Product Design to Reduce Restricted Substances

The experience of brominated flame retardants in vehicle design

Jennifer C Hall
Product Design to Reduce Restricted Substances

The experience of brominated flame retardants
in vehicle design

Jennifer C Hall

Thesis for the partial fulfilment of the
Master of Science in Environmental Management and Policy
Lund, Sweden, September 2000
Acknowledgements

I want to acknowledge Kemikalieinspektionen for their financial support of this project. Special thank you to my advisors at KemI, Lars Gustafsson and Eva Ljung, to Andreas Andersson at Volvo Car Corporation and to Björn Albinsson at Räddningsverket for the valuable discussions and support.

Thanks in this context also to Karin Jönsson, Naoko Tojo, Donald Huisingh, Philip Peck and the IIIEE. And to the fifth batch, for your energy and unbelievable synergy, thank you.

I am also indebted to Peter Lidholm, Tomas Rydberg and everyone at Teknisk Utveckling, Volvo AB, for all their support during my stay with Volvo.

I would like to thank the many people who gave their time for interviews during the course of this research. I have learned far more through our discussions than I could ever hope to convey in one paper. Thank you for making this a real learning experience.

And to one more person, for more encouragement and support than I could ever ask for, thank you.
Abstract

Vehicle producers are recognising the need to reduce the hazardous substances and materials used in vehicles. To do this, some producers are addressing these issues early in the vehicle design process. This is largely in response to existing and coming substance oriented regulations, product-focused policies and a subsequent pressure from actors along the vehicle design chain.

This research investigates the vehicle design chain to reveal how restricted substances are being addressed and the main factors influencing this. The specific case of brominated flame retardants used in vehicles is examined. Information is from interviews with a range of actors.

Overall, this research concludes that the restricted brominated flame retardants are not yet out of vehicles. In part, this is because the industry is not able to apply suitable alternative solutions for all applications in vehicles and components. Also, it is partly because vehicle producers and suppliers of components, such as electronics and textiles, do not know all cases where brominated flame retardants are used. Likewise, they do not know which flame retardants are used in many cases. The situation is similarly unclear for many other restricted substances.

A list of substances targeted for restrictions is currently the most common mechanism to address the use of brominated flame retardants and other restricted substances. While lists have brought profile to the issue, they alone are not enough to integrate restricted substance considerations into vehicle design decisions and thus, may not adequately address the issue.

In practice, substance lists lead to substitution of one substance with another. The mindset associated with substitution is to include restricted substance considerations in vehicle design when there is no disruption to the existing design process and minimal change to the vehicle. However, the problem with restricted substance use is not confined to a fixed number of chemicals with a negative impact. The problem is the use of a large number of poorly understood substances. Thus, substitution of one substance with another may not actually constitute a solution.

Changing the current mindset to actually integrate restricted substance considerations into vehicle design decisions increases possibilities to reduce the use of these substances. Integration can also lead to changes in the design process and the product that bring performance and business improvements. The research exemplifies the potential for this improvement.

However, the vehicle design process is geared to respond to continual time and cost pressures placed on the industry. Therefore, it is also key to recognise that integration into this process may still not adequately address restricted substance use.

Based on these conclusions, suggestions include a step-back approach when faced with a restricted substance in a design. Before looking for an alternative substance, there are benefits to first consider the necessity for the substance and its intended function. Further suggestions include requiring suppliers to work with restricted substances in a similar way in their product design.

There are constraints to such an approach. As anticipated, these include behaviour of actors and a lack of incentives along the vehicle design chain. Among specific constraints to reducing the use of brominated flame retardants is the current method for testing materials for fire safety in the vehicle industry. The research analyses a range of opinions on the test method and reveals opportunity to overcome such constraints.

A condensed version of this thesis is published as a report available from Kemikalieinspektionen, the Swedish Chemicals Inspectorate (KemI).
Executive Summary

Firms proactive in environmental work and those pressured by their product chain have a list of restricted substances that they do not want their products to contain. But as environmental management issues progress, what are companies doing to reduce the use of these restricted substances?

Brominated flame retardants used in cars, trucks and buses to improve fire safety are a rising public concern and have been a scientific focus for some time regarding their negative health and environmental impacts. Controls on brominated flame retardant chemicals and on products that contain them are currently profiled in the European Union Parliament, and in several member states.

In response, the vehicle sector has generally included the targeted flame retardants on their restricted substances lists. Further, organisations are recognising the need for mechanisms in vehicle design and development that will reduce restricted substance use, integrate this issue into product design decision-making and handle the inherent trade-offs.

It is the aim of this research to reveal the factors that influence a company to address restricted substance use in vehicle design, presenting this information in a way useful to companies and authorities acting to reduce restricted substances in products. The specific case of brominated flame retardants in vehicles is examined.

To fulfil the aim, a series of interviews are conducted with vehicle producers, supply chain actors and concerned external actors. Interviews investigate the vehicle design chain to reveal what mechanisms are built into the design process to reduce restricted substances and to identify main factors influencing this. A framework for the findings is developed from mechanisms and influencing factors identified in existing studies and literature.

Overall, this research concludes that the restricted brominated flame retardants are not yet out of vehicles. In part, this is because the industry is not able to apply suitable alternative solutions for all applications in vehicles and components. Also, it is partly because vehicle producers and suppliers of components, such as electronics and textiles, do not know all cases where brominated flame retardants are used. Likewise, they do not know which flame retardants are used in many cases. The situation is similarly unclear for many other restricted substances.

More information is becoming available and more substance restrictions are expected. The work that the industry still has to do should account for this and should ultimately focus on reducing the number of substances in use.

As anticipated, research findings show that support for broad Design-for-environment (DfE) and a life cycle approach in a company are an essential foundation for efforts.

Restricted substance lists are the main mechanism developed to address the use of brominated flame retardants and other restricted substances. While lists have brought profile to the issue, they alone are not enough to integrate restricted substance considerations into vehicle design decisions and thus, may not adequately address the issue.

Bringing these lists into early decision-making in vehicle design, lists lead to substitution of one substance with another. The mindset associated with substitution is to include restricted substance considerations in vehicle design only when there is no disruption to the existing design process and minimal change to the vehicle. However, the problem with restricted substance use is not confined to a fixed number of chemicals with a negative impact. The problem is the use of a large number of...
poorly understood substances. Thus, substitution of one substance with another may not actually constitute a solution.

In light of existing and coming product-focused policies and substance oriented regulations, restricted substance lists should not confine efforts to incremental change, but act as mechanisms for solving real problems around the use of potentially harmful substances and materials. Changing the current mindset to actually integrate restricted substance considerations into vehicle design decisions increases possibilities to reduce the use of these substances. Integration can also lead to changes in the design process and the product that bring performance and business improvements. Examples from the research illustrate the potential for this improvement.

The vehicle design process is geared to respond to continual time and cost pressures. Therefore, it is key to recognise that integration into this process may still not adequately address restricted substance use.

Based on these conclusions, suggestions include a step-back approach when faced with a restricted substance in a design. Before looking for an alternative substance, there are benefits to first consider the necessity for the substance and its intended function. Further suggestions include requiring suppliers to work with restricted substances in a similar way in their product design.

There are constraints to such an approach. As anticipated, these include behaviour of actors and a lack of incentives along the vehicle design chain. Among specific constraints to reducing the use of brominated flame retardants is the current method for testing materials for fire safety in the vehicle industry. The research analyses a range of opinions on the test method and reveals opportunity to overcome such constraints.
Readers Guide

Chapter one outlines the research questions, boundaries of the research and the purpose of the study.

Chapter two introduces the issues regarding chemicals, the vehicle sector and policy that define the research problem. It also provides the reader with background on the process of product design. Environmental product design is introduced with concepts such as DfE and a description of more specific tools, such as restricted substance lists. The Chapter ends with an overview of factors that influence the integration of environment to product design.

Chapter three describes initiatives at Volvo Car Corporation to integrate environment and restricted substance issues with vehicle design. Initiatives in other companies in the research are discussed briefly.

Chapter four presents findings from the interview discussions.

Chapter five is an analysis of the most important interview findings. Focus is on how restricted substance lists and the method of substitution are addressing restricted substances used in the vehicle design chain.

Chapter six presents conclusions of the research and suggested actions for improvement.
# Table of Contents

READERS GUIDE ........................................................................................................... IX

LIST OF FIGURES ........................................................................................................... XIII

LIST OF TABLES ............................................................................................................ XIV

LIST OF BOXES ............................................................................................................. XV

1. **INTRODUCTION......................................................................................................... 1**

   1.1 **AIM OF THE RESEARCH ......................................................................................... 1**
   1.2 **RESEARCH PARTNERS.............................................................................................. 2**
   1.3 **METHODOLOGY......................................................................................................... 2**
   1.4 **SCOPE & LIMITATIONS............................................................................................. 3**
       1.4.1 Restricted Substances .......................................................................................... 4

2. **PROBLEM CONTEXT & PRODUCT DEVELOPMENT FACTORS ......................... 5**

   2.1 **BACKGROUND – CONTEXT OF THE PROBLEM .................................................... 5**
       2.1.1 Chemicals ............................................................................................................... 5
       2.1.2 Profile of the vehicle sector .................................................................................... 7
       2.1.3 Brominated flame retardants in vehicles ............................................................... 6
       2.1.4 Governmental Approaches Towards Restricted Substances .................................. 8
   2.2 **PRODUCT DESIGN & DEVELOPMENT .................................................................. 10**
       2.2.1 The Product Design Process .................................................................................. 10
       2.2.2 Development of New Technology ........................................................................ 13
       2.2.3 A Summary .......................................................................................................... 13
   2.3 **ENVIRONMENTAL CONSIDERATIONS IN PRODUCT DEVELOPMENT ........... 14**
       2.3.1 Broad Concepts ...................................................................................................... 16
       2.3.2 Mechanisms for Restricted Substances ............................................................... 17
       2.3.3 Mechanisms from the Regular Design Process .................................................... 19
   2.4 **FACTORS INFLUENCING ENVIRONMENT IN PRODUCT DEVELOPMENT ... 21**
       2.4.1 Design for Environment & A Life Cycle Approach ............................................. 22
       2.4.2 Substitution & Substance Checklists ................................................................... 25
       2.4.3 Teamwork, Interaction With Suppliers & Product Testing .................................. 27

3. **INITIATIVES IN THE COMPANIES ....................................................................... 29**

   3.1 **THE CASE STUDY SITUATION .............................................................................. 29**
       3.1.1 DfE and A Life Cycle Approach in the Case Study Company .................................. 29
       3.1.2 Restricted Substance Lists & Substitution ............................................................ 30
       3.1.3 Teamwork, Interaction with Suppliers and Testing ............................................... 31
   3.2 **INITIATIVES IN THE OTHER COMPANIES ....................................................... 33**
       3.2.1 DfE and A Life Cycle Approach ........................................................................... 33
       3.2.2 Restricted Substances Lists .................................................................................. 33
       3.2.3 Cooperative Efforts .............................................................................................. 34

4. **INTERVIEW FINDINGS ............................................................................................. 35**

   4.1 **DfE AND LC APPROACH – INFLUENCING FACTORS ....................................... 35**
   4.2 **SUBSTITUTION & SUBSTANCE LISTS – INFLUENCING FACTORS ................ 41**
   4.3 **TEAMWORK, SUPPLIERS AND TESTING – INFLUENCING FACTORS ............. 45**
   4.4 **LIMIT – THE CASE TOOL .................................................................................... 52

5. **ANALYSIS & DISCUSSION ..................................................................................... 55**

   5.1 **INFLUENCE OF LEGISLATION .......................................................................... 55
5.2 Influence of the Market ........................................................................................................55
5.3 Substance Lists - Integrating into Vehicle Design ............................................................56
5.4 Substitution - Integrating into Vehicle Design .................................................................58
5.5 Substitution and Substance Lists - Phasing out Substances ............................................60
5.6 Case Tool - Limit ..................................................................................................................63

6. Concluding Remarks & Suggestions .................................................................................. 65
6.1 Concluding Remarks .............................................................................................................66
6.2 Suggestions ..........................................................................................................................66

BIBLIOGRAPHY .................................................................................................................. 69

