unit will be chosen in agreement with the functional unit of the LCA.

The next step is to further define what environmental costs are relevant in this specific study. The definitions of the possible environmental costs will be the starting point for further discussion with employees that might be in charge of the relevant costs. The results of the discussion will provide the environmental costs to be used in this study.

A model of the system studied is constructed. The system includes a flowchart of the relevant processes within the boundaries of the eLCC study. The groups of the environmental costs of the separate processes are also included in the flowchart. A more detailed description of the flowchart and the environmental costs of the process will also be presented.

The actual environmental costs are assembled through interviews with concerned personnel and reviews of economic reports. The costs are allocated on the studied products and are related to the functional unit of the study. Finally, the data will be presented and analyzed in detail.

2.6 Combination of LCA and eLCC

The life cycles that LCA and eLCC are based on differ from each other. The LCA life cycle includes all the steps involved in the everyday production and use of a product. The eLCC life cycle, on the other hand, considers the products life cycle from another viewpoint where all costs during the existence of the product are considered. These differences have been a major obstacle to combining the two life cycles in a satisfying way. To solve this problem the eLCC method is applied to all the raw materials that are considered in the LCA and the environmental cost that is studied by this system of eLCC’s is the total environmental costs caused by the production of a product for raw material suppliers and the producing company. The principle is illustrated in Figure 6 below.

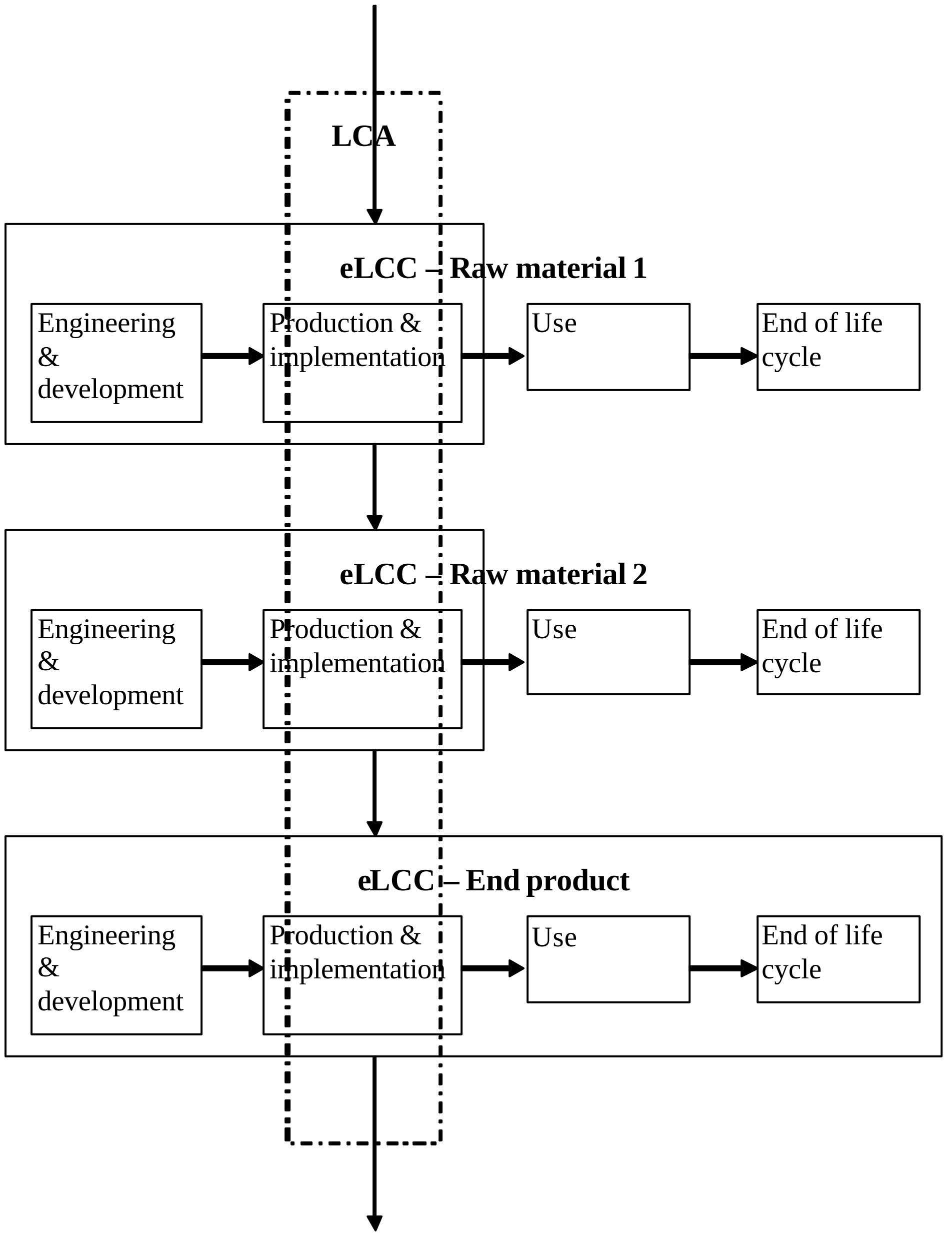

Figure 6. A flowchart that describes how the eLCC and LCA life cycles overlap.

The two life cycles described in the previous sections have been combined in the sense that they are overlapping each other in the most relevant phases. The use costs and the destruction cost in the end of the life cycle are not considered for the raw materials as these costs automatically will be included in the process where the raw material will be used.

2.7 Identification of environmental costs

The definitions and boundaries described in chapter 1.3 are used as basic framework in the process of identifying environmental costs.
In the environmental costs concept the following costs have been included; costs related to the toxicity of a product, costs related to harmful emissions caused by the product or its manufacturing process, overhead costs that relates to the company's environmental performance and finally, costs for investments and developments performed with the purpose of reduce the environmental impact of a product or the manufacturing process.

Costs related to the toxicity of a product are considered as the toxicity makes the product harmful to the environment as well as to the people working with the product. The toxicity of a product could affect the choice of manufacturing equipment used in the production process, the maintenance cost of the equipment and the way it is destructed. Costs of occupational health that the toxicity of the product may cause, such as protection clothes, occupational health is not considered to be an environmental issue.

If the product or the production process have harmful emissions, their effect on the environment is quite obvious. Costs that can be related to the emissions should therefore be considered as environmental costs. Such costs could be taxes or waste management costs for avoiding and reducing these emissions.

Overhead costs that relate to a company's environmental performance are mainly costs for staff working with environmental issues, as well as aggregated costs that relates to the company's environmental impact. Also included are costs, for example environmental permits, required for companies that run a business that have negative effects on the environment.

The investments made to reduce a product's or its manufacturing process' environmental impact could also be associated with the toxicity or the emissions of the product. The development cost could either be to reduce a products environmental impact or the cost of replacing a product which has a negative effect of the environment.

Environmental costs have been identified through interviews and discussions with staff in charge of the manufacturing of a product or the site where production takes place and staff in charge of environmental issues at the company. Web pages with general environmental information have also been studied, for example the Swedish Environmental Protection Agency's web page and the National Chemicals Inspectorates' web pages. The costs that have been identified as possible environmental costs are described further below in chapter 2.8.

2.8 Possible environmental costs

2.8.1 Environmental taxes

Three environmental taxes have been identified; energy tax, carbon dioxide tax and sulfur tax.

2.8.1.1 Sulfur tax

Emissions of SO_2 caused by the combustion of fuels are a major contributor to the acidification of water and ground. The sulfur tax is developed to reduce these emissions. [Naturvårdsverket 2003a] and therefore it is considered an environmental tax.

2.8.1.2 Carbon dioxide tax

The carbon dioxide tax is also related to the combustion of fuel. The tax is reduced for fuel used in manufacturing processes in the industry, fuel used for energy production and certain types of transportation, i.e. aircraft, train and boat transports. The reason for this tax is to reduce the use of fossil fuel, which in turn will reduce the emission of greenhouse gases such as carbon dioxide. [Naturvårdsverket 2003b]

2.8.1.3 Energy tax

The energy tax has the purpose to restrict energy use [Naturvårdsverket 2003c] and emissions of combustion gases. The industry is however excepted from this tax except for the energy tax paid on fuel used in transportation. [Näringsdepartementet 2003]

2.8.2 Environmental permits or certificates

2.8.2.1 Environmental permit

The environmental permit is needed in order for a company to run a business that contributes to pollution of the environment. The permit is needed in order to build, launch and run the business.

Companies apply for an environmental permit from the county administration. The permit is granted for a certain production level and differs in cost depending on how much and what the company produces. [Miljöbalken 1998a]

2.8.2.2 Environmental report

An environmental report is made in order to inform the public about the environmental status of a company, and to show that the company is within the limits of pollution and production established in the environmental permit. The costs for the environmental report vary from one company to another depending on the requirements of the county administration. [Miljöbalken 1998b]

2.8.2.3 Certificate cost

A certificate cost is considered an environmental cost if the purpose of the certification is to show that the company is committed and engaged in following a certain environmental standard. For example the International Organization of Standardization (ISO), ISO

14001 is a standard for environmental issues, and this certification cost is considered an environmental cost.

2.8.3 Environmental fees

Several fees were identified. They are: an environmental protection fee, NO_X-fee, registration fee and an environmental damage and clean-up insurance.

2.8.3.1 Supervision fee

The supervision fee is considered an environmental cost as it is paid to the county administration in order for them to supervise the companies and their emissions to water and ground in the county. [Svensk Författningssamling 1998]

2.8.3.2 NO_X-fee

The purpose of the NO_X-fee is to reduce the air emission of NO_X that contributes to the acidification and eutrophication of ground and water. [Naturvårdsverket 2003d] Companies that produce energy in stationary plants are obliged to pay the NO_X-fee. The fee is based on the amount of NO_2 released from the plant. The total fee is then repaid to the concerned companies, in proportion to how much energy the companies produce.

2.8.3.3 Registration fee

The registration fee is considered an environmental cost and it is paid to Kemikalieinspektionen (KemI) to make it possible to keep a record of all chemical products used in Sweden. The fee gives KemI economic means to supervise the chemicals used. The registration fee consists of two different fees, one that is based on the total production of a company and another that is based on the number of products a company produces.

2.8.3.4 Environmental damage and clean-up insurance

Companies that practice environmentally hazardous activities contribute to the environmental damage and clean-up insurance, which is more similar to a compulsory fee than an insurance. The purpose of the insurance is to cover bodily injury, material damage and pecuniary loss due to environmentally hazardous activities and is therefore considered an environmental cost. The insurance is used in the case no other compensation of the damage is paid due to lack of finances in the liable company or in the case no responsible parties can be found for the liable act. The insurance is meant to lessen the governmental costs for damages caused by companies that deal with environmentally hazardous substances.[Miljöbalken 1998c]

2.8.4 Environmental costs for tests in the development phase

When developing a new chemical substance the company is obliged to test it in several ways. [Miljöbalken 1998d] Sometimes the test results from very similar substances can be used. In other cases new tests have to be performed. The scope of the tests has been altered during the years and is now much more extensive than just ten years ago. The costs for the tests are considered environmental cost as the tests demonstrate to what extent a product is environmentally hazardous. The tests considered are not just the biodegradability tests and eco-toxicity test, but also tests related to human health such as tests for carcinogenic or regular toxicity are considered as environmental costs.

2.8.5 Environmental costs of transportation

A consequence of transporting goods is environmentally harmful emissions that origins form fuel combustion. Taxes and fees on the emissions are considered environmental costs. Fuels used for transportation are affected by two taxes, carbon dioxide tax and an energy tax. They are discussed earlier in this chapter.