APPENDIX I - INTERVIEWS ............................................................................................. 72

APPENDIX II - LIFE CYCLE ASSESSMENT ................................................................ 74

APPENDIX III - EXAMPLE RESTRICTED SUBSTANCE LIST ........................................... 75
List of Figures

Figure 1. The simplified flow of flame retardants (PBDE) in society (adapted from KemI report no.5/96)........................................................................................................................................................7

Figure 2. The main stages of product development (adapted from Karlsson, 1997 and ISO, 2000).. 10

Figure 3. Distinguishing product development from the development of new technology (adapted from Karlsson, 1997). ............................................................................................................................. 13

Figure 4. A simplification of the main activities in product design and development........................... 13

Figure 5. Relationships among DfE, a LC Approach, mechanisms to support restricted substance considerations and other mechanisms in product design........................... 14

Figure 6. Influencing factors for environmental considerations in product design ......................... 21

Figure 7. International Materials Database System & its potential to influence restricted substance use in vehicle design....................................................................................................................................... 48

Figure 8. Information losses on vehicle requirements as they pass between actors in the development process, adapted from a diagram (Garcia, 1999 pg. 14). ................................................................. 59

Figure 9. Hierarchy for redesign and substitution................................................................................ 62

Figure 10. Identifying designs made possible by the acceptability and availability of brominated flame retardants.......................................................... 67
List of Tables
Table 1. Functions and sectors interviewed for the research.................................3
Table 2. Summary of the mechanisms for environmental product design..................15
List of Boxes
Box 1. Definition of Substitution, source: Filskov et. Al. 1996................................................................. 18
Box 2. Business benefits and product improvement from removing, not substituting, a restricted substance - the example of Electrolux. Source: Holmberg and Robert, 2000........................................... 23
Box 3. History of the Volvo Black and Grey Lists of restricted substances. .............................................. 30
Box 4. Public pressure on fire safety in public buses. .................................................................................. 36
Box 5. Personal interest effects how restricted substances are considered in product design. ................. 39
Box 6. Illustrating the lack of knowledge on financial advantages of environmental improvements. 41
Box 7. Design solutions to improve performance and eliminate the need for BFRs. ............................... 42
Box 8. Communicating the difference between flame retardants in different applications. ................. 45
Box 9. Illustrating the benefits of communicating the aim of vehicle design requirements. ................. 49
Box 10. Actors along the polymer chain and responsibility for BFR issues......................................... 52
Box 11. Contradictory interview results - three examples. ...................................................................... 58
1. Introduction

Chemical substances provide benefits in almost every aspect of daily life; in everything from pharmaceuticals, to information technologies, to transport we rely on. Along with the functions they provide, many of these chemical substances have characteristics which make them harmful to humans and the environment, and even more are suspect for causing harmful effects.

The cars, trucks and buses in use throughout the world derive many benefits from the extensive use of chemicals incorporated into their design. Once in the vehicles, certain chemicals have the potential to adversely impact the environment. It is not necessarily the production or use of the substances, but rather their unintended release or emission as pollution that is a concern.

Approaches in the past have concentrated on pollution, once generated. This focus on end of pipe solutions has largely brought point source pollution in industrialised countries under control. But chemical substances contained in products continue to be a source of pollution. As economies globalize, vehicles – as other products – are traded across borders, unintentionally releasing chemicals they contain. Distinguishing the effect of these individual releases is difficult and this is compounded by the fact that only a small fraction of the chemicals in use have been tested for effects on humans and behaviour in the environment. Addressing these issues calls for a different approach.

Vehicle producers are responding. Many have developed, or have had to adopt lists of substances to phase out from vehicles. Going further, companies may begin to integrate considerations on restricted substance use into the process of vehicle design and development.

1.1 Aim Of The Research

It is the aim of this research to reveal the factors that influence a company phasing-out restricted substances from their products in the design phase, presenting this information in a way useful to companies and authorities acting to reduce restricted substances in products.

The research will investigate the following questions:

- What mechanisms are built into the vehicle design process to reduce restricted substance use?
- What main factors influence the reduction of restricted substance use in vehicles?
- Which factors are important to focus efforts, overcome obstacles and enhance driving forces?

The research focuses on the vehicle producing sector and initiatives for working with restricted substance considerations in vehicle design. To further narrow the focus, brominated flame retardants are taken as an example of restricted substances. Together, vehicles, restricted substances and brominated flame retardants provide a framework to reveal influencing factors, develop suggestions for overcoming barriers and enhancing drivers and to draw conclusions. Within this framework, the answers to the research questions are developed.

This thesis takes existing experience with integrating general environmental considerations into product design and adds new information from the specific case of brominated flame retardants and other restricted substances in vehicles. Brominated flame retardant chemicals are highlighted as an example restricted substance, targeted for phase out from vehicles.

---

1 The term ‘restricted’ is defined for the context of this research in Section 1.4.
1.2 Research Partners

Kemikalieinspektionen, the Swedish Chemicals Inspectorate, has fully funded and supported this research. Volvo Car Corporation and AB Volvo in Göteborg, Sweden, both provided working resources and the time and resources of various personnel related to this research. Räddningsverket, the Swedish Rescue Services Agency, has also contributed guidance and support.

1.3 Methodology

To complete the first step of the research, a case study company was chosen; Volvo Car Corporation, in Göteborg, Sweden. This enabled in depth study of the process by which a vehicle is developed and first hand understanding of how environmental considerations may work into this process.

In the next stage of the work, interview discussions were held with persons in the organisation and provided three levels of information:

- Information on the mechanisms in place,
- Impressions of main influencing factors to address restricted substances in vehicle development,
- Opinions and ideas about the mechanisms, from which additional influencing factors are developed.

For a broader perspective on the vehicle producing sector, interviews were also conducted with other car producers, a producer of trucks and of buses, supplier companies, electronics producers, a raw material manufacturer, authorities, industry associations and external consultants. A list of the sectors and functions interviewed is given in Table 1. These interviews add to the knowledge of the previous series of interviews and provide a range of perspectives on what the influencing factors are. A list of organisations and interviewees is provided in Appendix I.

Together, the information gathered provides a picture interesting to a range of actors.

To answer the questions, data for the research are primarily from a series of more than 35 interview discussions (Appendix I). Additional supporting and background information from literature introduces the main related concepts and issues to the reader.

Data are collected using a semi-structured, open-ended interview format2. To gather detailed knowledge on working with restricted substances, product design, BFRs and other points that the interviewee felt were relevant to their work, interviewees were free to expand on any issues raised. This approach yielded information specific to the different organisations, but also drew on the experience interviewees held outside or previous to their involvement in the current organisation, for example, academia. Persons were interviewed from many different organisations and from different functions within these organisations (Table 1). Given these various roles and perspectives on the issues, each interview discussion was unique and focused on different issues. These interviews were structured around seven key areas, as listed below:

- Restricted substance lists
- Brominated flame retardants
- Vehicle (or product) design

---

2 For reference to a similar methodology, see Bhamra et.al, 1999.
• Supplier relations and supplier management issues
• Legislation
• Cost
• Substitution & redesign

Table 1. Functions and sectors interviewed for the research.

<table>
<thead>
<tr>
<th>Summary of functions interviewed</th>
<th>Summary of sectors interviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire testing</td>
<td>Car producers</td>
</tr>
<tr>
<td>Purchasing</td>
<td>Producer of heavy trucks</td>
</tr>
<tr>
<td>Environmental management</td>
<td>Bus producer</td>
</tr>
<tr>
<td>Chemical assessment</td>
<td>Electronics producers</td>
</tr>
<tr>
<td>Environmental product development</td>
<td>Polymer manufacturer</td>
</tr>
<tr>
<td>electronics &amp; interior systems</td>
<td>Chemical Authority</td>
</tr>
<tr>
<td>Product design</td>
<td>Fire protection Authority</td>
</tr>
<tr>
<td>Life cycle assessment</td>
<td>Standards and testing Authority</td>
</tr>
<tr>
<td>Safety testing</td>
<td>Industry association</td>
</tr>
<tr>
<td>Standards development</td>
<td>External consultants</td>
</tr>
</tbody>
</table>

Key areas are based on discussions during formulation of the study. This pre-research indicated that these areas would be important to cover in interviews. The key issues also evolved throughout the study. As preliminary conclusions from the discussion interviews were drawn, they were raised during subsequent interviews. In this way, initial hypotheses and preliminary conclusions were tested and further developed in an ongoing process.

Interviews were recorded in transcripts after each interview according to key areas. Interview transcripts were analysed, taking significant quotes and separating stated influences from more general opinions. The statements were used initially to paint a picture of the situation, secondly to guide subsequent interview discussions and thirdly as a basis to draw conclusions to answer the research questions.

1.4 Scope & Limitations

The scope of this research encompasses restricted substance issues in the development of a vehicle from concept to production.

The research is not a comprehensive review of the environmental work of the companies in general, nor does it attempt to discuss all product chain or restricted substances initiatives. Where topics outside the initial scope are raised and explored, it is because interview findings have addressed these explicitly, and does not indicate a comprehensive exploration of such issues.

Thus, broad concepts introduced are addressed specifically in terms of how they apply to vehicle design in order to address restricted substance use.

Focus of the research is on current product development processes and mechanisms in the environmental division, work with restricted substances, and factors perceived to influence these efforts. Efforts of the different companies are not compared, but augment each other and serve to reveal a wider range of perspectives.
Initially, the research was intended to follow the history of one specific brominated flame retardant group (PBDEs)\(^3\) in one vehicle component and to examine one specific tool, Limit, developed to support the use of restricted substance lists in vehicle development. It was anticipated that this would provide a very specific example of one problem substance and how it was phased out, in order to illustrate how the phase out of restricted substances is currently working in vehicle design. Certain limitations altered this initial course.

Most actors do not speak specifically of one brominated flame retardant group, such as PBDEs, but more generally of ‘brominated flame retardants’, or ‘restricted substances’ or, even more broadly of ‘environment’ in vehicle design. Thus, details on use and phase-out of PBDE were not uncovered during interviews as anticipated.

Limit, the specific tool intended for focus in the research, has not been used in the organisation where it was developed. Thus, interviews are conducted with persons involved in development of Limit. They are asked about how Limit will relate to the current way of working, and other actors are asked how they expect such a tool will function.

The research is conducted in Sweden, and discussion focuses on the Swedish and European situation.

### 1.4.1 Restricted Substances

For this work, the term **restricted** refers to substances that are banned from or phased-out of products, or are to be reduced when possible. These may be stated in law or declared a company policy in the producer organisation. These are all a type of restriction on use and though at varying levels, will be referred to collectively as restriction. The term **substances** is used in this research to include chemicals, chemical products and certain materials that have stipulations on their allowed use. Together, the term **restricted substances** covers chemicals, chemical products and materials that may be hazardous, toxic, in public perception as dangerous (such as the controversy over PVC) or are legislated for other reasons. This is accurate for discussion here to refer collectively to those substances listed by some authorities and by several companies, as most companies have similar substances on their lists for restriction and banning from their products (Appendix III).

---

\(^3\) Polybrominated diphenylethers are introduced and described in Section 2.1.2.
2. Problem Context & Product Development Factors

The first Section of this Chapter provides the reader with background on the issues that define the problem. It introduces chemicals, the vehicle producing sector, brominated flame retardants used in vehicles and vehicle fire standards, together with approaches that governments, authorities and industry are taking to address the problem.

The subsequent Sections of this Chapter introduce the process of product development, the mechanisms to integrate environmental considerations into this process and the factors that influence integration. This final Section looks at general information on integrating environmental considerations into product design in the context of restricted substances and vehicle design, where possible.

At the end of this Chapter the reader should understand the problem context and the environmental product development issues as a foundation for the company descriptions that follow in Chapter three.

2.1 Background – Context of the Problem

The expanded use of chemicals and increasing vehicle production has triggered responses from authorities and from the vehicle producers themselves. The purpose of this Section is to provide background on chemical use, the vehicle sector and current approaches to manage the associated potential impacts.

2.1.1 Chemicals

During the past 50 years, the annual global production of chemicals has increased from 7 to 250 million tons, with over 50,000 different chemicals available on the European market today. Overall, information available on these substances is insufficient to meet standards set by the European Union or the OECD. Information available for the chemical products registered for use in Sweden, and for chemicals in use in the USA, also falls below national and international standards.

Work to ascertain the characteristics of substances and measure the associated risks continues. Nine of nearly 50,000 existing chemicals on the EU market have been assessed for risk and 25 more anticipate completion in 2000. Thus the extent of potential impacts on humans and the environment, interaction in this environment and with one another are still unknown. Another approach is to address the substances currently in use which are known or suspected to potentially harm humans and the environment. Drawing on the principles of prevention and precaution, focus is on the products in which these substances are used.

Of most concern are substances that persist and do not breakdown in the environment; accumulate in the tissues of organisms; are toxic to reproduction; are toxic in the aquatic environment; or disrupt normal endocrine functions in humans and other animals. A current example are polybrominated diphenylether chemicals (PBDEs), a group of chemicals recognised to have a number of these characteristics. PBDEs belong to a larger group of chemicals, called brominated flame retardants. A few particular PBDEs have been the focus of risk assessment and study in a number of countries, beginning in Sweden prior to 1989. Results show high levels of PBDE in the blood of persons who

---

4 In the EU chemicals database (IUCLID), only 14% of the 2 500 highest volume chemicals have enough data to meet basic requirements of the EU Directive on classification and labeling of dangerous substances, (Council Directive 67/548/EEC). In the USA, only 7% of the 3 000 chemicals used in highest volume have data to comply with OECD standards (SOU, 2000).
recycle electrical equipment.\textsuperscript{5} Studies also find elevated levels of PBDE in the breast milk of women, in aquatic organisms and in the environment, and these levels are increasing (Figure 1). Humans are exposed to PBDEs in food and through inhalation of PBDEs bound to particulates in the air of certain occupational settings (CEC, 2000). Among others, the impacts from certain brominated flame retardants include effects on the liver, thyroid hormone, reproduction and behaviour. PBDEs are also shown to disrupt endocrine function.

PBDEs and other brominated flame retardants are used to reduce the risk of fire in the textiles used for clothing and furniture and in the plastics used in consumer products such as vehicles, and in electronics and electrical equipment.

### 2.1.2 Brominated flame retardants in vehicles

Flame retardant chemicals are used to slow materials from catching fire and to impede the spread of flame once a material begins to burn. They are added to polymers, rubber compounds and textiles and are thus found in a wide range of consumer products. In a vehicle the plastics, electronics and textiles of the vehicle interior and the plastics and electronics of the engine compartment and the exterior are some of the components that have been traditionally treated for fire protection with different brominated flame retardants.

The amount of plastics in vehicles is increasing. For “thirty years the share of plastics in automobiles has continued to rise and this will continue”\textsuperscript{6}. This is coupled with increasing use of electronics in vehicles. Electronic systems and components in a typical automobile currently account for one third of the manufacturing costs. There is “extensive scope for future developments” and a prominent role for the electronics in a vehicle\textsuperscript{7}. This is coupled with a trend to produce smaller and more compact vehicles, which means decreasing the size of the engine compartment and bringing other systems closer to the engine.

In vehicles, over half of all fires begin in the engine and the interior may become ignited from heat from the blockhead\textsuperscript{8}. In addition to the risk from flames, a burning interior produces toxic gases. Increasing plastics, electronics and proximity to heat source increases the possible applications for flame retardants.

Brominated flame retardants migrate from the products that contain them, dispersing in the environment and leading to exposure. In 1995, more than 350 different substances used as flame retardants were described in the literature (KemI, 1995), including the brominated flame retarding group of substances.

\textsuperscript{5} OctaBDE has been measured in indoor air on premises containing flame-retarded electronic apparatus such as computers and television receivers. Elevated blood concentrations of octaBDE have been shown in occupational categories of people handling computers (personnel at an electronics-dismantling plant showed significantly higher levels of all PBDE congeners in their serum compared to a control group). In Swedish mother’s milk the concentration of tetra- and pentaBDEs has been rising exponentially since the 1970s. Freshwater fish also show high concentrations of these. All cited from EC, 2000.

\textsuperscript{6} This trend is explained by the chief of design at Chrysler as cited in Gale, 2000.

\textsuperscript{7} According to Schöpf, of Daimler-Benz passenger vehicle development (Schöpf, 2000).

\textsuperscript{8} This term refers to the barrier between the engine compartment of the vehicle and the passenger compartment.
A profile of the number of vehicles produced and in use provides indication of the scale of the issues regarding restricted substance use in vehicles.

### 2.1.3 Profile of the vehicle sector

In 1998 global vehicle purchases reached 36 million cars and 15 million busses and trucks, bringing the world total of vehicles on the roads to 670 million in the world. In 1999, another 38 million cars and 17 million more buses and trucks were sold worldwide.

Western Europe produces roughly one third of all cars, buses and trucks sold. To give some perspective of scale, Germany is Europe's second largest producer and consumer of vehicles. The country purchased 300,000 cars in 1998 and there are now 126 cars for every one square kilometer of land in Germany. Over 70 percent of these cars are scrapped before they are ten years old.

Sweden is ranked among the world’s largest producers of heavy trucks.

#### 2.1.3.1 Fire testing in vehicles

Fire protection authorities, industry and consumers are responsible for fire safety requirements of products. For vehicles, the current automotive and truck industry reference fire standard is the FMVSS302. The standard details a method to test propagation of flame in the passenger compartment. The standard was originally developed in the 1950’s for fire protection of materials inside a vehicle producing plant. It was later adopted to cars and trucks. The FMVSS302 is voluntary, but has become the industry standard used by most producers. The FMVSS302 states the testing level that different materials must reach, depending on their application. In many cases, producers treat materials to meet the highest test levels specified in the standard.

---

9 The figure refers to heavy trucks, over 6 tons (Bilbranchen, 2000).

10 In Sweden, there are four cars per square kilometer of land space. Fifty-five percent of cars are older than 10 years and 140,000 were scrapped in 1998.

11 Fire standards for the interior of a bus are much higher than those for a car. Certain formulations of polymers can meet the fire requirements of a car without the use of brominated compounds, but would be inadequate for fire standards on buses. Thus, bus manufacturers will use PBDE in application, while it is not needed in the same application in a car.

12 Buses are considered ‘fire sensitive constructions’ because they are used for public transportation and are thus subject to higher fire protection standards.

13 This highest level is referred to as V0, in the industry. The test stipulates a horizontal burning rate in millimeters per minute.
The standard is under criticism from fire protection authorities for different reasons. For example, the testing method assesses how rapidly a piece of material burns when held horizontally. However, surfaces are often angled or vertical in a burning vehicle situation, and the test does not represent a fully realistic scenario. Also, the test is not statistical and the same material can be repeatedly tested until it passes. Criticism of the standard also comes from manufacturers because it does not address flammability of materials as they breakdown and age. Overall, fire protection authorities feel the standard is inadequate, vehicle producers do not feel the standard is comprehensive and others feel these inadequacies are pushing the in appropriate use of flame retardant chemicals.

2.1.4 Governmental Approaches Towards Restricted Substances

2.1.4.1 Sweden

A Swedish Government Bill adopted in 1997 sets out measures for a ‘toxics free’ environment. But work focused on the environmental impacts from the use of chemical substances has been carried out for sometime. In 1991, Riksdag (Swedish Parliament) adopted a Government Bill restricting the use of brominated flame retardants. Kemikalieinspektionen (Kemi), the chemical authority, carried out a project to determine and suggest the most environmentally harmful substances for phase-out. The project recommended in 1995 that the use of PBDE be discontinued. But these substances are present in imported products, and thus Sweden has been one of the forces behind recent initiatives in the EU, described in the following Section.

2.1.4.2 The European Union

The EU authorities are currently conducting risk assessments on certain flame retardant chemicals and the PBDE group has been under review since 1995 in the EU programme on existing substances14. But prior to this, the European Commission drafted a proposal of several measures to reduce the environmental impacts from electrical and electronic products. The first proposal was drafted in 1993, and in June 200015 was sent to EU parliament, as a formal Proposal for a Directive on Waste Electrical and Electronic Equipment (EC, 2000). The proposal has now been accepted and includes a ban on PBDE from most applications in electrical and electronic products16.

In addition, the EU is currently re-evaluating its approach to chemicals management, under pressure from member states. Some states are calling for the new approach to manage chemicals in groups according to their harmful characteristics, as opposed to assessing and proposing action on harmful chemicals individually. Such an approach could increase pressure on member states and product manufacturers to choose chemicals without potentially harmful environmental impacts.

The European Parliament have also agreed on a Directive on End-of-Life Vehicles. The Directive will cover vehicles, end-of-life vehicles, their components and all materials. Its first priority is to prevent waste from vehicles and it covers all economic actors in the vehicle life cycle. The Directive aims to reduce the use of “hazardous” substances. These include lead, mercury, cadmium and hexavalent

---

14 EU Programme on Existing Substances, Directive 793/93.
15 The initial Directive has been divided into two separated Directives just prior to submission to EU Parliament in June 2000. This is significant, as restrictions on hazardous substances in waste electronics and electrical equipment (WEEE) will now be handled separately from other stipulations on WEEE. The two are named: Council Directive on the restriction of the use of certain hazardous substances in Electrical and Electronic Equipment and Council Directive on the restriction of the use of these substances in Electrical and Electronic Equipment.
16 The Directive will also ban Polybrominated Biphenyls (PBB), but these flame retardant chemicals are no longer produced and the last of them are being sold in the market by one company in the United States.
17 Hazardous substance in this Directive means any substance which is considered to be dangerous under Directive 67/548/EEC.
chromium, which are all found on the restricted substance lists of most producer companies. Relevant to this research, wording in the Directive specifies focus on product design to reduce hazardous substances, i.e. “it is important that preventive measures be applied from the conception phase of the vehicle onwards and take the form, in particular, of reduction and control of hazardous substance in vehicles” (European Parliament and the Council, 2000).

2.1.4.3 Reflections

Product-oriented environmental policy can be seen as a growing policy trend to manage a range of adverse impacts from products. Of specific focus are electronics, as seen in the EC Directive on waste electronic and electrical equipment and vehicles, as reflected by the Directive on end-of-life vehicles.

These policies make a direct link between product design and environmental impact. They are based on the principle of producer responsibility which intends to influence improved product design, partly by making producers responsible for their products at the end of their use. The logic is that if a producer must deal with the waste product, the incentive is to design that product so it can be re-used, dismantled, recycled and not contaminated with dangerous substances or materials.

Either as pioneers of this policy activity or in response to it, several companies are looking toward a product-oriented approach and are beginning to address dangerous substances such as PBDE in the design of their products. However, the issue may not end with the phase-out of certain PBDs. There remain a number of other PBDs for which there is no testing information and which are widely used in products. The “most commercially important” flame retardant, TBBA will soon be assessed by the EC Commission (ENDS, 05/2000a). Certain phosphate flame retardants, one of the proposed replacements for brominated flame retardants, also await EU risk assessment with “high likelihood” of control measures (ENDS, 05/2000b). Little is known about the impacts from other brominated and halogenated flame retardant chemicals and beyond that are a range of other chemicals in use which may put humans and the environment at risk.

An authority like Kemikalieinspektionen can use their knowledge to influence how companies act when it comes to restricted substances. In the past, this has been done through regulatory demands but current pressure from government is for authorities to employ softer mechanisms, such as fostering alternative approaches with industry. This is not distinctive to Sweden, but more characterises the situation in many governments. Thus, it is important to understand the mechanisms and processes inside a company to reduce restricted substances and what drives and hinders these.

18 The principle of Producer Responsibility is included among the pillars of Swedish Law, along with the Precautionary Principle and the Product Choice Principle (principle of substitution).

19 Tetrabromobisphenol-a, TBBA, is a brominated flame retardant and accounted for 1/5th of the Western European market for brominated flame retardants in 1998. This is almost twice as large as the market for PBDs.

20 Three phosphorous-base flame retardants are reportedly added to a new EU priority list of 30 chemicals for detailed risk assessment. According to a European Commission Official quoted in ENDS (05/00) there is a “high likelihood” that all 30 will be followed with control measures.
2.1.4.4 International Cooperation

With the phase-out of PBDE for environmental reasons, the issue of fire safety is also raised. This connection has spread interest to North America. The US National Association of State Fire Marshals have joined Räddningsverket (Swedish Rescue Services Agency), to explore ways to simultaneously address the issue of fire safety, while influencing producers to choose less environmentally harmful flame retardants. Such an initiative may seek scientific guidance from Natuvårdsverket (Swedish EPA), Sveriges Provnings- och Forskningsinstitut (the Swedish National Testing and Research Institute) and Kemikalieinspektionen (the Swedish Chemicals Inspectorate) and perhaps the US EPA.