If the cost of a transport is higher due to the environmental hazardousness of a product the additional cost is considered an environmental cost.

2.8.6 Measuring and testing costs during production

Some products may cause emissions to water, ground and air when they are being manufactured. To keep track of the level of environmentally hazardous substances in the surrounding environment continuous testing of the outlet from the process and on the surroundings has to be performed.

2.8.7 Education of employees

In the case that additional education is needed for employees to handle products that are toxic or because of other environmental properties the additional cost to educate employees is considered an environmental cost.

2.8.8 External information

For some companies and products external information is needed to inform the public about the environmental hazardousness of a product or production process.

2.8.9 Environmental investments

Investments in production equipment might be made in order to reduce environmentally hazardous emissions. Such investments are considered environmental costs. Most investments however are not made solely for environmental purposes but also to increase the utilization capacity. These investments are not considered as entirely environmental but also as regular investments. In these cases the environmental costs only consist of the part of the investment considered an environmental investment. [SCB 2001]

2.8.10 Continuous development of the product

In order to make a product or a process less environmentally harmful the company might have to develop them further. If the development is performed in order to lessen the environmental impact of the product, the cost for the development is considered an environmental cost.

2.8.11 Cost for additional cleaning

Cleaning of process equipment is an environmental cost if additional cleaning is needed due to the environmental properties of a raw material or the final product.

2.8.12 Cost for waste management

Waste produced by a process often has to be processed before being released to the environment. Some of the waste can be handled by the company itself, other waste is better handled by external waste treating companies. Handling of the waste causes environmental costs either way. The cost of waste transportation is also considered an environmental cost.

2.8.13 Potential clean-up costs for shut-down of business

In the case a company runs out of business and has to shut-down its factories there are costs for clean-up and demolishing of the production sites. The demolishing and clean-up of a plant or smaller production unit is also included in this cost. The clean-up cost that is related to the environmental hazardousness of the production in the plant is an environmental cost.

2.8.14 Membership of special interest organizations

Some companies are members of special interest organizations that have a common interest in environmental issues. The companies within the organization can create a new common environmental policy. A constellation of companies that have a common interest protecting the aquatic environment in the region where they operate could be considered as a special interest organization. Other examples of special interest organization are CEFIC and the Swedish Plastics and Chemicals Federation. Costs for membership and for participating in activities, related to environmental issues, of these organizations are considered environmental costs.

2.8.15 Raised insurance cost due to environmental impact

There is reason to believe that the environmental impact of products should have an effect on the cost of the company's insurance. However, no such insurance exist in Sweden today.

2.8.16 Staff

The cost for employees that work with environmental issues is an environmental cost. The cost is not just the wages but the total cost the company has for its employees. In addition to wages these costs consist of for example office space, software and computers.

Regulatory Affairs (RA), a unit at Akzo Nobel Surface Chemistry, is for example included due to the administrative work that is necessary for the products due to the chemical legislation [Svensson 2003]. The legislation considers risks for health and environment and regulates how a chemical industry should deal with their products in i.e. what information that needs to be distributed to costumers and how transportation of the product in question should be carried out.

2.8.17 Costs not covered by the criteria

The environmental profile of a company and its products affect a company in many different ways that are not covered by the criteria for environmental costs used in this study. An example of this is the costs and benefits associated with the company's environmental image. A good environmental image might for example increase sales volumes and the value of the company. Additionally, a company with an environmentally friendly reputation could attract skilled employees who prefer to be associated with a company that has a good environmental image. A company with an unfavorable environmental image on the other hand might lose out on some deals and have higher costs for recruiting because of their reputation as an environmental villain. There is also a financial aspect; a company with a good reputation is more likely to get more profitable loans than other companies.[Steen 2003]

Factors such as these have a clear connection to environmental issues and could affect the economy of the companies significantly. It is very difficult to measure how the environmental performance of one product affects the environmental image of a company with thousands of products in their portfolio and even if an estimate was made the effect of the environmental image is difficult to measure directly in economic terms. Since the criteria states that only clearly identifiable costs that Akzo Nobel actually have paid for are to be considered, costs and effects that depend on the environmental image are not considered in the study.

2.9 Grouping of environmental costs

In the following table the possible environmental costs have been grouped depending on the relevant phase in the eLCC. There are also aggregated definitions of environmental costs to group them even further. This grouping of environmental costs will be used in the presentation of the results.

Table 1 Possible environmental costs and where in the life cycle of a product they arise.

LCC phases / Environmental costs	*Engineering & Development*	*Production & Implementation*	*Use*	*End of life cycle*
Product development	**Continuous development**			
	Environmental investment			
	Staff			
Test	**Test**			
Administration – RA		**Staff**		
		Registration fee		
		External information		
		Membership of special interest organization		
Site administration		**Environmental permit**		
		Environmental report		
		Certificate cost		
		Environmental protective fee		
		Environmental damage and clean-up insurance		
		Education of employees		
Environmental investment		**Environmental investment**		
Manufacturing		**Sulfur tax**		
		CO_2 tax		
		Energy tax		
		NO_X fee		
		Measuring and testing costs		
		Cost for additional cleaning		
		Waste management		
Transport		**Transport**		
Other costs		**Potential clean up cost**	**Transport**	**Transport**
	Good Will	**Good will**	**Sulfur tax**	**Sulfur tax**
			CO_2 tax	**CO_2 tax**
			Energy tax	**Energy tax**
				Waste management

3 LCA and eLCC on Colorants

3.1 Goal Definition

The purpose of the life-cycle assessment has been to compare the environmental performance of the two surfactants from a life cycle perspective. The reason for the substitution of surfactants was mainly due to the perceived environmental and health benefits of Bermodol SPS 2532. It is therefore of interest to investigate if Bermodol SPS 2532 is the environmentally preferable choice from a life cycle perspective as well.

It has also been of interest to see how the environmental costs vary with the substitution. Another goal has been to prepare LCA and eLCC results that are comparable between themselves.

3.2 General Boundaries

3.2.1 LCA

This LCA attempts to cover the production of two colorants and their respective raw materials. The environmental impact is only considered for the actual process and transport steps and thus impacts related to the manufacturing of machines and industrial plants are omitted, and so are the environmental impacts caused by the work force and their transports.

Emissions to air and water are studied but the differing effects of emissions due to their geographical location have been neglected.

The study spans from the cradle of the colorants, the extraction of necessary resources to the gate of the colorant manufacturer. The use of the colorant in paint and the waste management of paint and colorant residues are omitted from the study as the colorants are expected to have roughly the same environmental impacts in this step.

3.2.2 eLCC

The environmental cost study takes place in Sweden and is mainly performed at Akzo Nobel in Stenungsund where raw materials to the colorant are produced. The environmental costs of the colorant manufacturer will also be considered. In addition to the environmental costs of the raw materials and the final product, the environmental costs for transportation of other raw materials than the raw materials produced at Akzo Nobel have been studied in order to expand the system as far as possible.

All costs considered are only direct cost taken by the companies of the study, a major part of test costs will therefore be excluded from the study as the tests have been performed and paid by other parties.

3.3 Time Perspective

3.3.1 LCA

The system model used in the LCA attempt to model the production of the colorants as it is today. The exception is the production of Nonyl phenol, a raw material used in Berol 09, where data for the production of 1999 at the Akzo Nobel Nonyl phenol plant in Mölndal is used. Data from the Akzo Nobel is used as it gives a good opportunity to compare it with easily accessible environmental cost data for the eLCC from the same plant.

3.3.2 eLCC

The time perspective considered in the eLCC study depends on the raw materials studied. Generally, the study is performed from the time when the product was just a concept up until today; some raw materials are also studied ten years in the future. To compare costs they are calculated into 2003 years value by using inflation or an approximation of the value.

3.4 Energy

Average electricity production of the country where the process takes place is used if the specific supplier of the electricity is not known.

3.5 Transports

For road transports in Sweden emission and resource consumption data from an average Swedish diesel truck (Environmental Class 1) with 70% filling coefficient is used. Road transports in Europe are treated similarly, except data from average European diesel trucks (Environmental Class 3) are used. Data from boat transports are derived from average fuel consumption and emission values.

3.6 Functional unit

The functional unit of the scenario is 1 kg of iron oxide yellow colorant produced by the Colorant Manufacturer. A more traditional choice of functional unit when dealing with paint or paint additives would be square meter and year of painted wall [Baumman & Tillman 2003]. However, since the two colorants are used in similar amounts in paint and as their life expectancies are approximately the same there is no real benefit in choosing this functional unit. In addition the colorant is added to the paint by the retailer and amounts used depend both on the retailers' preferences and on the particular shade of yellow the customer want. Since the use phase is largely omitted in this study the inclusion of these factors is somewhat out of the study's focus.

3.7 Allocations

Emission data that has been received for the total production of a certain site, such as environmental reports, have been allocated exclusively on mass basis.

How allocations are made in the environmental cost study will differ depending on the cost being calculated. The allocation depends on the circumstance it is made, mainly however it is made on mass basis, in some cases it is made on product basis..

3.8 Type of Data

For the production of the major raw materials site specific data have been used a majority of the time. Production data for some of the minor raw materials is scarce, and in some cases European industrial averages or data from other plants is used instead of the data from the actual supplier. Average data is used for all transports since the scope of the study is too limited to allow an in depth investigation of the specific transports used.

3.9 Model flowcharts and data

3.9.1 Flowchart for the Old Colorant

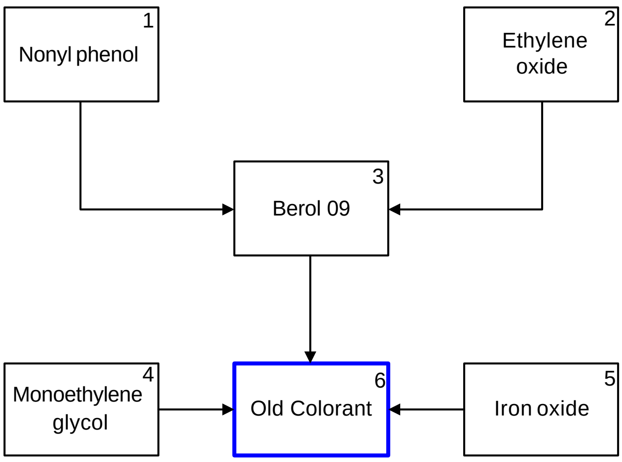

Figure 7. Flowchart of the major raw materials included in the production of Old Colorant and Berol 09.

3.9.1.1 Nonyl phenol

Production of nonyl phenol in Akzo Nobel's plant in Mölndal. The factory in Mölndal ceased to operate in 1999. This data is used instead of data from the current supplier as it is readily available and makes for valuable comparisons with the environmental cost data of Akzo Nobel's late nonyl phenol production.

3.9.1.2 Ethylene oxide

Ethylene oxide production by Akzo Nobel Functional Chemicals, Stenungsund. The ethylene oxide produced by Akzo Nobel Functional Chemicals is used as a major raw material in various processes at the Stenungsund site.

3.9.1.3 Berol 09

Berol 09 is produced by Akzo Nobel Surface Chemistry, Surfactants Europe at the site in Stenungsund.

3.9.1.4 Monoethylene glycol

Monoethylene glycol is a by-product to the production of ethylene oxide in Stenungsund.

3.9.1.5 Iron oxide

The production of iron oxide in Malmberget is used to estimate the production by the supplier of the iron oxide yellow pigment in Germany.