2.2 Product Design & Development

There are as many different design and product development processes as there are products. This is because the product development process is dynamic. It is not a linear, stepwise process but more a spiralling flow of interaction and exchange of ideas, information and materials. It is a challenge to present a complex and intangible reality as a simple series of steps, and thus, not fully accurate. The simple model presented here represents a structure for the interactions from which a product evolves to give the reader an idea of the important considerations and interactions during product design and development. It will serve as reference in later Sections, to be altered and augmented with specific information on environmental considerations and from companies in the research.

In vehicle producing companies, this process occurs at the level of the whole vehicle, while inside supplier companies, it occurs at the level of vehicle systems. Thus, simultaneous development processes will influence product development and there will be interaction between these processes. A vehicle is developed through goal setting, creative thinking and compromise that do not always follow one after the other, but interact continuously.

2.2.1 The Product Design Process

From the time a project to develop a new product begins, a large number of persons are involved to perform the necessary functions. These functions include translating demands from customers in the market into product characteristics, developing solutions to meet the characteristics, selecting materials to make these solutions, supplying materials and negotiating contracts for supply. Respectively, marketing, designers, product engineers, quality assurers, suppliers and purchasers perform these functions. These stages of product development and personnel functions are illustrated in Figure 2 and are described in the text below.

![Figure 2. The main stages of product development (adapted from Karlsson, 1997 and ISO, 2000).](image-url)
Product specification - A typical product development process\textsuperscript{21} begins with identifying the needs of the potential customer. Customer needs for a vehicle might be grouped into characteristics, such as handling, styling, safety, noise and vibrations, weight, etc. These are expanded into a set of criteria for the design to meet the customer needs. This set of criteria will be referred to as ‘requirements’, where one set of requirements is developed for handling, one set for safety, and so on. A team of persons from marketing and design engineers develops requirements for each characteristic. This is done independently of the other characteristics to ensure there is no compromising between characteristics in this early stage and that customers needs are clearly conveyed.

Requirements are set for the whole product and then broken down into requirements for each system and component in the product. Requirements should specify a level at which that particular requirement is met and a method for measuring this level. They are then given to a project team, each responsible for one or more systems in the vehicle. A project team in a traditional product development process primarily involves design engineers, quality assurers, suppliers and purchasers.

Conceptual design - At the stage of ‘conceptual design’, design engineers look for different systems and components to fulfill the requirements. These are called ‘design solutions’, and engineers often come up with a number of alternative solutions to choose from. A solution that meets all the set requirements is impossible, and this stage involves ongoing balance and compromise. Creative thinking and cooperation of the project team will be important. Alternative solutions are measured against each requirement, and this process can be more efficient if the requirements have been well considered during their development (Keoleian, 1994). Thus, in conceptual design the requirements translate the initial customer needs into solutions - components - that will eventually form the product.

Detailed design - Detailed drawings of the design solutions that have been selected, or are still being considered, from the previous stage are made in ‘detailed design’. The drawings specify measurements, dimensions, materials and even suppliers, to specifically define the conceptual designs from the previous stage.

In choosing materials and suppliers, the design engineer, product engineer and quality assurer give the specifications for a material or component and the purchaser then negotiates cost and volume with the supplier. The aim is to order the most efficient material to meet the set requirements. In larger companies, the purchasers update a list of materials for designers to select from (Åkermark, 1999).

In the conceptual design and detailed design stages, there is ongoing evaluation and selection of alternative design solutions. This requires balancing requirements for the different characteristics of the final product. As mentioned, it is not possible for a particular component to meet all requirements. Thus, requirements that cannot be met are discussed within the team and with those responsible for setting the requirements, to re-evaluate their necessity and priority. Usually, action is either to change the requirement or to deviate from it with a plan to meet it next time. In some processes, the severity of the problem might be ranked in attempt to facilitate this.

At this point, a prototype of a design solution or component is made and tested, or the supplier submits it together with testing documentation to the company. The project team looks to see if the protocol fulfills the agreed requirements, and no more major changes are taken after this stage.

\textsuperscript{21} This simplified model of product development is generated from personal communication with M. Karlsson, August 2000, a study authored by Karlsson (1997) and an ISO technical report (nr.14062) on ‘integrating environmental aspects into product development’, released as a working draft in June 2000.
At the end of the detailed design stage, solutions are chosen that will eventually come together to form the complete product.

Manufacturing preparation - In ‘manufacturing preparation’ engineering, a small number of products are produced. This serves both to test the process that assembles the product, i.e. the manufacturing process, and to test how easy the product is to produce.

A rough model or a prototype of the different components and systems may be made at any stage. But the prototype made in the manufacturing preparation stage may be the first time that all systems and components of the product come together from the suppliers, sub-assemblies, company designers, etc. Thus, it may be the first time for evaluating their interaction as a product system. If a component is causing unforeseen problems in the assembly of the product, changes may have to be made in this stage. It may also still be possible to make ‘fine tuning’ changes to the product components, though both such changes at this point may be very costly and slow the development process.

This stage mainly involves manufacturing engineers, and they will interact with design and product engineers when changes need to be made.

Market launch - Finally, the product is manufactured on full scale and sold. With just-in-time manufacturing, these activities run nearly simultaneously. This is the ‘market launch’ stage, and is the final stage before the product reaches the customer.

There is an element of review at the end of the product development process, but there should also be ongoing review throughout. Common to most product development are ‘check gates’ set between each stage. Before the design proceeds to the next stage, it is checked for compliance with the requirements initially set. This is necessary as designers continually review and evaluate alternative design solutions in the conceptual and detailed design stages. In fact, there may be several gates within these two stages alone. Review is also important as the design passes through different levels and between different stakeholders who may give contradictory input and have different visions of the final product.

If requirements are not met, the gate may be closed until the problem is solved, or the problem is documented as a ‘deviation’ and the product moves through to the next stage of development. The requirement itself is evaluated, and may be changed, or remain unchanged in anticipation that a solution is possible for next time. During this continuous review and revision of the initial requirements, problems implementing and combining the design solutions arise.

While most companies will have further breakdown and detail within the stages presented here, this model is sufficient for the findings and analysis to follow. Thus is an overview of product development and design.

It is important to distinguish between this process of product development and the separate process by which new technologies arise in a company.
2.2.2 Development of New Technology

New technology development - In large companies, new technology development is a separate function. While a product development project is initiated based on a customer demand, new technology development is independent from these projects. It provides a forum for creativity to generate new concepts, solutions and even whole products. As a result, new solutions are often waiting in ‘storage’ for a project in which they can be used. In some instances, a new technology development project may be ordered to find a solution to a requirement that cannot be met in the product development project.

Figure 3 outlines the factors that distinguish the two processes and illustrates how new technology solutions are introduced into products during various stages of the product development process.

2.2.3 A Summary

Figure 4 is a simplified overview of the process of product design and development described previously. It illustrates the main activities of the process.
2.3 Environmental Considerations In Product Development

To understand how the product design process can be adapted to include environmental considerations, it is important to be familiar with the broad concepts that are precursors to this. This Section introduces the concept of design-for-environment (DfE) and life cycle approach (LC Approach). It will subsequently discuss the method of substitution and the use of restricted substance lists as mechanisms to address the use of these substances in products. Methods well known to the product development process, namely teamwork, interaction with suppliers and product testing, can also be adapted and utilised as mechanisms to incorporate environmental considerations. Information presented here is from existing studies and current literature. Concepts are summarised in Table 2 and are described in detail in the subsequent Sections of this Chapter.

![Diagram of Design for Environment & Life Cycle Approach]

Why DfE and a LC Approach?

The environmental strategy of an organisation can be described as the approach it proposes to address environmental impacts from its operations. Within this approach an organisation may develop an environmental design strategy, whereby an environmental focus and actions are applied to the specific context of products. The purpose of an environmental design strategy is to improve the environmental performance of the product across its life cycle.

An organisation that recognises the need for and has begun to implement environmental considerations into the vehicle design process is exhibiting aspects of DfE and LC Approach.

---

22 Those working closely with the concepts are familiar with existing literature, debating and comparing the terms. The intent here is not to present a comprehensive picture of this analysis, but to introduce the concepts to the reader and provide a framework for the company’s restricted substances initiatives and the influencing factors revealed in the research.

Why Substitution and Substance Lists?

With a **product focused environmental design strategy**, an organisation will have a number of **issues** to address to improve the environmental performance of the **product over its life cycle**. For example, the issue of restricted substances. Issues are addressed directly through the use of specific mechanisms and indirectly through other mechanisms.

Regarding the **issue of restricted substance use in vehicles**, specific mechanisms of focus are substitution and restricted substance lists. Teamwork, interaction with suppliers and product testing will then influence these mechanisms and indirectly, the phase out of restricted substances.

This framework is not the rule for addressing restricted substances in vehicle design, but serves to clarify the inherent overlap and inter-linkage of the concepts, the mechanisms and the influencing factors.

Table 2. Summary of the concepts and mechanisms for environmental product design.

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Summary of Function</th>
<th>Relation to the Product Design &amp; Development Process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concept of Design for Environment</strong></td>
<td>A concept to introduce environmental considerations as early as design conception</td>
<td>Gets designers to recognise their choices during product design will determine how the product interacts with humans and the environment</td>
</tr>
<tr>
<td><strong>Life cycle Approach</strong></td>
<td>An approach to support changes that improve the product through its whole life cycle</td>
<td>Make environmental improvements in the design that do not increase impacts of the product at other life cycle stages</td>
</tr>
<tr>
<td><strong>Substitution</strong></td>
<td>A method to operationally provide alternatives for substitution</td>
<td>A problem substance in a design solution is replaced with an alternative substance, not recognised as a problem</td>
</tr>
<tr>
<td><strong>Restricted substance lists</strong></td>
<td>A list of substances banned by legislation, targeted for legislation or otherwise recognised as a public or environmental concern</td>
<td>Lists are given to relevant actors along the design chain and they should not use the specified substances</td>
</tr>
<tr>
<td><strong>Teamwork</strong></td>
<td>An operational mechanism bringing a range of stakeholders together to accomplish a task</td>
<td>Design teams of actors from various disciplines coordinate separate design activities, generate design solutions and anticipate and solve problems</td>
</tr>
<tr>
<td><strong>Interaction with suppliers</strong></td>
<td>The exchange of physical goods and information between a producer and its suppliers</td>
<td>Information flows between producer and supplier throughout the design process in discussion and balancing of requirements. Ideally, most info. should flow from producer to supplier at the very start of a design project.</td>
</tr>
<tr>
<td><strong>Testing of the product &amp; components</strong></td>
<td>Ensuring components, supplied systems and the final product meet set requirements</td>
<td>Design solutions are compared against initial product requirements. Requirements are fulfilled, not fulfilled or are changed</td>
</tr>
</tbody>
</table>

*These 2 concepts* are an umbrella to the environmental initiatives a company pursues. Under these concepts, the company will have many issues to address. Restricted substance use is one such issue.

*These 2 mechanisms* to directly address the issue of restricted substance use.

*These 3 mechanisms* are part of the regular design process. How they operate will influence integrating environmental considerations and specific consideration on restricted substance use.
2.3.1 Broad Concepts

2.3.1.1 Design for Environment

Environment and design are directly linked. The choices a designer makes during product development directly, or indirectly, requires the use of a range of substances. As discussed previously, an increasing number of these are targeted for restriction. It is clear then that the **choices made in product design** influence how that product will interact with humans and the environment through its life cycle (Keoleian, 1994).

Design-for-environment 24, or DfE, is a term commonly used to describe activities focused on this link. According to the concept of ‘design-for-environment‘ the potential impacts a product may have on the environment throughout its life can be reduced if these impacts are kept in mind during the design of that product. In practice, this means acting in product design to ensure environmental considerations are among the many considerations taken when the product is designed and developed.

The earlier environmental requirements are put into the stages of product development, the greater the possibility of developing a product with less environmental impact (Keoleian, 1994). In design for environment, environmental requirements are formulated and balanced together with traditional product design requirements, for instance on performance, cost, business, quality, and legal requirements. In product development, formulating requirements may be the step that most influences the characteristics 25 of the final product and hence this integration is important to improve the environmental performance of the product (Keoleian, 1994).

For instance, requirements to restrict certain substances are incorporated with the other environmental criteria, and all are to be considered early in design.

2.3.1.2 LCA

Confusingly, the term ‘LCA’ is often used to mean two distinct things, life cycle assessment and life cycle approach.

2.3.1.2.1 Life Cycle Assessment

The term LCA is an acronym for Life Cycle Assessment. LCA is a tool defined in the ISO 14040 series of standards (and is described in Appendix II). LCA is relevant to product design when results are used to support decisions and choices on different design solutions. Conducting LCAs have also highlighted that many actors along the product chain influence the environmental impact of a product (Wolters et. al, 1997).

When speaking about environmental design initiatives, there is often reference to life cycle assessment. However, the results from an LCA do not show a pay off for reducing the use of restricted substances in product design, the way they do for changes in energy or material use. This is because LCA conducted according to the ISO standard must be based on quantitative data and a globally accepted environmental impact category. Such a category is not currently agreed for restricted substances. This is directly linked to the lack of risk assessment data described previously in Section 2.1.1. Thus, LCA

---

24 There are several names that mean taking environmental considerations into product design processes. Life cycle design, Eco-design, Sustainable product development, Green design and Design-for-environment are the most common (Karlsson, 1997) and though the aim of each varies, this research will use the term Design-for-environment (DfE) collectively.

25 Keoleian (1994) makes a parallel comparison with quality in a product. Quality is designed into the product, rather than achieved through later remediation and this logic holds for environmental requirements as well.
as a tool currently does not support reducing restricted substance use in the products, and is not included in further discussion.26

2.3.1.2.2 Life Cycle Approach
The term LCA is also often used, imprecisely, to refer to a life cycle approach. To clarify, the term LC Approach (not LCA) is used in this paper. In product development, a Life cycle approach means those involved in development will have to consider the impact that a potential design solution might have at all stages of a product’s life. It also means that improvements in one stage of the product life cycle should not cause increased impacts from other life cycle stages. Thus, in phasing restricted substances out of products, removing one substance should not require the use of a more harmful one or otherwise increase the negative impacts from the product at other life cycle stages.

Such an approach, as argued by the Nordic Council of Ministers, is necessary. It will allow actions that are more effective and conclusive than the “end-of-pipe” solutions that pioneered environmental actions for “point-source” pollution problems. It is also a necessary approach to take to combat further environmental damage. Academia, consultancies and industry have collaborated on different types of life cycle-based studies. These first lead to the recognition of significant environmental impact of various products associated with the use phase. These findings highlighted the potential to minimise environmental impacts by designing a product in a way to decrease these impacts.

A LC approach pre-empts proactive environmental activities in an organisation. It can bring an organisation to integrate environmental considerations into product design and development processes. It can also lead a company to focus on restricted substance use to decrease negative effects in the vehicle life.

2.3.1.3 Relation of the DfE and LC Concepts
There is much discussion in the field around the relationship between DfE and a LC Approach.27 For this research, it suffices to say that an effective design-for-environment strategy requires looking at the whole life of the product to make improvements. Also, looking at the whole life of the product requires that many of the improvements be made in product design.

2.3.2 Mechanisms for Restricted Substances
Under the umbrella of DfE and LC Approach is the issue of restricted substances.

2.3.2.1 Substitution
Specific to restricted substances, is the method of substitution. Substances used in products are each intended to serve a specific purpose. Logically, one mechanism to phase out problem substances is to operationally provide alternatives for substitution. A substance can be removed from a product by replacing it with a substitute and this has been done in many instances, some more successful (for example, water-based solvents in place of organic solvents) than others (for example the replacement

---

26 There is currently discussion in the field and work underway, especially in the United States, to develop an index for toxicity that allows the application of LCA as a decision tool to more comprehensively address the use of restricted substances.

of CFCs with HCFCs). In all cases the purpose of substitution is to remove the negative effects from substances (Filskov, 1996).

As a method, substitution has its roots in protecting worker health and safety, where it is not allowed to use a substance or material which may be hazardous to or otherwise reduce safety or health if it can be replaced by a non-hazardous, less hazardous or less irritant substance or material”. Concerns about certain substances have extended to include their negative effects on the environment and substitution is now done in this context as well. For instance, in one section of the EU Commission Directive on Waste Electronics and Electrical Equipment entitled Alternatives to substitution, the Commission states that “substitution of those substances, which are most problematic in the waste management phase, is the most effective way of ensuring a significant reduction of risks to the health and the environment related to these substances” (CEC, 2000). The Directive further states that “where substitutes are not yet available, they are exempted from the substitution requirement” (CEC, 2000).

Box 1. Definition of Substitution, source: Filskov et al. 1996.

The definition of substitution (Box 1) is essentially removing a harmful restricted substance from the product by means of replacement with a less harmful alternative. Substitution should be carried out via a specific plan to ensure full consideration of the problem to find an optimal solution (Filskov, 1996), and might include formulating the problem, assessing alternatives and deciding on a substitute.

How the problem is formulated very much affects which solutions will be generated. For instance, these two problems – 1) “we need a substance to replace BFR” and 2) “we need an environmentally better way to protect a material from catching fire” – will generate very different possible solutions.

Work to compile information on substitutes for current restricted substances is being conducted within companies, externally by suppliers and as a coordinated effort in industry sectors.

In some literature, the term substitution may more broadly encompasses the concept of replacing one ‘solution’ with another to decrease the life-cycle impact of the product (Filskov et al., 1996, and Keoleian, 2000). In this sense, it is possible to substitute for a particular chemical demand entirely and still get the same service (Geiser, 2000). For this research, the term substitution will exclusively refer to the substitution of one substance for another substance, while a separate term will be used for changing solutions. This distinction reflects the way the term is used in interview discussions, Chapter four.

---

28 As stated in an order from the Danish Ministry of Labour, Bekendtgørelse om stoffer og materialer, Ministry of Labour order no. 540,2 September 1982.

29 The CEC Directive on Waste Electronic and Electrical Equipment provides no definition for the term substitution. At the time of writing this thesis, no official could be reached to comment on what the term intends.

30 The Swedish industry association, IVF, is developing a project to establish a database of industrial chemicals. The database would organise the chemicals based on their environmental, health and function information. The intention is that a chemical for a certain application could be queried to reveal information on it’s effects in these three areas and suggested alternatives with less environmental and health impact, but that have also been tested for their functionality in that application.
2.3.2.2 Substance Checklists

Lists of restricted substances have been developed specifically to address the issue of restricted substances.

In traditional product development, designers are provided with a range of supportive tools. These are commonly used in the later stages of design, after specifications have been set for the product (Poole et. al 1999), and include checklists, guidelines, scoring systems, screening matrices and priority lists. For instance, in the conceptual design stage, a design engineer may consult a checklist or a manual to know what features are highest priorities or which aspects to keep in mind for a certain design option.

Environmental aspects may be added to these existing tools, or new tools may be developed with a distinct environmental focus. Topics covered may be anything that the designers need assistance with, or that the organisation feels is important in design, for instance a checklist on general design-for-environment. Checklists may also be used more specifically, as is often the case with restricted substance checklists, where designers tick-off substances, indicating if they are or are not in the design.

Checklists and guidelines are perhaps the mechanisms most commonly used to address restricted substances. Companies develop or adopt lists for the internal use of their designers and purchasers. Lists may also be sent to suppliers, requesting them to consider their use of restricted substances.

2.3.3 Mechanisms from the Regular Design Process

2.3.3.1 Teamwork

The appeal of working in teams in product development has been realised for many years. Teams that are cross-disciplinary combine several perspectives to generate ideas and address problems. To integrate environmental considerations, existing design teams may be adapted and extended to include environmental expertise. Inversely, design and product development expertise may be brought into the formulation of environmental work. Teamwork can be used in different ways, at different stages in product development and at different levels of the organisation. They may be permanent teams which address on-going issues and problems, or ad hoc teams assembled specifically to address one emerging problem. A specific example of the former is described in Section 3.1.3 on E-FMEA at Volvo Car Corporation.

While a team with all pertinent knowledge would require too many participants, there are certain general functions to be considered depending on the project or problem (adapted from Karlsson, 1997):

- suppliers
- environmental experts (e.g. on recycling, LCA, materials)
- marketing, customer perspective
- purchasing, cost perspective
- product design engineers
- process design engineers
- broad environmental expertise, management and policy perspective
- legislation, standards and sector initiatives perspective
2.3.3.2 Interaction With Suppliers

It has been shown that suppliers may be included in product development teams inside the producer organisation. But, working with suppliers and supply chain issues is rapidly increasing as an important strategic consideration in developing a product (ISO, 2000). Therefore, interaction with suppliers is considered itself as a mechanism to integrate environmental considerations into existing product development processes.

Producers are decreasing the number of suppliers they deal with and establishing collaborative relationships (Garcia, 1999) and risk sharing (Andersson, 2000) with those that remain. The complexity of the product chain is likely to decrease (Garcia, 1999) as this trend progresses. Regardless of decreasing complexity, successful relationships and programmes with suppliers become even more essential for companies, for two main reasons.

First, out-sourcing assembly and sub-assembly of components, out-sourcing the supply of full systems and out-sourcing the design of components and whole systems are more a rule than an exception. To ensure their requirements are met, a company must effectively interact with the suppliers that provide them with these design solutions.

Secondly, as companies search for the most effective and efficient point to make environmental improvements along different stages of the product life cycle (ISO 2000), they will inevitably have to act at points beyond their internal operations. Effective relationships will be essential to finding the best points to act and to developing actions (Garcia, 1999).

2.3.3.3 Testing

What constitutes ‘testing’ in product development is not always explicitly stated as such. Checking a possible solution against initial requirements in the ongoing development of design solutions is essentially testing. Building prototypes can also be considered a way of testing. At one point in the development process the full prototype of a vehicle system is tested simply by looking at it to see that it literally ‘fits’ into the part of the vehicle it belongs.

There is a quality engineer responsible to check the quality of supplied components coming into the company. Often, the responsibility for checking if environmental requirements have been met also falls to this person. For environmental requirements, this may involve checking a prototype to see that the supplier has filled out an environmental requirements form and documenting the information. Documentation may include which environmental requirements have not been met and whether any corrective actions are planned. The quality engineer or responsible person will often “sign-off” on the prototype, indicating requirements are met or plans are in place to correct any problems. “Testing” the prototype at this point via analysis for a certain chemical, for example, is not done. It is too late in the process to change the product, regardless of test results. Thus, testing might focus on the idea of prevention. Suppliers are given requirements and asked to sign a declaration to ensure prevention.

Testing may also be conducted externally, by suppliers. In these cases, they submit test results, indicating whether the prototype meets the test levels set in the product requirements.
2.4 Factors Influencing Environment In Product Development

Many factors influence a company’s attempts to address environmental issues in product design. This Section is an overview of these factors, as identified from existing studies and literature. Influencing factors are separated as drivers and barriers and are illustrated collectively in Figure 6.

Given the relationship between the concepts, the mechanisms and the product design process (Figure 5), factors that influence one will influence the others. Thus, the influencing factors are described here and presented according to where they may have the most direct influence.

This list of factors influencing environment and restricted substances in product design is not comprehensive. It does however provide enough background for the reader to understand the company initiatives that are introduced in the next Chapter.

Figure 6. Factors influencing the consideration of environmental issues in product design.
2.4.1 Design for Environment & A Life Cycle Approach

The purpose of an environmental design strategy is to improve the environmental performance of the product across its life cycle.

Design for environment and a life cycle approach are interrelated (Section 2.3.1.3) and the factors that influence them are presented here together.

2.4.1.1 Drivers for DfE and a LC Approach

The following factors may act as drivers, influencing a company to work with DfE and take a LC Approach.

Regulatory measures - Six years ago, Keoleian stated that bringing environmental issues to the level of product design requires government policy and regulation. Specific to restricted substances, there are existing regulations targeting specific substances and pending regulations targeting specific products. This is seen in EU directives on end-of-life vehicles and on waste electronics and in similar national policy initiatives at the national level. Focus is thus on producers, who have the greatest knowledge and ability for adapting product design to meet these requirements (Åkermark, 1999).