3.9.1.6 Old Colorant

Production of the Old Colorant by the Colorant Manufacturer.

3.9.2 Data to the LCA

The processes described in the flowchart for the Old Colorant are all included in the LCA study. A more detailed system description can be found in appendix I.

3.9.3 Data to the eLCC

The only processes studied in the eLCC are Akzo Nobel processes and the colorant manufacturer. All processes described in the flowchart for the Old Colorant is therefore considered except for the iron oxide process. Costs for transportation of raw materials to the considered process are taken into account for all raw materials. The processes considered are described more thoroughly in appendix II.

3.9.4 Flowchart for the New Colorant

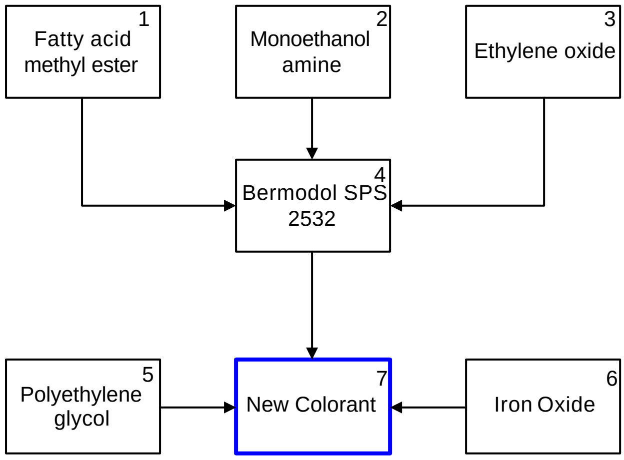

Figure 8. Flowchart of the major raw materials included in the production of New Colorant and Bermodol SPS 2532.

3.9.4.1 Fatty acid methyl ester

Fatty acid methyl ester is produced in Belgium.

3.9.4.2 Monoethanol amine

Monoethanol amine is produced by Akzo Nobel Functional Chemicals, Stenungsund. Monoethanol amine and fatty acid methyl ester combine to form the fatty acid monoethanol amine that forms the hydrophobic part of Bermodol SPS 2532.

3.9.4.3 Ethylene oxide

See **3.9.1.2**

3.9.4.4 Bermodol SPS 2532

Bermodol SPS 2532 is produced by Akzo Nobel Surface Chemistry, Surfactants Europe.

3.9.4.5 Polyethylene glycol

Production of Polyethylene glycol at the Akzo Nobel Surfactants Europe in Stenungsund is used as a model system for the polyethylene glycol used in the colorant.

3.9.4.6 Iron Oxide

See **3.9.1.5**

3.9.4.7 New Colorant

Production of the New Colorant by the Colorant Manufacturer.

3.9.5 Data to the LCA

The processes described in the flowchart for the New Colorant are all included in the LCA study. A more detailed system description can be found in appendix I.

3.9.6 Data to the eLCC

The only processes studied in the eLCC are Akzo Nobel processes and the colorant manufacturer. All processes described in the flowchart for the New Colorant is therefore considered except for the iron oxide and the fatty acid methyl ester process. Costs for transportation of raw materials to the considered process are taken into account for all raw materials. The processes considered are described more thoroughly in appendix II.

4 Environmental costs considered in the report

In this section an attempt is made to further explain the environmental costs considered in this specific study. First, the general environmental costs of the companies and their relevant processes are dealt with. Secondly, the separate costs of the processes in concern for this study will be treated in further detail.

4.1 General environmental costs

All of the following environmental costs have been described previously and are more or less applicable in all companies concerned in this study. The costs listed can not be directly related to a product or a process; they are mainly associated with the companies' business. As the concerned companies are in the same business, dealing with chemical substances, the requirements for the companies are roughly the same. They might however differ in the size of costs depending on volume of production and emissions of the company.

The environmental permit, the environmental report and the environmental protection fee are considered for all production sites in the study. They differ in size depending on the business the permit is applied for.

All the concerned companies pay the environmental damage and clean-up insurance. The companies in this study are all manufacturers of chemicals which mean that they have to pay the registration fee to the National Chemicals Inspectorate.

All companies concerned except the factory in Mölndal have ISO 14001 certification. The cost for ISO certification differs for the different subunits of Akzo Nobel that are studied.

4.2 Environmental cost that differ for the substances

The companies and their environmental costs will be listed in the next section. The listing will start with the final product and then proceed to the raw materials in order of significance.

4.2.1 The colorant

4.2.1.1 Common costs for the colorant manufacturer

Site costs at the colorant manufacturer are the environmental permit, the environmental protection fee, the environmental damage and clean-up insurance and costs for ISO 14001. There is also a cost for the environmental department that is distributed evenly among the production units at the site. One of the production units at the site produces the colorants. [Colorant Manufacturer 2003]

4.2.1.2 Environmental costs for the studied Colorants

The environmental department has a cost for regulatory affairs for the colorants. The environmental department provides the colorants with data sheets and keeps track of safety data sheets for the raw materials used in the final product.

Environmental costs considered for the manufacturing process are mainly related to waste treatment. The internal handling and the external destruction of wastewater are two closely related costs. The wastewater originates from cleaning of stationary manufacturing equipment. The cleaning of mobile vessels is a source for another internal destruction cost. Besides wastewater other waste is also produced, treatment of this waste also generates a cost that is considered an environmental cost.[Colorant Manufacturer 2003] The consumption of heat and electricity for the manufacturing process is not included as an environmental cost for two reasons; the heat and electricity consumption for the production of this specific colorant is not large, the environmental tax for emissions associated with the heat and electricity consumption for the colorant could not be detected.

All costs for the colorants are common and have been distributed evenly on the total amount of colorants produced at the production unit in order to obtain the cost per functional unit.

4.2.2 Surfactants

Both Berol 09 and Bermodol SPS 2532 are produced by Surfactants Europe (SE), a sub business unit (SBU) of Akzo Nobel Surface Chemistry (ANSC). The former surfactant is also sold externally by SE but the later is a product of Cellulosic Specialties, another SBU of ANSC.

4.2.2.1 Site

The site is owned by ANSC which has costs for running the site, the costs have been distributed on the production of SE and Akzo Nobel Functional Chemicals (ANFC), another business unit active on the site.

Site costs that have been identified for ANSC are: The environmental permit, environmental report, fee to the county administration, environmental damage and clean-up insurance, ISO 14001 certification, staff, education and leakage search and costs for internal consultants. [Andren & Lindqvist 2003] These costs have been distributed on a mass basis based on the total amount produced at the site each year [Env. Report Stenungsund 2002], no product is considered to contribute more than any other to any of these costs.

4.2.2.2 Berol 09

4.2.2.2.1 Administration – Regulatory affairs

All products produced at the site have to be administrated by the environmental department at the SBU, Service Unit Sweden (SUS) at ANSC. There is one general service for which the cost depends on whether the product is considered a hazardous or a regular product. This cost is a bit higher for Berol 09 as it is considered hazardous due to the nonyl phenol content. This cost covers the computer systems used, staff, keeping track of legislation of the products, classification and labeling of products, and the registration fee to KemI.[Svensson 2003]

The environmental department also offers a service where chemical health hazard of raw materials used in the manufactured products is evaluated. To get an approximation of these costs, the total costs are divided by the total number of modified products at the site. The cost for safety advisers are divided by the number of supplied product to costumers produced by SE in Stenungsund, this basis for allocation is chosen due to the nature of the cost. The safety advisory cost is related to the transportation of products from the site, to make sure that the labeling of the product is correct. The environmental department does also charge their customers for Product Stewardship and Sustainability services. This is a fixed cost that includes thesis projects and presentations at schools. The cost is divided by the total amount of product produced by SE in Stenungsund. There is also a toxicology service offered, this service is however not used for the substances studied and is therefore excluded. [Svensson 2003]

As Berol 09 contains nonyl phenol that is a toxic substance, AN have participated in a consortium where this substance has been discussed and tested [Haux 2003]. A cost for these activities has been estimated on a yearly basis as such consortiums have been and most likely will be a reality for substances like nonyl phenol as long as it is produced. The cost is divided by the total amount of nonyl phenol containing product produced in one year, 2003.

Except for the environmental department, SE has some staff of their own that works with environmental issues that concerns their products. This cost is divided by the total amount of chemicals produced by SE in Europe.

4.2.2.2.2 Development

Production of Berol 09 in Stenungsund began during the 1960's. As it was not developed by Akzo Nobel no development cost can be detected in the company. Even if development costs could be detected they would not be included in this study as the reason for development was most likely not to reduce the environmental impact of another product.

4.2.2.2.3 Tests

No initial tests have been identified for Berol 09 at Akzo Nobel, tests have however been performed later in the product's life [Safety data sheet: Berol 09 2003]. The actual costs for these tests could not be found and they are instead approximated by the cost for similar tests performed today. [Haux 2003][25] The cost for the tests is divided by the total amount of Berol 09 produced during the years.

4.2.2.2.4 Environmental investment

To estimate the environmental investments for Berol 09 the annual depreciation of total investments at SE is used as a base. To what extent the depreciation is considered an environmental cost is estimated as approximately 20%.[Svensson & Rees 2003] As Berol 09 contains nonyl phenol, specific investments considered just because of this substance is accounted for separately, this investment is estimated to be 0,2% of total investments. [Svensson & Rees 2003]

Along with the investments comes a cost for maintenance of the investments, this cost is of the same size as the environmental investment, i.e. 20%. [Svensson & Rees 2003] Specific maintenance cost for the nonyl phenol investments are neglected, as these investments do not have the same need for maintenance. [Svensson & Rees 2003]

4.2.2.2.5 Transport

The environmental cost of the transportation is calculated by determining the theoretical fuel usage and calculating the energy and carbon dioxide taxes based on this. The carbon dioxide and energy tax is determined by the tax on diesel. [Preem 2003]

4.2.2.2.6 Manufacturing

Environmental costs related to the manufacturing of the products in concern are costs paid internally to Functional Chemicals for incineration of discarded products, process and wastewater as well as carbon dioxide taxes from the heating of the processes and a cost for the lab at the site that supervises the emissions. SE is charged by the ton for incinerated water and the amount incinerated depends on how much wastewater a process produces and to what extent the product is discarded.[Gerdner 2003] No difference is made depending on the process the waste water comes from; the cost is the same per ton of incinerated water.

Approximately 0,14 ton of waste water is produced for each ton of manufactured Berol 09. [Bill of Materials: Berol 09 2003] The cost per ton incinerated discarded product is the same as the incineration cost for waste water, the amount of discarded surfactant is low and approximated to 0,16 % for Berol 09. [Svensson & Rees 2003]

FC also performs continuous testing at the site in order to keep track of the emission from the processes. [Rönnmark 2003] A large part of the testing is performed due to the occurrence of nonyl phenol at the site, this test cost is allocated on the products containing nonyl phenol. The rest of the test cost is distributed on all the amount of tons produced at the site. Berol 09 has both the regular test cost and the nonyl phenol test cost.

The environmental cost for heat and steam used in the manufacturing costs is as the rest of the manufacturing costs handled by FC. The total carbon dioxide tax paid by FC during 2003 [Jansson 2003] is allocated among the site's products depending on the amount of steam that is used in production of these products. [Bill of Materials: Berol 09 2003]

4.2.2.3 Bermodol SPS 2532

4.2.2.3.1 Product development

Cellulosic Specialties has a considerable environmental cost for the development of Bermodol SPS 2532. [Munk 2003] The reason why this cost is considered an environmental cost is the purpose of the development. The product is developed solely to replace Berol 09 in a product in order to make it less environmentally hazardous. Several Bermodol SPSs were developed at the same time; therefore, the development cost is divided by the total amount of Bermodol SPS in production today and an approximation of the future production during the next 10 years. The reason for including the future production in the calculation is that the sales of the product are assumed to increase for at least 10 years; the cost is distributed over these years. The cost accounted for is the cost for the developing team.