Government regulation and related economic instruments are also an effective way to address the environmental costs of a product to society (Keoleian, 1994) and can drive companies to reduce and prevent these costs through improved product design.

Public awareness - Consumer demands are one of the main forces steering companies to integrate environmental issues into product design (Tulenheimo, 1995). For some products, consumers are pressing manufacturers for products that are "more environmentally friendly". Consumers are supporting schemes that pressure manufacturers to design products with less environmental impact (Nordic Council of Ministers, 1995). In this way, companies improve the environmental performance of their products to maintain or to enhance the image of their brand.

The influence of consumers on product design is not new, nor is it specific to environmental issues. For instance Gale (2000) writes when "dealing with a vehicle architecture of the future, the question of what our customers really want is of paramount concern". Design strategies to focus on customer orientation and satisfaction may span "all areas and corporate divisions and remain[s] a constant presence" (Gale, 2000).

Benefits from effective environmental design strategy - Environmental protection is a strategic issue of increasing importance for industry and the business sector in the technical performance of products. An environmental design strategy integrates environmental issues into the product, and if done effectively, can benefit an organisation in a number of ways. Cost savings, new market opportunities, competitive advantages (Tulenheimo, 1995), overall improvements to product performance and additional potential benefits from communicating this environmental work in the market are among those most commonly referred to in the literature. Often, being the first to move on these issues can offer significant advantages and this is demonstrated in practice and documented in much recent literature (Box 2).

---

31 The Directive of the European Parliament and of the Council on End-of-life Vehicles and on the Restriction on the Use of Certain Hazardous Substances in Electrical and Electronic Equipment were introduced in Section 2.1.4.2
Electrolux was faced with the problem of CFCs in their refrigerators and freezers. As part of their strategy development, the company assessed its options to move from CFCs to HCFCs. In the course of doing this, they adopted a completely different approach. Electrolux was the first to launch freon-free refrigerators and freezers. The company realised increased market shares in several important market areas as a result and presented a new overall business strategy.


Some companies equate a design for environment strategy with ‘good design’, as environmental design may serve to improve other parameters, reveal inefficiencies and lead to previously unrealised solutions. Others consider environment early in design so as to avoid costly problems in later stages, seeing DfE as good ‘business sense’ (Bhamra et al, 1999). The Society of Automotive Engineers describe possible synergies between the environmental and the economic performances of a product, by taking environmental considerations in the product development phase (SAE, 2000). And Keoleian states that knowledgeable cost analysis for product development can be the “most influential tool guiding decision making [and] properly allocating environmental costs can be one of the most powerful motivators for addressing environmental issues in design” (Keoleian, 2000).

Hansjürgen (1999) states that it is no longer sufficient to discover new solutions by means of long consideration and that successful solutions to meet a complex of demands are not just found, but are worked out in an oriented and provocative manner. He describes a ‘Way of Oriented Innovation Strategy’ (WOIS), a development strategy that orients designers toward the contradictions in development, instead of avoiding them. While analysis of this strategy is beyond the discussion here, it is worth highlighting Hansjürgen’s remarks on how new solutions arise. WOIS endeavours to specifically define the future for new products and processes and to create new products offering new solutions (Hansjürgen, 1999), as well as reducing costs. With this strategy, the goal is initially set so high that it appears impossible to devise a solution and in this way is used to find future oriented systems.

The strategy reveals a synergistic effect of performance of more efficient technical systems using an integrated, cross functional team approach (as is done by some companies studied in this research).

The author is not suggesting or recommending WOIS, but there is value in one of the key phrases of WOIS that can be applicable to addressing restricted substances in products: “for solving a problem, first we have to go in given distance to the problem”. Translated from German, it means, first we have to look from a distance, like the view of a bird to a given problem, to find out the right task for the future (Hansjürgen, 1999).

Top management commitment and company policy – Product development occurs “within the broader corporate management structure” and a formal environmental management system with a policy, goals, performance measures and strategic plan that support environmental improvements will be a driver for successful integration of environment and product development.

The success of DfE tools can ride on the organisation. Poole et. al. (1999) state that “tools are valuable because they support good management processes” and simply having tools available to designers is not sufficient to integrate environmental considerations into design (Poole et. al, 1999).
Personal awareness - People in the organisation with an interest in environmental issues will often drive the environmental work in a company. Designers and product engineers with this personal commitment can bring this work to the product development process. In a study of environmental considerations in the later stages of design (Poole et. al, 1999), findings indicate a good deal of designer interest to change designs for environmental improvements of the product. However, these designers were found to be frustrated at their ability to make such changes once key decisions in the design of the product had been made.

2.4.1.2 Barriers to DfE and a LC Approach

Several factors from the literature are perceived to act as barriers to working with the concept of DfE and taking a LC Approach.

Unable to charge a premium – For many products, customers are not willing to pay a premium for lowered environmental impact. If a price premium is acceptable, it must still ensure the product is offered at a competitive price or customers will not buy the product with better environmental performance (Keoleian, 2000). De Oude (2000) further points that while it may be technically possible to reduce the impact from a product, society may not be ready to pay for certain substitutes or new design solutions, for instance to remove BFR from an electronic component. As a result these solutions wait “in cool storage”. In particular for brominated flame retardants, substances with a less hazardous profile are available, but technical reasons and higher costs prevent their general substitution (CEC, 2000).

Lack of methods and tools for early stages of design – There is an acknowledged lack of effective design responses to the existing drivers for environmental design (Keoleian, 1994). Most current design methods do not explicitly address “environmental issues” and Finkbeiner (2000) supports this. He cites the lack of practical and efficient ways for organisational implementation of environment into development as an initial limitation to DfE work. A lack of tools and decision support in the early stages of design, is also revealed in a study of 30 European and US companies in the electronic and electrical industry sector (Bhamra et al, 1999).

Using various tools to support environmental considerations in product design is now a widely accepted practice (Greame, 1996). However, lack of time and support are barriers to their use in product design. Tools not supported by strong company management and policy can go unused. New tools that are time-consuming and software based tools often remain unused (Poole et. al, 1999, Jones, 1992).

Existing processes – Existing standards, testing requirements and methods to ascertain product quality can limit the substitution of alternative substances and the acceptance of new technologies. Also, existing plants and processes can restrict new designs. They may also constrain design solutions for small improvements on existing products (Keoleian, 1997). Thus, changing to an alternative substance in one product or altering its design might require more extensive changes to operations.

Time – Environment adds another layer of complexity to the design process and as illustrated with literature findings on DfE tools, this complexity can be more time consuming. For instance, in a review of supportive tools for DfE all actors agreed on the importance of making them user-friendly and on the need to minimise the time needed for their use (Karlsson, 1997).

Lack of knowledge on cost-benefit – The lack of awareness, information and expertise in the market conceals the economic advantages of environmental improvements to products (Jackson, 2000), for example removing a restricted substance. Costs are often overlooked or incorrectly allocated as

33 Jackson (2000) illustrates how this was done with fuel. It was assumed consumers wanted fuel, so structures are designed to supply fuel and the revenue basis of fuel supply depends on increased sales. Jackson cites regulatory structures that reinforce this bias toward increased fuel consumption. And within this scenario, energy efficiency is a threat to economic
overhead, and are a barrier to realising the financial advantages of designing for better environmental performance (ISO, 2000 and White et. al, 1992). Thus, there is disincentive\(^{34}\) for companies to go beyond compliance to reduce the impact of their products. (White et. al, 1992).

Confused customer – The complexity of environmental issues, particularly the environmental impacts associated with products, poses a problem for customers to express their demands. Niva et. al. (1996) state environmental issues are too complex for customers to express their environmental preferences in terms that product development traditionally uses to determine customer needs. This is a barrier to incorporating environmental requirements with requirements for quality, cost, etc. and ensuring they receive equal weighting.

Behaviour changes needed – Customer preferences are a design challenge, for example preferences for shiny vehicle surfaces or cooled passenger compartments of a vehicle\(^{35}\). Changes in the values and behaviour of society and consumers will be required to bring environmental considerations to the level of product design, and give them importance.

Such changes will also be necessary within an organisation. In product development, a designer’s perception that “only certain solutions are the right way” is identified as an important barrier (Garcia, 1999). Also, designers very much rely on past experience of how materials perform under certain conditions and in certain systems (Åkermark, 1999). Under time and cost pressure, a designer may more ‘safely’ chose the same solution that has met requirements in the past.

These recognised barriers illustrate how institutional factors can play at least as important a role as technical factors in reducing hazardous substance content of products (Jackson, 2000).

### 2.4.2 Substitution & Substance Checklists

Substitution as a method to reduce restricted substances in a product and checklists to identify and communicate these substances, are directly linked. Influencing factors that relate to substitution and checklists are presented together below.

#### 2.4.2.1 Drivers for Substitution & Substance Checklists

Knowledge on environmental impact of product – Designers need to recognise that dispersion and accumulation of chemicals and generation of hazardous waste are associated with their products and thus need to be addressed in their work. This will facilitate integrating environmental considerations into how designers work (Keoleian, 1997). As risk assessments are carried out on certain substances, resulting information acts as a driver of substance-focused regulations, product-focused regulations and internal company policy and initiatives.

Technical solutions – Technical solutions to certain environmental problems associated with products have often been developed, but are not used for a number of reasons. According to the EU Directive on the Restriction on the use of Certain Hazardous Substances in Electrical and Electronic Equipment, substitutes that are less hazardous than the substances targeted for phase out in the Directive do exist. Jackson (2000) profitably. A similar picture can be assumed for brominated flame retardants, other chemical substances, vehicle components and even vehicles themselves. Thus, there is potential to reveal the economic advantages of removing restricted substances from vehicles by examining the market forces in place.

\(^{34}\) A company who goes beyond complying with the law to reduce the use of hazardous substances is paying to reduce the costs their product has on society. This is a competitive disadvantage unless their competitors do the same, or unless they realise other benefits of a “beyond compliance” strategy.

\(^{35}\) These consumer preferences have been meet in the past through the use of chrome finish and CFCs, respectively. Both chromium VI and CFCs are on the restricted substances lists of most companies.
recognises that product quality, standards, testing requirements and increased costs may act as barriers to the implementation of new technologies, but states the availability of solutions can drive companies to overcome these impediments (Jackson, 2000).

### 2.4.2.2 Barriers for Substitution & Substance Checklists

**Supplier cooperation** - In vehicle development, a typical vehicle series may have three- to four-hundred suppliers. These range from global corporations who supply to many producers and industry sectors, to small shops that supply goods on such a small scale that sales are poorly recorded and tracked. Requesting these suppliers to accurately fill in and return a design checklist or restricted substance checklist may not yield results, and is a barrier to effectively using such a mechanism.

**Lack of information on product in early stages of design** - At the early stages of the design process, data on product content is not available or is of poor quality (Bhamra, et al., 1999). Lack of a fast and reliable supply of information is cited as a main barrier to implementing ‘design for environment’ (Finkbeiner, 2000). Environmental information that is available to designers is not often of the same quality as information on cost and performance issues (Keoleian, 1994).

Information on the chemicals and substances added to the product is often not available for a number of reasons. Substances impurities not intentionally added to the product (ISO, 2000) are difficult to identify and track, thus impeding addressing them in design.

**Assessment of alternatives** - To substitute an existing restricted substance with an alternative substance, the alternative should be assessed for environmental impact and technical performance. In operation, determining the environmental impacts and effects of different substances requires formalised risk assessments, conducted according to standardised procedures and methods. Such assessments may yield a good deal of information, but can be expensive and time consuming. In the end, the potential effects of a substance may still not be fully understood36 and it is difficult to know if environmental impact is truly reduced from a particular alternative (Dethlefsen, 2000). Even the most complete risk assessment is restricted to effects that can be anticipated, as ‘you cannot ask about what you do not know’.

The properties of the existing substance must be understood to be able to evaluate whether the substitute reduces the risk, but information on possible substitutes is often lacking information. Information on basic properties and on interaction with humans and the environment may be lacking, as well as information on technical properties and performance (Filskov, 1996, p9). A chemical well understood from a scientific perspective can be missing technical performance data for the range of applications in which it is proposed for use (Bergendahl, 2000). Given the lack of information on certain substances, it may be argued that there are benefits to choosing an understood risk instead of substituting it with one that is unknown (Ljung, 2000).

---

36 For instance, impacts from interaction with other substances, effects of very low does over time, or impacts from metabolites and degradation products often are not known. This is the case with deca-brominateddiphenylether, as it is suspect but not confirmed for degrading to lower brominated and more dangerous compounds.
2.4.3 Teamwork, Interaction With Suppliers & Product Testing
Less directly, teamwork, interaction with suppliers and product testing that are already established in product development processes will influence the phase out of restricted substances. Influencing factors that can be related to these mechanisms are presented below.

2.4.3.1 Potential Drivers
Benefits to the development process - Work in cross-disciplinary teams gathers competency and knowledge, spreads commitment and responsibility and may generate environmental design ideas in the organisation (Karlsson, 1997). It is also recognised in the literature that such teams have the potential to accomplish product development task more quickly, than if all efforts are isolated in various divisions.

Product chain pressures - Companies integrating environmental considerations into their product development realise the necessity to involve actors up (and down) the ‘product chain’ (Garcia, 1999). Thus, companies supplying components and systems and companies dealing with the use and disposal of products find their environmental work driven by other actors in the system.

Industry associations and industry trends - Trade associations and pressure from competitors are both described as drivers for environmental initiatives in a company. Associations can help smaller companies to develop technical solutions and provide a forum for exchanging knowledge and information37. There are benefits to not changing alone, and as competitors adopt these solutions this raises the industry standard. In numbers, these actors have more potential to influence in their markets and supply chains, and this type of association can eliminate some of the barriers companies face and be a driver for environmental design.

2.4.3.2 Potential Barriers
Internally, successful environmental design requires commitment from a large number of actors; employees and all levels of management (Keoleian, 1994).

Externally, it is becoming well recognised that many actors along the product chain influence the environmental impact of a product, and this has been highlighted by the use of life cycle assessment (Wolters et al, 1997). Thus, environmental information needs to be integrated into traditional flows of information, materials, money and products between actors.

Work with suppliers and supply chain issues will directly affect how successfully a company is able to integrate environmental concerns into development of their products, both in a positive and a negative manner. Producers and suppliers can both obstruct or facilitate how successfully environmental information is integrated into the existing flow of information between them (Kärnä & Heiskanen, 1998). Thus, the behaviour, values and decisions of the producers and their suppliers will directly influence the life cycle impact of a product.

Number of actors - Incorporating environmental issues into product development involves an increasing number of actors from inside and from outside an organisation. While new channels of

37 IVF, a Swedish association of industries, is conducting a project to help small and medium sized electronics manufacturers deal with managing their supply chains to understand the restricted substances used in the products. While these manufacturers are often only acting as final assemblers of many components and sub-systems, they must have effective communication with their suppliers in order to handle the environmental impact of their products. This is especially pressing with the pending proposal for an EU directive on waste electronics and electrical equipment which will require them to take back their products at the end of the product’s life.
communication can bring significant benefits to a company, establishing these channels and breaking down traditional communication barriers can be a significant hindrance.

Even governmental policies will need to address many actors, including the producer of the restricted substance, the handlers of that substance, the actor incorporating the substance into a product, the user of that product and any end-of-life actors. In many product chains, policy will have to address this complexity (Jackson, 2000).

One barrier to bringing all these product chain actors together is the lack of consensus on environmental goals (Garcia, 1999). This may be considered in a different way, when suppliers are providing full systems and are responsible for the design and testing of the systems.

Secrecy – Secrecy and lack of trust often characterise relationships between companies, their suppliers and other actors in the product chain. These have been identified as major obstacles for realising environmental initiatives (Garcia, 1999).

38 A typical vehicle development project may have three- to four-hundred suppliers, where 20 percent of these supply full systems. This is figure given by H. Schöpf of Daimler-Benz Passenger vehicle development, Germany, 2000.
3. Initiatives in the Companies

The previous Chapter presented theory from literature on factors that influence integrating environmental considerations into product development. The factors were organised into a framework showing how an organisation may work to address restricted substances in product design. Chapter three now describes how the companies interviewed are working, presented according to this same framework. This brings the information to the specific context of vehicle design and development and, where appropriate, to restricted substances. Together, these Chapters lay the foundation for the main findings of the research, presented later in Chapter four.

In the first Section the information is gathered from the case study company describing their environmental design initiatives and the mechanisms they use to address restricted substance use in vehicle design. The next Section presents information from other companies interviewed, vehicle producers, actors in the vehicle chain and external actors. This augments the case study to provide a wider view of activities in the sector. Together, information in Chapter three answers the first research question: What mechanisms are built into the vehicle design process to reduce restricted substance use?

Chapter three adds case specific information on addressing restricted substances in vehicle design, to the theory and framework previously developed in Chapter two.

The information is gathered from vehicle manufacturers directly, company literature and external actors knowledgeable in vehicle development. The activities described do not give a full picture of the environmental work at any of the companies. Instead, the initiatives described are: those directly aimed at restricted substances in vehicle design; initiatives supporting this work; or are those referred to during the course of the interview discussions.

3.1 The Case Study Situation

This Section describes initiatives to integrate environment into vehicle development at Volvo Car Corporation (VCC). The description begins with a broad picture of the environmental decision fora, then describes how the fora supports environment in product development through different processes and mechanisms. The discussion is related to processes and mechanisms for restricted substance reduction where they exist.

As background, Volvo sold almost 400,000 cars last year. The environmental division at Volvo Car Corporation employs twenty persons, with additional environmentally related functions specified in the eight product development divisions, and in the new vehicle projects.

3.1.1 DfE and A Life Cycle Approach in the Case Study Company

An environmental council coordinates the environmental work at VCC and this council is located within the product development division. Environmental working groups from all divisions of the organisation report their environmental strategy to the council, stating where they will focus efforts, what they will accomplish and by what dates. The council may ensure some degree of consistency between the working group strategies\(^{39}\) and then coordinates all strategies into a set of goals for the organisation. Goals\(^{40}\) specific for product development and new technology development are fed into these processes and should also be reported back to the council. The council is then responsible to report

---

\(^{39}\) At this point the council sends the strategies of the environmental working groups to each division for their approval.

\(^{40}\) Environmental goals for the organisation are also used in areas other than product development, but these are outside the scope of this research.
goals that are not met to the product development executive management and set corrective actions to address this.

Relevant to restricted substances, there are working groups to develop environmental strategies for the interior of the vehicle, for materials of concern, for environmental management tools and for supplier environmental requirements. Thus, strategies for these four areas will include specifications on reducing restricted substance use that become translated into goals for the product development.

The environmental goals are fed into the first stage of product development, product specification, when the future vehicle is described in terms of customer needs. Environment is one of 27 characteristics\(^{41}\) in the product development process and the next step is to gather all descriptions of customer needs relevant to ‘environment’ into one document. This document thus contains all environmental customer needs for the vehicle. These are further broken down into a document\(^{42}\) of environmental customer needs for each vehicle system, (e.g. vehicle interior, vehicle electronic systems, brakes, etc).

### 3.1.2 Restricted Substance Lists & Substitution

In the next stage, one person (SAE) is responsible to translate environmental customer needs into environmental technical requirements. Requirements will refer to environmental legal requirements and to Volvo internal standards. Specifically, requirements for each system state that systems must not contain substances listed in the Company Standard on restricted substances. This standard is called the ‘Black List’ and is described in Box 3. (The Volvo Black list is included as Appendix III).

The Black & Grey Lists - When Volvo Car operated together with Volvo Bus Co., Volvo Truck Co., Volvo Penta and Volvo Aero, the environmental council at the time developed the ‘Black’ and ‘Grey’ Lists. The lists were distributed to the different companies for voluntary use. Informally, the lists were introduced into the environmental requirements for product development and eventually became adopted formally as an internal Volvo Standard. Conceptually, the lists support mechanisms in product development to reduce restricted substances because they are a formal company standard. Operationally, the lists are used in one distinct step in the product development process as a tool to reduce the use of restricted substances in the final vehicle. That is, translating customer needs into technical requirements for each system. Once included in the requirements, the lists are intended as tool for three distinct actors: 1) for design engineers to ensure the system complies with the lists; 2) for purchasing engineers to ensure systems purchased from suppliers comply with the lists; and 3) for suppliers to ensure their system complies with the lists (Appendix III).

Box 3. History of the Volvo Black and Grey Lists of restricted substances.

These requirements are the way to communicate customer needs to design engineers inside the organisation and in supplier companies. The SAE gives requirements to the project management for each system who passes them to two levels. First they are passed to the design engineer who is responsible for ensuring components within the system meet all requirements. On the second level, requirements are passed to the purchasing engineers responsible to ensure the systems and components designed by suppliers meet these requirements.

A number of mechanisms are established to support identification and replacement of alternative substances in the production. There is a division\(^{43}\) working to assess and gather information on

\[^{41}\text{It is interesting to note that environment has been a characteristic in product development at Volvo for more than five years. Other vehicle characteristics include weight, handling, fuel consumption and styling.}\]

\[^{42}\text{The document for a new vehicle will contain all requirements, but in product development of a new model of an existing vehicle the document may only contain requirements that are different from the last vehicle model.}\]

\[^{43}\text{This division is no longer part of Volvo Car Corporation, but still provides such information through an consultant relationship.}\]
existing substances and proposed new substances. This division developed a list of alternative substances recommended as substitutes to replace some substances on the restricted lists. Regarding brominated flame retardants, the company has undertaken several projects in cooperation with other vehicle and electronics producers to look into non-brominated replacement compounds.

Volvo has recently begun an overall inventory of certain vehicles and their systems, to identify full material and substance content related to restricted substances and other environmental issues of focus (e.g. recycled content, weight of materials, and so forth).

### 3.1.3 Teamwork, Interaction with Suppliers and Testing

Within the project, the management, design engineers of different systems and components, purchasers and suppliers work as a team to find technical solutions that will form the components and systems of the final vehicle. To do this, they balance requirements from all areas, including restricted substances. Designer guidelines are available to consult for tips on meeting environmental requirements. Also, lists naming all restricted substances are available for design engineers and should be consulted when solutions are being developed. Restricted substance lists are also available to purchasing engineers in a document to assist them with communicating environmental requirements to suppliers. Thirdly, the restricted substances are listed in a full set of requirements sent to suppliers, which should be applied to every system and component supplied.

As problems to meet environmental requirements arise the team communicates with the SAE and they work together to re-assess the problem requirement and discuss deviations. This occurs in an ongoing loop until requirements are met, changed, deviations are documented and solutions are chosen. Discussions may be trying to balance requirements from different areas and will involve actors from several different divisions. The SAE is responsible to follow these requirements through this ongoing loop in the development process and should report them back to the environmental council.

Within each system (e.g. interior) there are environmental contact persons for the main components (e.g. rear seats, dashboard, etc.) and one environmental coordinator for the overall system\(^44\). Thus, there is an environmental coordinator for interior of the vehicle, electronics in the vehicle, brakes, etc. The company is currently reorganising their systems, and environmental coordinators are new to some areas. Environmental product development requirements are only one of several job responsibilities for the environmental contact persons, but their role as contact person is to provide environmental support to the project as requirements are balanced and solutions are chosen.

When a design solution is chosen, a prototype is made and tested according to the test methods stipulated in the set of requirements. If it is a purchased system the supplier submits the prototype along with the documented test results. Prototypes are then ‘signed off’ by the responsible engineer or purchaser, and production begins (i.e. the manufacturing preparation stage begins, Figure 2 in Chapter 2). Ideally at this stage, any deviations from environmental requirements should be reported to the SAE, who reports to the environmental council, who in turn report to the executive management of the product development division.

As solutions are chosen, they may be evaluated through a process called E-FMEA (environmental failure mode & effect analysis\(^45\)).

---

\(^44\) This system is also in place for safety and quality, with one person identified as ‘contact person’ in each sub-system and an overall ‘coordinator’ for the whole system (e.g. interior, brakes, engine, etc.).