4.2.2.3.2 Tests

Several initial tests have been performed on Bermodol SPS 2532, some of the tests have been performed on other Bermodol SPSs [Safety data sheet: Bermodol SPS 2532 2003]. The costs for the tests are therefore divided by the total production of Bermodol SPSs from the year of development to the estimated production during the next ten years. The costs for these tests are also approximated with the cost for similar test today.

4.2.2.3.3 Administration and regulatory affairs

Bermodol SPS 2532 has mainly the same costs for the environmental department as Berol 09. Bermodol SPS 2532 is however considered a regular product, as opposed to a dangerous product, and the cost for such a product is a bit lower. The rest of the costs for the environmental department are distributed in the same way as for Berol 09.

Bermodol SPS 2532 has an additional cost for staff working with environmental issues at Cellulosic Specialties, this cost is approximated to be 20 % of a man-year and is distributed over all CS's products.[Munk 2003]

4.2.2.3.4 Environmental investment

The cost for environmental investment is the same for Bermodol SPS 2532 as for Berol 09 except for the additional nonyl phenol investments that the latter surfactant has.

4.2.2.3.5 Manufacturing

The only difference in manufacturing costs of Berol 09 and Bermodol SPS 2532 is the amount discarded product per ton manufactured product. Bermodol SPS 2532 is a much more complex product and more difficult to produce which results in substantially larger amounts of discarded product, approximated to 4%. [Svensson & Rees 2003]

4.2.2.3.6 Transport

The transportation is the same for Bermodol SPS 2532 as for Berol 09 in this study as they are used in the same product which is manufactured at the same plant.

4.2.3 Other raw materials for the colorants

Monoethylene glycol (MEG) and polyethylene glycol (PEG) are also produced at the Akzo Nobel Site in Stenungsund. The former is sold and manufactured by Functional Chemicals and the latter is produced and sold by Surfactants Europe. Since the site cost is the same for all products produced at the ANSC site in Stenungsund, the site cost of MEG and PEG is the same as site cost of the surfactants.

4.2.3.1 MEG

4.2.3.1.1 Administration – Regulatory affairs

At Functional Chemicals the cost for the environmental department is included in a cost for product stewardship. Besides the environmental department at SUS, the cost for FC's staff working with environmental issues is included, as well as the cost for CEFIC. The cost considered is an approximated average cost for MEG per year as it differs from year to year depending on what tests that are performed on the substance. [Ahnsberg 2004]

The membership fee for The Swedish Plastics and Chemicals Federation is not included in the product stewardship cost. [Sköld 2004] The cost is distributed on the amount of products sold. The salary for the HSE manager is not included in the product stewardship cost but is estimated to be the cost for one man-year. The cost for the registration fee to KemI is neither included. [Sköld 2004] These three costs are therefore considered separately. The salary is distributed on FC's products by the amount produced and the membership fee is distributed on the amount sold. The registration fee to KemI is based on the number of products produced and the total amount produced by FC..

4.2.3.1.2 Development costs

MEG has not been developed in order to reduce the environmental impact of any other product.

4.2.3.1.3 Tests

No tests have been performed by Akzo Nobel.

4.2.3.1.4 Environmental investment

Continuous environmental investments made solely for MEG have been approximated. [Kindstrand 2003]

4.2.3.1.5 Manufacturing

No process water is incinerated in this process, thus there is no cost for this. The only manufacturing costs for MEG that are considered are the continuous testing cost that all products at the site have and the carbon dioxide tax due to the heating of the process. The carbon dioxide tax is calculated in same way as for Berol 09. [Jansson 2003] [Kindstrand 1998]

4.2.3.1.6 Transport

The transportation is the same for MEG as for Berol 09 in this study as they are used in the same application which is manufactured at the same plant.

4.2.3.2 PEG

4.2.3.2.1 Administration – regulatory affairs

These costs are practically the same as for Berol 09 except that PEG is considered as a regular product. The extra cost for nonyl phenol is not included as there is no nonyl phenol in PEG.

4.2.3.2.2 Development costs

PEG has not been developed in order to reduce the environmental impact of any other product.

4.2.3.2.3 Tests

No tests have been performed by Akzo Nobel.

4.2.3.2.4 Environmental investment

Continuous environmental investments are approximated in the same way as for Bermodol SPS 2532.

4.2.3.2.5 Manufacturing

The environmental cost for manufacturing is the same as for Berol 09 except for the extra test as PEG does not contain nonyl phenol.

4.2.3.2.6 Transport

The transportation is the same for PEG as for Berol 09 in this study as they are used in the same application which is manufactured at the same plant.

4.2.4 Raw materials used in the surfactants

Ethylene oxide and Monoethanol amine are both produced and sold by Functional Chemicals in Stenungsund and therefore have the same site costs per ton product as all other products at the Akzo Nobel Stenungsund Site.

4.2.4.1 EO

4.2.4.1.1 Administration – Regulatory affairs

These costs are calculated in the same way as for MEG.

4.2.4.1.2 Development costs

EO has not been developed in order to reduce the environmental impact of any other product.

4.2.4.1.3 Tests

No tests have been performed by Akzo Nobel.

4.2.4.1.4 Environmental investment

Continuous environmental investments made solely for EO have been approximated. [Kindstrand 2003]

4.2.4.1.5 Manufacturing

No process water is incinerated in this process, thus there is no cost for this. Neither is any steam or heat used in the process in contrary the process produces steam which is used in other processes. The only manufacturing cost considered for EO is the cost for continuous testing that all products at the site bear.

4.2.4.1.6 Transport

As EO is used at the same site as it is produced there is no cost for transportation.

4.2.4.2 MEA

4.2.4.2.1 Administration – Regulatory affairs

These costs are calculated in the same way as for MEG.

4.2.4.2.2 Development costs

MEA has not been developed in order to reduce the environmental impact of any other product.

4.2.4.2.3 Tests

No tests have been performed by Akzo Nobel.

4.2.4.2.4 Environmental investment

Continuous environmental investments made solely for MEA have been approximated. [Kindstrand 2003]

4.2.4.2.5 Manufacturing

As environmental manufacturing costs the cost for incineration of process water, carbon dioxide tax due to heating of the process and the continuous testing costs at the site are considered. The amount of process water that needs incineration is approximately 2 % for MEA. [Safety data sheet: mono ethanol amine 2003]

4.2.4.2.6 Transport

As MEA is used at the same site as it is produced there is no cost for transportation.

4.2.4.3 NP

The environmental costs for this production unit differs a bit from the others as the factory studied is no longer in use and was demolished 1999. There are still some data available from this production unit but it could not be achieved in the same way as environmental costs for other production units. The costs received mainly come from the economic reports of 1998 and as some relevant costs could not be detected, these costs had to be estimated.

4.2.4.3.1 Product development

Since nonyl phenol is an old product, from the mid 40's, and was not developed at Akzo Nobel no development costs could be found for Akzo Nobel.

4.2.4.3.2 Tests

Since the product was not developed at Akzo Nobel no major costs for tests could be identified. There are, however tests performed at a later stage of the production which Akzo Nobel have been charged for. [Sjöström 2003] The test costs are distributed on an estimated total production of Nonyl Phenol in Mölndal [Billstedt 2003] as the tests influence the entire production. The test costs have been approximated with the cost for similar tests made today.

4.2.4.3.3 Product Stewardship and RA

There is an estimated cost of work and investigation done on the substance Nonyl phenol during the last ten years of the production in Mölndal. One person spent approximately 10% of his time on issues related to Nonyl phenol.[Svennberg 2003] This cost is divided by an approximation of the production during these years as it is assumed that Nonyl phenol would have caused the same cost per year since it was found to be environmental hazardous.

A cost for membership in a consortium discussing nonyl phenol is estimated per ton product in the same way as the work done on nonyl phenol described in the previous section.[Haux 2003] This cost includes tests, salaries, travel expenses and membership cost.

4.2.4.3.4 Environmental investment

Environmental investments are estimated by the depreciation of last investments done on the site. [Economic report, Mölndal 1998] [1]This cost might have a low estimation due to the shutting down of the factory a year later.

4.2.4.3.5 Manufacturing

A majority of the identified manufacturing costs are related to the handling and transportation of waste and process water. Maintenance of the plant is also included in this cost. [Avdelningsrapport Budget, Mölndal 1998] All costs identified are calculated into 2003 years value by assuming an inflation rate of 2%.

4.2.4.3.6 Transport

The environmental costs of the transports are calculated in the same way as for SE. There is no additional cost for the hazardousness of the product.

4.2.4.3.7 Other costs

As the plant manufacturing nonyl phenol has been shut down and demolished there is a clean up cost associated with this that is considered in this study. The entire cost for the clean-up will not be considered as it includes both costs that can be related to the toxicity of the nonyl phenol produced and other costs that arises irrespective the toxicity of the products. The clean up cost related to the toxicity of nonyl phenol is estimated [Lundström 2003] and allocated on an approximated production of nonyl phenol [Billstedt 2003] in the plant since the 1950's in order to obtain the clean up cost per ton of nonyl phenol.

4.2.5 Environmental costs of colorants and raw materials

Table 2 A summary of the environmental costs that affect the raw materials from Akzo Nobel and the colorants.

		Old/New Colorant	PEG	MEG	Berol 09	Bermodol SPS 2532	MEA	EO	NP
Product development	**Staff**					X			
Test	**Tests**				X	X			X
Administration – RA	**Staff**	X	X	X	X	X	X	X	X
	Registration fee to KemI	X	X	X	X	X	X	X	
	RA – regular product		X	X		X	X	X	
	RA – dangerous product				X				X
	Safety Advisors		X	X	X	X	X	X	X
	Chemical health hazard		X	X	X	X	X	X	X
	Product stewardship and sustainability		X	X	X	X	X	X	X
	Risk assessment				X				X
	CEFIC								
	The Swedish Plastics and Chemicals Federation		X	X	X	X	X	X	X
	Göta älvs vattvårdsförening								X
Site administration	**Environmental permit**	X	X	X	X	X	X	X	X
	Environmental report	X	X	X	X	X	X	X	X
	ISO 14001	X	X	X	X	X	X	X	
	Environmental protective fee	X	X	X	X	X	X	X	X
	Environmental damage and clean-up insurance	X	X	X	X	X	X	X	X
	Education of employees		X	X	X	X	X	X	
	Product stewardship and sustainability		X	X	X	X	X	X	
	Staff	X	X	X	X	X	X	X	X
Environmental investment	**Environmental investment**	X	X	X	X	X	X	X	X
	Environmental investment – NP				X				X
	Maintenance	X	X	X	X	X	X	X	X
Manufacturing	**CO_2 tax**		X	X	X	X	X		X
	Measuring and testing costs		X	X	X	X	X	X	X
	Measuring and testing costs NP related				X				X
	Incineration of discarded product		X	X	X	X	X	X	X
	Incineration of waste water	X		X	X	X	X		X
	Internal waste management	X							
	External destruction								
Transport	**CO_2 tax**		X	X	X	X			X
	Energy tax		X	X	X	X			X
Other costs	**Clean up cost**								X

5 Results

5.1 LCA

In the following chapter a summary of the results of the LCA study will be presented. A full ecoprofile for the production of the colorants can be found in appendix III and IV.

5.1.1 Natural resources

Natural gas and oil are the two major resources used in the production of colorants.
The production of the old colorant requires significantly more energy resources of all kinds than production of the new colorant.

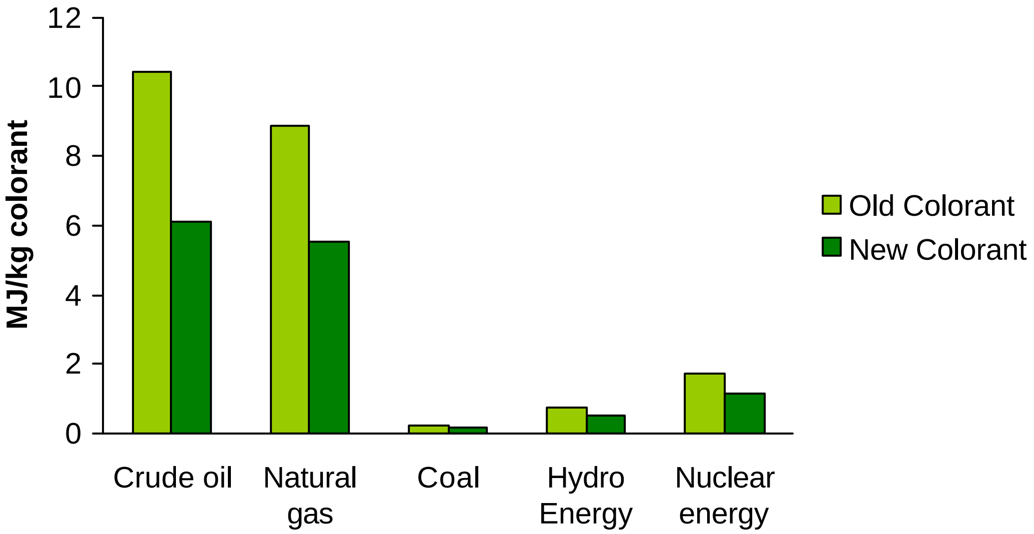

Figure 9. Use of energy resources caused by the production of 1kg of colorant.

5.1.2 Air Emissions

Since energy resource use often lead to air emissions they follow a similar trend with production of the old colorant giving larger emissions of all noteworthy air emissions.

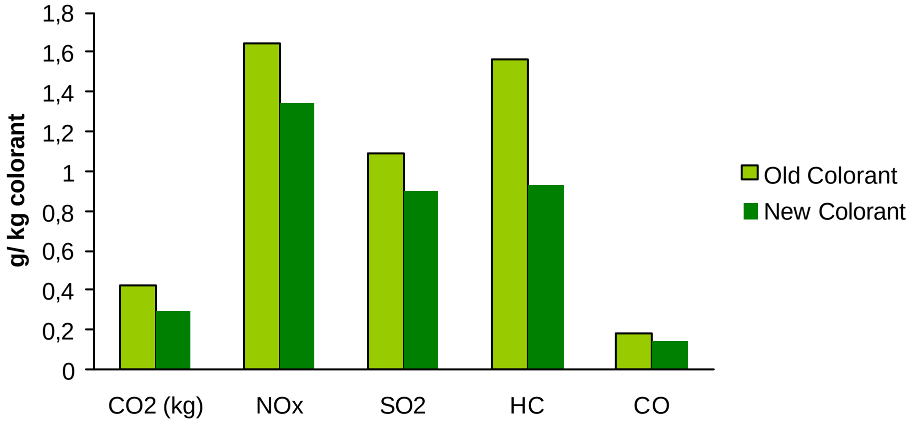

Figure 10. Noticeable air emissions caused by the production of 1kg of colorant.

5.1.3 Water emissions

The Chemical oxygen demand (COD) of waste water has been used to estimate the significance of water emissions from the processes studied. In case of the new colorant the process that gives the single largest contribution to the water emissions is the production of fatty acid used as a raw material for the surfactant. No emissions of comparable size have been identified in the study of the old colorant. The major contributor to the water emissions caused by the production of the old colorant is from the incineration of process water at Akzo Nobel site Stenungsund. This emission is of approximately comparable size for the old and the new colorant.

5.1.4 Contribution to LCA results by transports and raw materials to the colorant

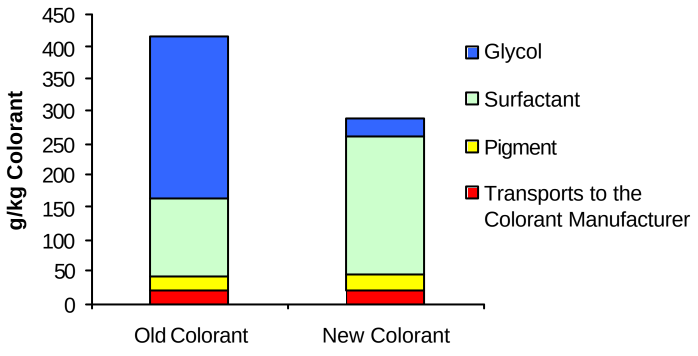

Figure 11. Contributions to the emissions of carbon dioxide to air caused by the production of raw materials and transports.

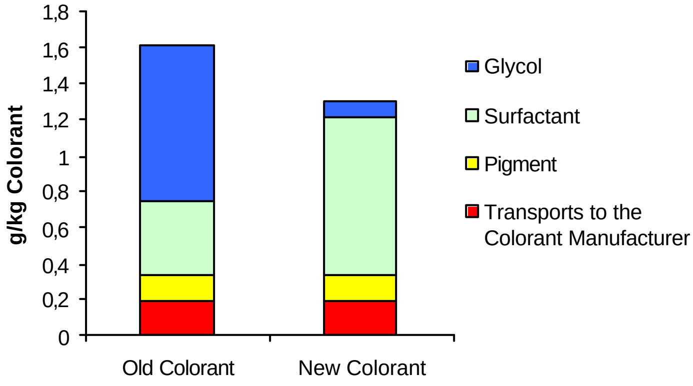

Figure 12. Contributions to the emissions of NOx to air caused by the production of raw materials and transports.

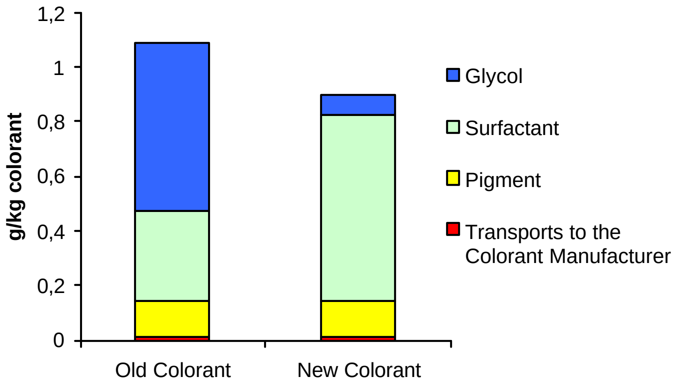

Figure 13. Contributions to the emissions of sulfur dioxide to air caused by the production of raw materials and transports.

The main part of the emissions caused by the production of the old colorant originates from the production of monoethylene glycol and another major contributor is production of the surfactant Berol 09.

Production of the raw materials, ethylene oxide and nonyl phenol, and production of heat used in the production of monoethylene glycol causes a majority of these emissions.

Production of Bermodol SPS 2532 is the largest contributor to the emissions caused by the production of the new colorant. Production of ethylene oxide is responsible for a majority of the emissions caused by the production of Bermodol SPS 2532. The other major raw material, fatty acid methyl ester is not of fossil origin and this shines through in its comparatively lower contribution to the emissions.

5.2 Discussion of LCA results

Data from the production of iron oxide pigments, one of the major raw materials in both colorants, is based on average data from the production of iron oxide. Using this data the impact from iron oxide pigment is relatively minor. It is possible that with more accurate data this process could prove to be a more important contributor to the environmental impact of the colorants. However since both colorants contain roughly equal amounts of pigment this is not likely to affect the results of comparison of the two colorants.

Transports have only a minor influence on the results of the study. Most of the raw materials are transported within Europe and even with pretty generous estimates the emissions from transports fail to influence the results significantly.

5.3 eLCC

More detailed information about the various environmental can be found in appendix V.

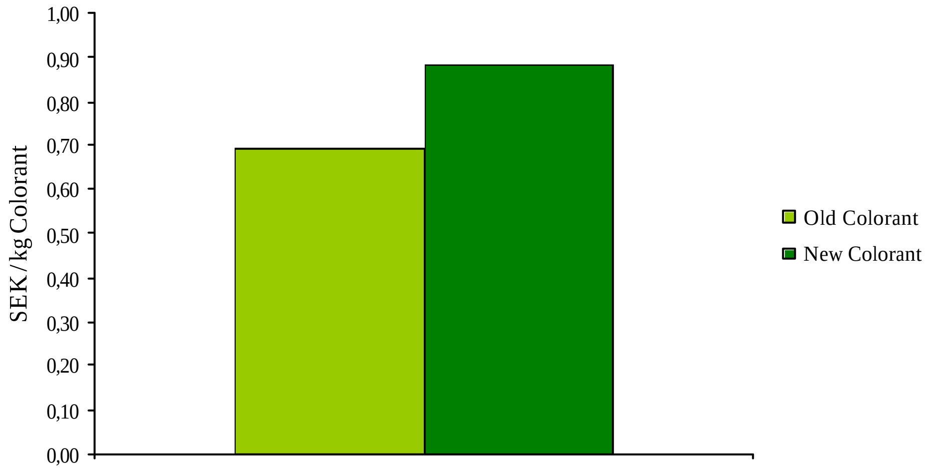

Figure 14. The total identified environmental cost of both colorants including costs for raw materials produced at Akzo Nobel.

In Figure 14 all identified environmental cost for the two different colorants are added in order to demonstrate what the environmental costs of the colorants are. As the diagram shows, the environmental cost for the New Colorant is larger. This will be further studied in the following figure where the environmental costs of the raw materials used in the colorant as well as the cost for the colorant manufacturer is displayed.

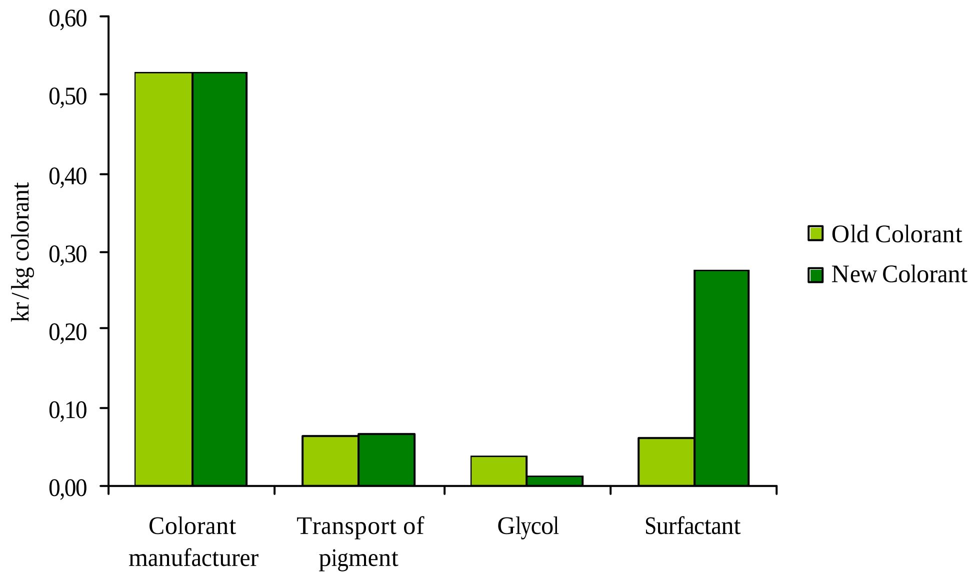

Figure 15. Contributions from raw materials and the colorant manufacturer to the total environmental costs of the two colorants.

In Figure 15 the contribution of the environmental costs from the raw materials as well as the colorant manufacturers own environmental costs of one kg colorant are presented.

The environmental cost of the colorant manufacturer is the cost that has been identified at that plant. Other costs displayed are the transportation cost for iron oxide as no other environmental cost is considered for that raw material. Two different glycols are used in the two processes and depending on the difference in amount used and that they have different producers, the environmental cost differs between them.

The environmental cost of the surfactants arises from the production of the surfactants as well as the environmental costs of the raw materials used.

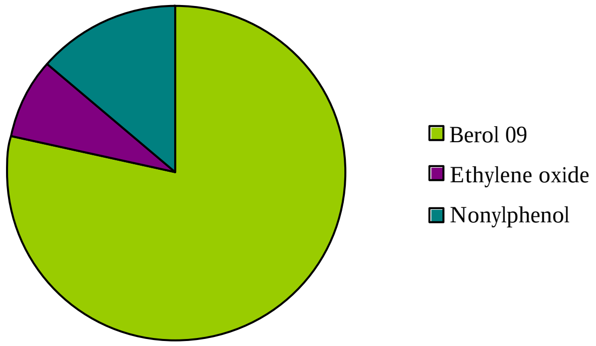

Figure 16. Contributions to the environmental costs of Berol 09 from raw materials to Berol 09 manufactured by Akzo Nobel and from the production of Berol 09.

In Figure 16 the environmental costs of the raw materials used in Berol 09 and the cost for Berol 09 are compared.

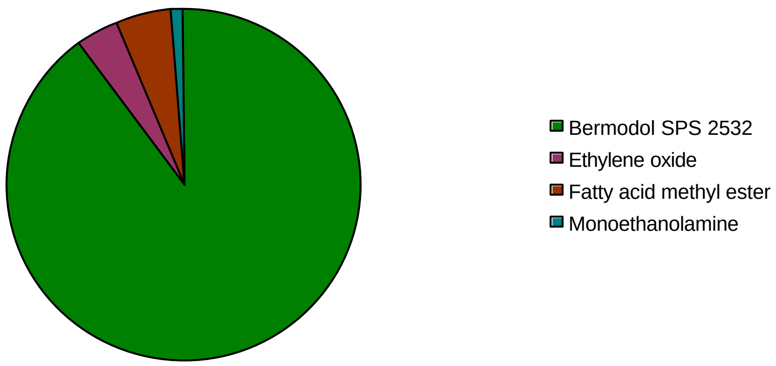

Figure 17 Contributions to the environmental costs of Bermodol SPS 2532 from raw materials to Bermodol SPS 2532 manufactured by Akzo Nobel and from the production of Bermodol SPS 2532.

Figure 17 displays the environmental cost of the raw materials used in Bermodol SPS 2532 and the environmental cost for Bermodol SPS 2532 itself. Since environmental cost data only have been included for processes at Akzo Nobel some of the raw materials are only burdened with the environmental costs associated with transportations. The transport of the fatty acid methyl ester is the only transport that causes a noticeable cost.

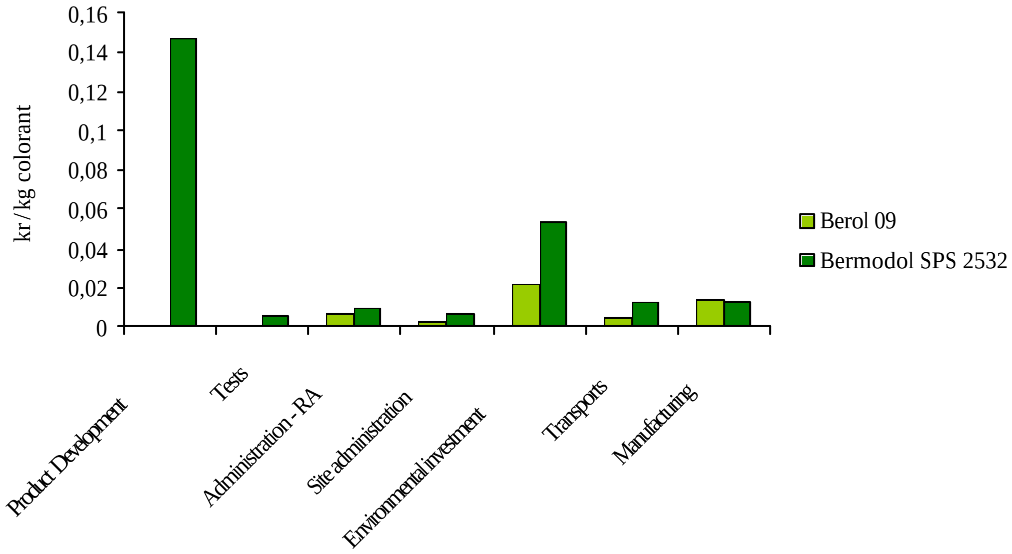

Figure 18 A detailed figure showing the environmental costs caused by the surfactants Berol 09 and Bermodol SPS 2532. Contributions from different activities in the life cycles of the surfactants are considered.

In Figure 18 the environmental cost of the surfactants used in the two colorants are compared. The comparison is made on amount of surfactants used in one kg of colorant. The environmental costs of raw materials are not considered in this comparison.

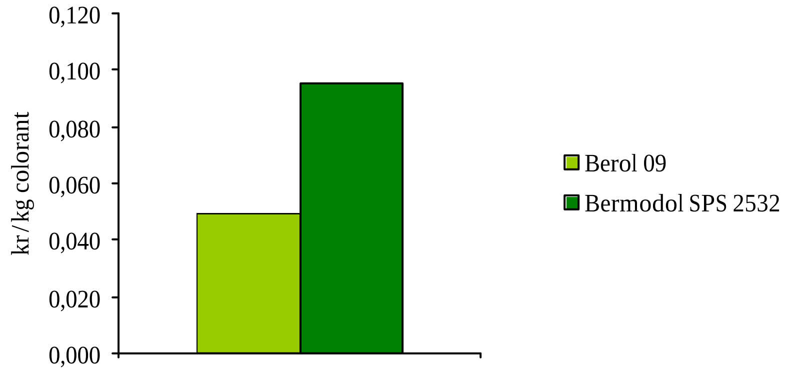

Figure 19. Environmental costs for the surfactants, here including the environmental costs of raw materials to the surfactants produced at Akzo Nobel.

The environmental costs displayed in Figure 19 are the costs that have been identified for the two surfactants studied. The difference in proportion of surfactant used in the two colorants is the main difference of their environmental cost per kg colorant. The environmental cost per kg Bermodol SPS 2532 is significantly larger than the environmental cost for Berol 09. This is primarily due to the high volumes of Berol 09 that has been produced for a very long time while Bermodol SPS 2532 is a fairly new product that is produced in small volumes. This leads to large development costs for Bermodol SPS 2532 used in colorants. The manufacturing costs are however higher for the Berol 09 as it contains nonyl phenol that demands special testing of the surroundings of the site.

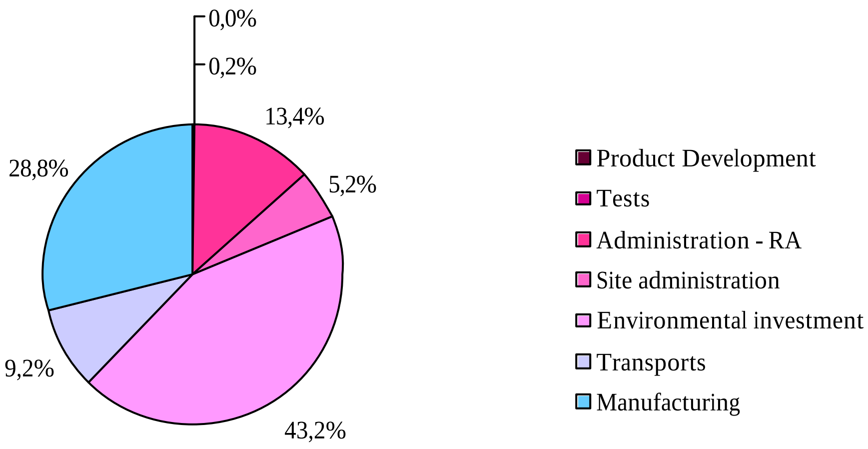

Figure 20. The figure shows the contributions to the environmental costs of Berol 09 by activities in the Berol 09 life cycle.

The identified environmental costs of Berol 09 are presented in Figure 20. In the administration cost there is a cost for participation in a consortium due to the products content of nonyl phenol included. This cost is an estimation that assumed to appear continuously for this substance. The cost for site administration is not directly dependant on the environmental impact of specific products and has the same size per ton of product regardless of the product considered. The environmental cost for product development is zero because the cost has not been directly taken by Akzo Nobel. The test cost for Berol 09 is low due to its age and the fact that is was not developed at Akzo Nobel. In the costs for environmental investment an estimated additional cost for investments due to nonyl phenol is included. Transportation cost considered in this figure is just the cost for energy and CO_2. The manufacturing cost is affected by the content of nonyl phenol which results in a higher cost for testing and measuring made on a regular basis.

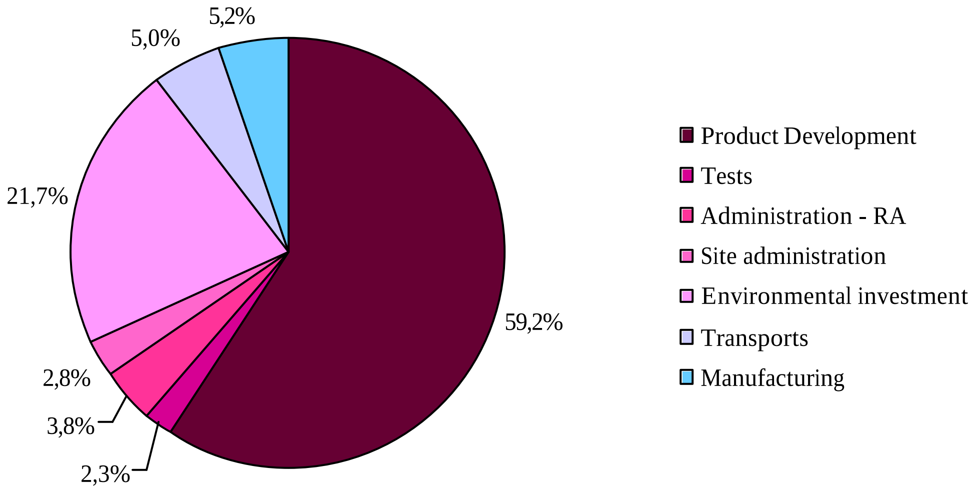

Figure 21. Contribution to the environmental costs of Bermodol SPS 2532 by activities in the Bermodol SPS 2532 life cycle.

The environmental costs of Bermodol SPS 2532 are presented in Figure 21. In the cost for product stewardship there is a small difference in the cost for the environmental department since well as the cost for staff working with environmental issues. The greatest cost of the product is the product development cost as the entire development is an environmental cost as the purpose of the development was to replace Berol 09 due to its environmental impact. The low volume of the product is also an explanation of the size of the development cost as it is divided by the total production up to today and the expected production of 10 years in the future. No specific cost for site administration is identified in relation to Bermodol SPS 2532. Since this is a fairly new product, developed exclusively by Akzo Nobel, the tests performed are more numerous and more extensive than for other older products. Bermodol SPS 2532 does not cause any environmental impacts that create a need for product specific additional environmental investments. The environmental cost for transportation only depends on the amount and distance the product is transported. The manufacturing cost is mainly affected by the complexity of the production process of Bermodol SPS 2532.

5.4 Contribution of environmental costs to a product's price

The environmental costs that Akzo Nobel has for the products that have been at the focus of the study, the two surfactants, have been compared to these products' price. The environmental costs are approximately 6,3% for Berol 09 and 4,8% for Bermodol SPS 2532. In absolute numbers the environmental costs of Bermodol SPS 2532 are higher, but as a share of the price environmental costs are lower for Bermodol SPS 2532 as the sales price is higher for Bermodol SPS 2532.

6 Comparison of LCA and eLCC

6.1 Expanding the eLCC – Model and assumptions

The scope of the LCA and the eLCC studied so far differs significantly. The LCA covers the entire cradle to gate of the studied colorants while economic data only has been obtainable for raw materials and processes at Akzo Nobel. To allow a fair comparison between environmental costs and environmental impacts this has to be addressed. In this chapter a model is presented that give approximate estimates of the environmental costs of raw materials from outside of Akzo Nobel.

The model is based on the assumption that the relative sizes of different costs are similar for all raw materials in the supply chain. Thus the product price of any raw material consist of; environmental costs associated with the specific product, other costs and profit and raw material costs from the next level in the supply chain. The raw material cost of a product is equal to the price of the used raw materials.

The raw materials are considered to be established chemical products without any extraordinary environmental problems and the modeling is done bearing it in mind. Where data is lacking the raw materials cost is assumed to be equal in size to the raw materials cost of Berol 09. The size of the environmental costs is also derived from the study, but since the raw materials are assumed to be free of special environmental problems a lower value than the one for Berol 09, an environmental cost of 5% of the price is assumed for the raw materials.

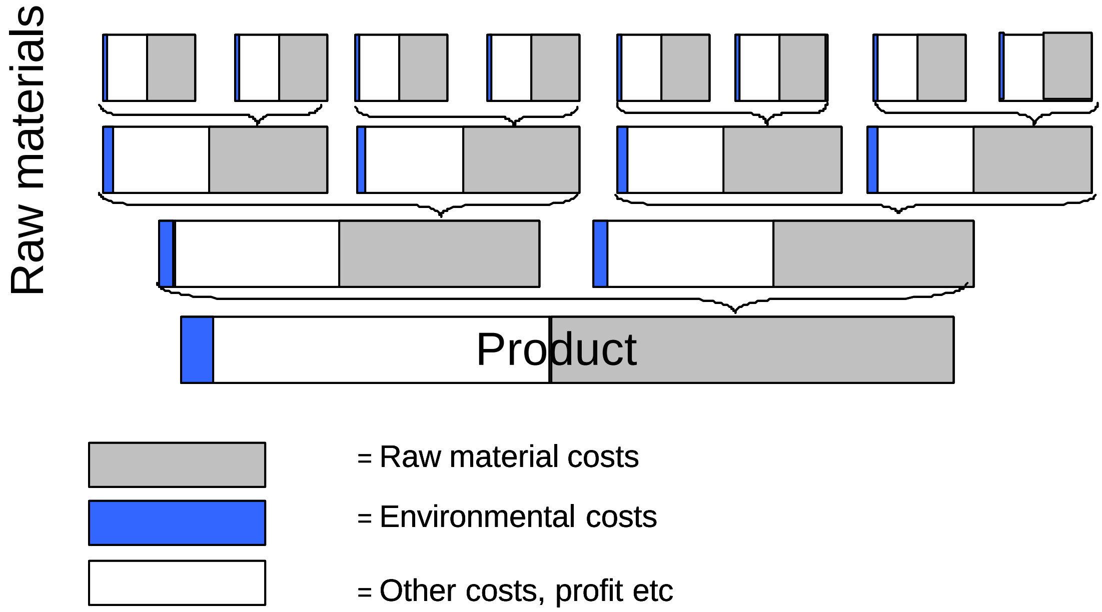

Figure 22. A schematic overview of the model used to estimate the environmental costs from the raw materials outside of Akzo Nobel.

The environmental costs from the entire system of raw materials are then added together to give the total environmental costs of the entire system. This gives an approximation of the environmental costs that can be compared more directly with the LCA data for the entire system.

6.2 Weighting Indices – The EPS method

To allow easily understandable comparisons of LCA and eLCC data the environmental impact needs to be presented in the form of a weighted index. In this study the EPS method has been chosen since it presents environmental impact data in economical units.

The EPS method is based on the definition of five safeguard subjects and the willingness-to-pay for protecting them. The five safeguard subjects, human health, biological diversity, ecosystem production capacity, abiotic resources and cultural and recreational values are based on the UN's Rio declaration. [Steen 1999] The safeguard subjects are divided in sub-categories, called unit effects. Unit effects could for example be: pollution-caused decreased production of 1 kg of crop or seed or wood or fish.

Each unit effect has an economic value described as the willingness to pay to avoid the negative effects defined by the unit effect. To calculate an index it is first necessary to describe the extent of the impact of a pollutant on each unit effect. The index is then obtained by multiplying the size of the impact per unit effect with the respective "price" of the unit effects and summing them. Using the EPS method allows a comparison of the 'willingness-to-pay' to avoid the environmental impacts with the actual environmental costs described in the study.

6.3 Evaluation of substitution: eLCC & LCA approach

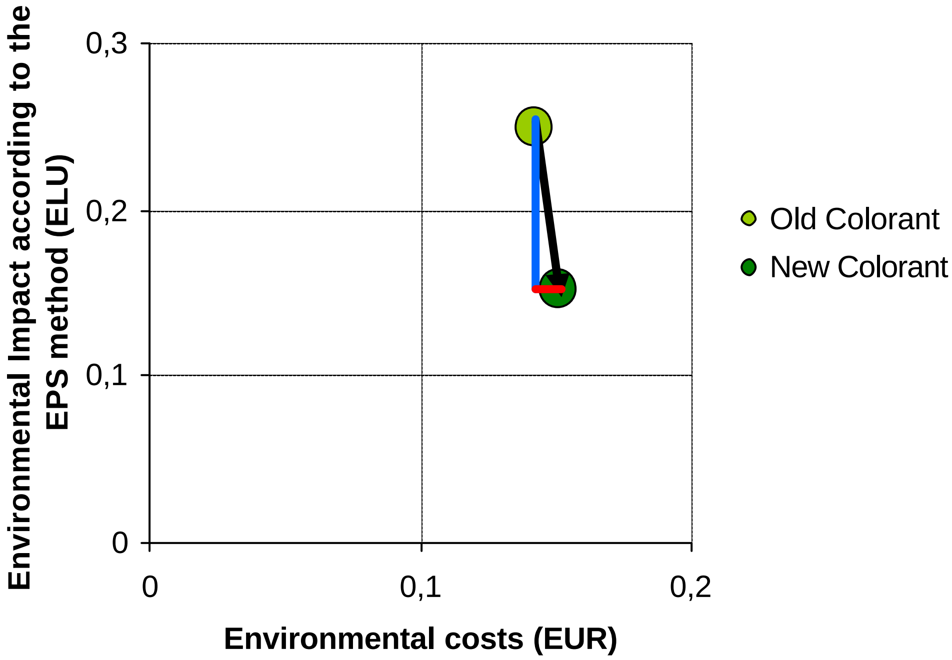

Figure 23. A comparison of environmental impact, using the EPS method to aggregate environmental impact data to one unit, and the total environmental cost of the colorants, including the estimated costs for raw materials outside of Akzo Nobel.

The substitution has lead to a decrease in the environmental impacts and an increase in the environmental costs of the colorants. The increased environmental costs can be considered as a "payment" to decrease the environmental impact of colorants.

The change in environmental impact divided with the change in environmental costs can be considered an estimate of the effect of the environmental costs. This concept, the Environmental cost efficiency, describes the value of the environmental improvement per environmental cost unit (EUR). However the model to expand the environmental costs is based on fairly rough estimates and the environmental impacts considered do not take the toxicity of the products, a major concern for at least one of the colorants, into account. In conclusion it is still too early to evaluate the environmental cost efficiency for this particular study. The concept as such can find use in future studies of environmentally motivated investments and substitutions.

7 Discussion

7.1 Environmental costs

A chemical producing company like Akzo Nobel has several reasons for studying the environmental costs of the company.

Since this is the first time that environmental costs are studied separately on a detailed level at the Akzo Nobel plant in Stenungsund, Sweden, one of the main points of interest for Akzo Nobel has been the actual identification of the costs.

Both to determine where in the company the environmental costs arise and what processes or products causes the costs, but also to determine whether the environmental costs are of sufficient size for the company to study them further.

Knowledge about the environmental costs of the company can also be used in the communication with customers and authorities. A potential customer may be more likely to accept a higher price if they know that a large part of the product's costs are caused by work to improve the environmental performance of the product. In discussions with authorities and legislative bodies a firm knowledge of the company's current environmental costs should be a valuable asset when new fees and taxes are discussed.

The environmental costs described in this report are either compulsory or voluntary. The compulsory costs consists of taxes and fees on emissions as well as costs for environmental permits and investments to reduce emissions that the company is forced to go through with due to legislations. The voluntary environmental costs are more proactive in nature. Development of environmentally preferable products or committing to technology that lowers the emissions below the legislative guidelines give rise to costs that are considered voluntary environmental costs.

A quick study of the relationship between voluntary and compulsory costs seems to indicate that as the voluntary costs increase the compulsory costs decrease. For example: a product that causes less emissions could be economically favourable even if its development costs (voluntary cost) are considerably higher since it is subject to lower environmental taxes (compulsory cost). This example is of additional interest since the cost for product development is not subject to future increases or changes which the taxes very well might be. It is probably better to follow a thoroughly planned if costly path of action than to be pushed into one because of new legislation and regulations.

This puts the company in a position where it up to a point can decide the composition, if not the size, of its environmental costs. Is it preferable to invest in process equipment and product development to decrease taxes and fees, or is it better to simply pay for the damage the product or process causes?

From a public relations point of view the image of a company that willingly commits to proactive voluntary environmental improvements might be easier to convey than that of a passive company that grudgingly obeys the regulations but does not make any additional exertions.

7.2 LCA and eLCC, a combination of two different kinds of life cycle studies

The LCC and LCA methods are originally designed to answer very different questions. An LCC is performed to measure the costs that a specific company or organization has for the studied product. An LCA on the other hand is not normally concerned by the environmental impact at a specific company but rather the focus lies on the total environmental impact from all the production, transportation and use of all materials and processes needed. Ever since stating the aim, to study and compare environmental costs and impacts, the goal has been to perform this study in accordance with the LCA viewpoint.

The environmental impacts considered in the study are not limited to specific companies or even geographical locations. It is fairly unproblematic to claim that environmental impacts are global and that the LCA model is suitable to study and account for environmental impacts, but how about the environmental costs? If the LCC method is used as a theoretical foundation to base the study of environmental costs there will be large differences in the scope of the studies.

To study environmental costs from an “LCA-like” perspective LCC studies that only considers environmental costs are performed for all raw materials and processes that would normally be included in an LCA study of the system.

A large part of the environmental costs are not directly associated with the material and energy flows that constitute the LCA, they arise instead in the development stages of a product or in administrative and regulatory work that it is not always possible to directly associate with the studied product. Administration and product development are, just as production capital, not included in a typical LCA, mainly as the environmental impacts of development and administration are comparatively low and it’s often deemed that inclusion of data from these areas are not worth the extensive work needed to find and allocate this environmental impact data. [Baumann & Tillman 2003] There are however no methodological problems with including data from development and administration in the LCA method. Even though the allocation of the environmental impacts caused by product development and administration are not obvious this is also true for LCC’s where development and administration are included on a regular basis. [Woodward 1997] Thus, when the eLCC is applied to all the significant raw materials considered in the LCA study, the difference in system boundaries between LCA and eLCC is a question of convenience.

When studying the environmental impacts we can with the help of standards and guidelines quickly neglect the parts of the system that normally is not associated with any notable environmental impact and concentrate on getting a complete picture of the rest of the system. The environmental cost study has no such firm theoretical and practical framework to lean on and additional studies are necessary before general guidelines can be developed to simplify the eLCC process.

Since the LCA and the eLCC can be said to study roughly the same system, one of the problems with comparing the results of the two methods are solved. But what does the study of environmental costs from this viewpoint actually say, and how and why should this environmental cost be compared with the environmental impacts?

The environmental costs considered are all costs that are associated with the studied product. This includes costs for suppliers of raw materials as well as the manufacturer of the studied product. Since all costs in the life cycle of a product tend to affect the end customer in the form of increased prices for the final product, the costs studied could be thought of as the environmental costs for the end customers aggregated over the life cycle. Even though the end price is affected by many other factors an eLCC/LCA study is still a helpful tool to assist in decisions regarding environmental investments and improvement work. How much more will the end consumer have to pay for this environmentally favorable alternative?

A combination of LCA and eLCC studies could be useful to evaluate the efficiency of environmental investments and can assist in the decision-making process when different environmental improvements are considered.

However, reliable environmental cost data is difficult to come by for raw materials to the studied products. If the raw materials are neglected in the eLCC while they are still included in the LCA the two studies (LCA and eLCC) do not describe the same system. This could be solved by estimates of the environmental costs of raw material suppliers but these estimates will lead to additional uncertainties in the results. When performing comparisons between alternatives with significant differences in the supply chain this problem should be kept in mind. For the time being, maybe LCA & eLCC studies are best suited for evaluating alternatives where a majority of the important raw materials is produced by the company performing the study.

7.3 Substitution of a hazardous chemical

The substitution of Berol 09 in water based indoor paint was motivated by concerns for the toxicity of one of the constituents of Berol 09, nonyl phenol. When Akzo Nobel decided to find an alternative to Berol 09 extensive research was performed to identify a group of chemicals that could provide the colorant with similar properties as Berol 09 gave. [Munk 2003] As the study has shown Berol 09 was not replaced right off in a one to one substitution. Rather the entire composition of the colorant changed when Bermodol SPS 2532 was used as surfactant instead of Berol 09 to get a colorant with similar properties that could be used in the same way as before the change.

Since only this one substitution has been studied, it is too early to state that this is the general behavior for substitutions of established chemicals. But if any conclusions are to be drawn from this study it is that chemicals are developed to perform the same function as the product they are substituting in one specific application, and that there is no guarantees that the newly developed product will be able to replace the established chemical in other applications where it is used. Also it is of interest to note that the substitution might very well lead to considerable changes to the composition of the final product.

7.4 The case study

The eLCC shows that the environmental cost of the New Colorant is higher than the environmental cost of the Old Colorant, mainly because of the relatively large impact of the development cost of Bermodol SPS 2532. However, it could be argued that this development cost should be allocated to Berol 09, as the main reason for the development of Bermodol SPS 2532 was the environmental hazardousness of Berol 09 [Munk 2003]. It should be noted that allocating the development cost to Bermodol SPS 2532 is not uncontroversial. However it is the unit that developed Bermodol SPS 2532 that actually has paid the development costs of Bermodol SPS 2532 so in accordance with the criteria for environmental costs stated in this thesis, allocating the cost to Bermodol SPS 2532 seemed like the most appropriate alternative.

Furthermore it is interesting to note that the new surfactant was developed under completely different conditions than the old surfactant. The legislations and demands on product development to take environmental concerns were not as developed as they are today when the old surfactant was developed. Since the demands on the two products differ it is difficult to make any unanimous conclusions concerning the comparison of the two colorants.

8 Conclusions

8.1 Conclusions LCA

The LCA study shows that the environmental impact of the new colorant is significantly lower than the impact of the old colorant. A large part of this difference can be ascribed to the fact that a substantial amount of the new colorant consists of water.

The largest contributor to the environmental impact of the old colorant is the production of monoethylene glycol and Berol 09. Both of these substances are of petrochemical origin and a lot of their environmental impact is caused by the ethylene used as a raw material. For Berol 09 the raw materials used for nonyl phenol production also bears a substantial amount of the impact.

Bermodol SPS 2532 is by far the largest contributor to the impact of the new colorant. In this case as well, the ethylene used in production of the raw material ethylene oxide is the most significant contributor.

The study has not considered the potential toxicity of the colorants or their raw materials and the health and environmental hazards that it can lead to. Environmental impacts considered are mainly air emissions and resource use in the production of the colorants and their raw materials. However, during the development of Bermodol SPS 2532 the focus was mainly on toxicity. It can be concluded that the substitution performed to avoid a toxic raw material lead to the added benefit of lower air emissions and resource use for the production of the colorant.

A study that considers other environmental impact categories, such as for example the toxicity of the colorants or their raw materials, would provide additional insight in the environmental benefits and drawbacks of the substitution.

8.2 Conclusions eLCC

8.2.1 Data assembly

Assembling data for the eLCC study has been more difficult than was first expected. One of the problems was that there is no global definition of environmental costs and it differs from person to person what meaning they put in the expression environmental cost. A large part of the environmental cost data is based on interviews with persons familiar with the products. These persons have made estimations of the environmental costs where no specific data was found. The uncertainty of these estimates could affect the results of the study. Data is collected from different persons with different ideas on environmental costs and this should also be taken into account.

8.2.2 Environmental costs

The environmental cost for the New Colorant is approximately 20% larger than the environmental cost for the Old Colorant. This is mainly due to the differences in the composition of the two colorants and the differences of the environmental costs of the surfactants, Berol 09 and Bermodol SPS 2532. The New Colorant contains more surfactant than the Old Colorant and it is the surfactants that are responsible for the largest part of the environmental costs of the raw materials in the study. The largest environmental cost is however the environmental cost of the Colorant Manufacturer. This cost does not differ for the Old and New Colorant as they are treated in the same way by the Colorant Manufacturer whose main costs are waste management costs.

The total environmental costs of Bermodol SPS 2532 are higher than the environmental costs for Berol 09 as used in the studied colorant. The major reason for this is the much higher development and test costs for Bermodol SPS 2532 that Berol 09 does not have due to the high production volume and age, the product was neither directly developed by Akzo Nobel and is therefore not included in the study. Berol 09 does however have substantial environmental costs due to additional lab costs and environmental investments in the manufacturing phase due to the toxicity of the raw material nonyl phenol. Akzo Nobel's cost for the participation in the consortium discussing the environmental hazardousness of nonyl phenol makes up a part of Berol 09's environmental costs.

If a comparison is made between the environmental cost and sales price of Bermodol SPS 2532 and Berol 09 the difference is not as significant, both surfactants has an approximate environmental cost of 5 % of their sales price. The environmental cost is of a magnitude that makes it interesting to investigate further, especially in the light of the increasing amount of work and time spent on environmental issues by companies due to stricter legislation on chemicals that lies just beyond the horizon.

9 References

Publications

- Persson, P. O. & Nilsson., L; Miljöskyddsteknik, kompendium i miljöskydd del 2, Miljöskyddsteknik; Industriellt Miljöskydd KTH; 1998
- SCB; Rapport 2000:2 Industrins miljökostnader; 1997
- Baumann, H. & Tillman, A-M.; The Hitchhikers Guide to LCA, Manuscript in preparation; 2003
- ISO standard for Life Cycle Assessments (ISO 14040); 1997
- Woodward, D. G.; Life cycle costing – Theory, information acquisition and application; International journal of project management; pages 335 – 344; 1997
- Naturvårdverkets yttrande; Remiss av Skattenedsättningskommitténs betänkande ”Svåra Skatter” (SOU 2003:38) dnr Fi2003/2414; 2003
- Miljöbalken
  - Chapter 9
  - Chapter 26
  - Chapter 33
  - Chapter 14
- Svensk Författningssamling; 1998:942
- SCB; Industrins miljöskyddskostnader – Vad, varför och hur?; 2001
- Steen, B.; External environmental costs in LCCCPM Report 2003:1; ch 3.2.4; 2003
- Environmental Report Akzo Nobel Site Stenungsund; 2002
- Steen, B.; A Systematic Approach to Environmental Priority Strategies in Product Development (EPS). Version 2000 – Models and Data of the Default Method; Chalmers university of technology; Gothenburg; 1999
- Jobling, S. & Sumpter, J. P.; Detergent components in sewage effluent are weakly oestrogenic to fish: An in vitro study using rainbow trout (Oncorhynchus mykiss) hepatocytes; Aquatic Toxicology; 27; 1993; pages 361 - 372

Interviews with employees at concerned companies

- Munk, C.; Product Manager, AN; 2003
- Environmental Controller; The Colorant Manufacturer; 2003
- Svensson, L.; Environmental Development Manager AN; 2003
- Andren, K. & Lindqvist, M.; Site Manager & Environmental Engineer; AN; 2003
- Haux, C.; Toxicologist; AN; 2003
- Svensson, S. & Rees, T.; Plant Manager & Plant Controller, AN; 2003
- Gerdner, M.; Materials Manager; AN; 2003
- Jansson, I.; Economist/Tax Expert; AN; 2003
- Schröder, U.; R&D Manager; AN; 2003
- Ahnsberg, G.; Regional Accounting Manager; AN; 2003
- Sköld, E.; Plant Manager; AN; 2003
- Kindstrand, M.; Process Engineer; AN; 2003
- Kindstrand, M; Process Engineer; AN; 1998
- Rönnmark, U.; Laboratory at the site in Stenungsund; AN; 2003
- Sjöstrom, P. O.; Formerly at AN plant in Mölndal; 2003

- Svennberg, S.; Former employee, AN
- Billstedt, L.; Formnerly Plant Manager AN Site in Mölndal; 2003
- Lundström, M.; Special Projects; AN; 2003

Akzo Nobel Internal Publications

- Svennberg, S.; Miljöfaktablad Nonylfenol – Nonylfenoletoxylat; 1999
- Safety data sheet: Berol 09; 2003
- Bill of Materials: Berol 09; 2003
- Safety data sheet: Bermodol SPS 2532; 2003
- Bill of Materials: Mono ethanol amine; 2003
- Safety data sheet: Nonyl phenol; 2003
- Economic report Akzo Nobel plant in Mölndal; 1998

Internet sites

- www.akzonobel.com; 2003
- http://www.naturvardsverket.se/dokument/hallbar/miljoeko/energi/svavel.htm; 2003
- http://www.naturvardsverket.se/dokument/hallbar/miljoeko/energi/koldio.htm; 2003
- http://naring.regeringen.se/fragor/energi/energiskatter.htm; 2003
- http://www.naturvardsverket.se/dokument/hallbar/miljoeko/energi/kvaveo.htm; 2003
- www.preem.com; 2003