\(^45\) E-FMEA stands for Environmental-FMEA and descends from FMEA. FMEA, failure mode & effect analysis, is a process commonly used in product development to assess quality of the product. To adapt the tool to perform environmental assessments, it has been changed in several ways. As a result of the changes, the term ‘failure mode effect analysis’ does not
E-FMEA is a tool intended for two purposes. Firstly, it is used to assess if a component or system chosen for the vehicle meets environmental requirements. Restricted substance use is only one of the environmental aspects assessed. Secondly, the result of an E-FMEA should indicate how the environmental process is functioning within the product development process. An E-FMEA is conducted in one day, by a group that consists of one person from the environmental division together with design engineers, purchasers, suppliers and the environmental coordinator from the system under assessment. Essentially, the group ‘troubleshoots’ for the system from an environmental perspective.

The EFMEA process is considered for existing systems that are of particular environmental concern, and for some new systems or components, such as a new door or dashboard. An E-FMEA may be initiated by someone within the environmental division, or requested from an engineer within the product development project. E-FMEA is the main environmental tool in product development that the company is working with currently and roughly twenty-five E-FMEA have been conducted to date.

The process intends to identify which environmental requirements the design might not be able to fulfil, where information on the composition of a certain component is lacking and what the consequences of these two elements might be. The process brings specific questions to suppliers and designers about product composition. In this way, an E-FMEA might reveal where a restricted substance has, or has likely, been used. Often one outcome of the process is the task to gather more comprehensive information (e.g. the supplier must go and ask their suppliers). The group will then make suggestions to the project team regarding the system.

As more E-FMEA are conducted in future, they may serve to assess how the process to integrate environmental considerations is functioning in product development by indicating ‘trends’ where environmental requirements are not being met.

### 3.2 Case Study Tool – Limit

Limit is a tool developed at Volvo, specifically to address restricted substance use. Limit is a booklet listing several vehicle components. For each vehicle component, there is a small table of information on the specific restricted substances commonly used in that component, and on the associated environmental impacts. It is both paper and internet based. Limit is intended for purchasers, designers and suppliers to improve their understanding of the restricted substance lists. These actors may not have competence to understand a list of chemical names and scientific names of certain materials. Further, they may not have competence to identify the materials and components where these substances are used. This is identified as a problem by the environmental division and Limit is being developed to partly address this problem.

Limit was introduced in pilot phase to the purchasing division in 1999. In autumn 2000 the first version will be introduced to designers and purchasers in the product development division.

For each environmental requirement, there must be a measure to indicate when the requirement is fulfilled. Limit is intended as a test or measure for restricted substances in the vehicle. It does not measure in the traditional sense, (i.e. measuring contents once a component is chosen), but should be used when requirements on restricted substances are initially communicated. The purpose is that it should improve information on which components contain restricted substances before they are chosen, when there is still possibility to influence the design. When introduced this autumn, Limit will be presented to design engineers and purchasers inside the organisation.

accurately describe the outcome of the E-FMEA process. The reader is referred to Wendel, 1999 and Karlsson, 1997 for comparisons of the original FMEA tool to its descendant, E-FMEA.
3.3 Initiatives in the Other Companies

For the other vehicle producers and supplier companies (Appendix I) that are working toward a similar point of implementing their restricted substances lists into product development, the research has not gathered the same level of information as is gathered from the case study company. Thus, it is not the intention to draw full comparisons. This Section highlights the main similarities and differences, that became apparent when speaking with other companies during the course of the research and that are relevant to the drivers and barriers presented in the subsequent Chapter.

3.3.1 DfE and A Life Cycle Approach

Some companies have included ‘environment’ as a characteristic. Within the last five years, Daimler-Benz have set ‘environment’ as a category under which to define specific environmental targets for product development. ‘Environment’ is also a characteristic in the process for developing new products at SAAB 46.

Companies in the research who did have restricted substances as a priority describe a process similar to the one outlined in the previous Section. For all companies, these are generally very new and though the process is ‘introduced’, projects have not been operating according to this structure fully or at all in some companies. For instance, they may only be in practice for a small number of projects or small part within projects. For components to be used in a project, environmental information should be checked, but most often this information is not available, and the outcome is to send a request to suppliers.

Often in the companies interviewed, persons felt environment was alongside and not integrated in the development process and this is the impression of the author as well. For instance in one company, a design project should not pass a certain point in development until a discussion with the environmental department is taken and documented, however this is not part of initial project planning.

3.3.2 Restricted Substances Lists

Certain companies with restricted substances lists explicitly state that addressing restricted substances in product development is not currently a priority consideration. One of these companies is sending general environmental requirements to their suppliers, focusing on environmental management systems, and not on product design or restricted substance use. Others have recently begun to actively include the lists in communication with their suppliers, indicating restrictions on the use of these substances in the product. At a further stage are companies who are receiving and documenting the information on restricted substance content, received from their suppliers.

Where there is no process to integrate environmental considerations into vehicle or system development, each time environmental information on product content is lacking, they must identify a person on the project to be responsible for sending this request, receiving and documenting the answer for each component. And in all cases focus is on asking for information on the components most suspect as a problem.

One company in particular has held training in design for environment type thinking. Topics cover existing and coming regulations, customer demands, ‘rules’ for designers to apply, what components to watch for problems and the restricted substances list. The training emphasised that designers should ask the customer about their environmental requirements, especially any new demands, at the initiation

46 SAAB is also working specifically to decrease the risk of fire in the finished product by setting certain requirements in the early stage of design.
of a project. This training did not talk to designers about discussing the use of restricted substances with their suppliers.

### 3.3.3 Cooperative Efforts

IMDS – International Material Data System is an initiative from the European automotive industries to gather information on product contents in a central database. The intent is for all manufacturers in the product chain to submit product content information to their customer. Thus, as components and systems are built, product content information is aggregated and sent along to each tier of suppliers in the chain. In the end, the vehicle producer should have information on the full contents of all components and systems in the vehicle (see Figure 7, Chapter 4). As the standardised form can also be submitted to regulatory authorities in the different market countries, all actors involved benefit from reduced reporting requirements. Secrecy is to be protected via firewalls between certain users, so not to reveal product contents to competitors (Müller, 1999).
4. INTERVIEW FINDINGS

The previous Chapter has shown how the main mechanisms identified relate to the situation in the companies and in what ways they address restricted substance use in the vehicle design process. To answer the research question, Chapter four builds on this picture with the findings of the research. It presents the influencing factors identified during the interview discussions; and opinions about working with restricted substances and flame retardants in vehicle design stated by the interviewees.

Not surprisingly, the findings indicate that each mechanism is interlinked and hence, so are the factors that influence them. ‘Environmental considerations in design’ and ‘life cycle approach’ are broad concepts and cover initiatives beyond restricted substances. The factors influencing initiatives on restricted substances within these two concepts are presented and organised according to the framework developed in Section 2.3, that is, DfE and LC Approach; restricted substance lists and substitution; and teamwork, supplier interaction and testing in vehicle design. Attention is given to the factors revealed as part of the focus on brominated flame retardants in vehicles that are outside the current framework.

4.1 DfE and LC Approach – Influencing Factors

There are influencing factors identified that do affect reducing restricted substances in vehicles, though not directly. This Section presents interview findings related to these indirect factors. Public awareness and regulatory measures very much affect incentives for an organisation to take a life cycle approach and undertake environmental issues in the design of their vehicle. Benefits the organisation can realise from implementing an environmental design approach, top management commitment, and personal interest among actors may also influence DfE and a life cycle approach, as identified in the previous Chapters.

Factors that may negatively influence environment and restricted substances as considerations early in product design were also presented previously. These included: customers not willing to pay a premium for improved environmental performance; a difficulty to integrate environmental considerations because of a lack of tools and methods for the early stages of design; the existing infrastructure and processes; an existing mindset and behaviour toward vehicle design processes; and a lack of information on financial advantages of working in design to reduce substances.

These factors are expanded and augmented from the interview findings in the subsequent paragraphs to present more specific details and reveal factors beyond those identified in the literature review.

Public Awareness

The interviews very much support the influence that public awareness has on company initiatives. While presented as a ‘driver’ in Section 2.4.1.1, the interviews highlight that a lack of pressure from customers on restricted substance use is a factor hindering its consideration in vehicle development processes.

Demands from customers in the market are identified in Section 2.4 as a major driver for environmental considerations. In one company market pressures were used to drive environmental issues into product development. The environmental department created this external pressure on the company by communicating highly about the company’s planned environmental initiatives for development and ‘promising too much’ to the market so the company had meet the market expectations. Environmental considerations directly in product development among the other considerations then became an internal driver for furthering environmental work and improving environmental performance of the vehicle.
The majority of interviewees do feel that customer demands are directly reflected in planning the product, however automotive, truck and bus producers feel pressures from customers regarding restricted substance use are lacking. They identify this as a barrier to bringing environmental considerations into the design of the vehicle. Specifically for reducing restricted substances in a vehicle, interviewees believe that the customer will not currently pay for an environmentally improved car, truck or bus. For cars, interviewees feel the customer does want environmental improvements, but more as an expected minimum and not something they are willing to pay extra for. Interviewees identify two barriers in relation to this point. First, it is difficult to justify charging a customer more to cover the costs of removing a restricted substance that could potentially damage health from the compartment where the driver is meant to sit. Second, impressions are that the customer does not want to be reminded of negative environmental consequences, such as dispersion of toxic substances, when purchasing a new car.

Following from this, interviews reveal that it is harder for a company to communicate their efforts to integrate environmental considerations into design than to communicate efforts on other environmental areas. One interviewee explains design focused work does not have the same profile in the automotive industry, and difficulty to communicate initiatives is mentioned as a barrier to establishing and maintaining commitment to these activities.

According to one interviewee, legislation is reflecting the market and a company acts as a link between the two. The company is pressuring legislators for policy that supports what the company plans to work with, based on predictions of future market demands.

Box 4. Public pressure on fire safety in public buses.

Pressure to improve fire safety of buses is coming directly from customers. These customers are operating their bus fleets without fire insurance, because the financial losses of one burned bus are less than the costs to insure the fleet against fire. Thus, these customers exert a lot of pressure on the bus company, along with the media who exert pressure by covering bus fires in the news. Fire safety has taken a more prominent role than environmental concerns, but perhaps they need not be exclusionary. Working with fire protection without a commitment to address BFR does not make sense, as the company will likely have to turn around in a few years time and redress their fire protection measures in order to be in compliance with Swedish and EU law. Arguably, there are advantages to addressing both fire risks and the use of restricted BFRs simultaneously.

Regulatory Measures

Findings reveal regulatory measures as a positive influence to bring restricted substances as an important consideration in balancing requirements and design solutions. However, it is also apparent that when speaking more broadly than restricted substances, regulatory measures hinder a company in taking a holistic approach to reduce environmental impact of the vehicle in the most effective or efficient way.

Legislation is described in existing studies as a driver for companies to consider environmental issues and this is reflected in the majority of interviews. As one interviewee states, legislation was the initial driver for environmental work and is still the main driver today. Interviews further indicate product

---

47 For instance, efforts to improve fuel efficiency can be more effectively communicated to customers, according to several interviewees.
focused legislation as a specific pressure to consider the use of restricted substances in the design of vehicles. Legislation focused on products is identified as an important way to make vehicle producers aware that ‘they too deal with chemicals’ and are thus responsible.

Regulations on substances are also identified as a main influence, specifically for considering environmental aspects in vehicle development. Several persons state that materials policy at EU level increases the number of companies making demands on suppliers in other regions and increases their ability to influence suppliers. Pending restrictions on the use of brominated flame retardants and possible controls on the use of PVC\(^{48}\) are given as examples that interviewees feel will improve this influence. One interviewee has research to show that since international focus on brominated flame retardants, electronics producers in Europe declare they have decreased their use of these substances or left them out of products entirely.\(^{49}\)

Alternatively, other interviewees identify regulations on substances as a factor stifling environmental work. Such legislation does not allow a company to take a systematic approach. It requires a lot of time and cost to focus effort on one material. This interviewee provides the same example of PVC, and feels efforts required to focus on this one use may not be the best way for the company to spend its resources at that time. Thus initiatives dealing with more significant problems or otherwise more pressing for the company fall by the wayside. Regulations on substances do not allow a holistic view and those developing regulations do not have an industrial perspective or knowledge about producing vehicles. This is stated as a barrier for a company to take a systematic approach.

Legislation is also recognised as a financial incentive for undertaking environmental work, in general and in product development specifically. But overall, interviewees feel these incentives for decreasing vehicle emissions and not for decreasing restricted substance use in the vehicle\(^{50}\). This is particularly the situation for bus and truck producers interviewed. In response, they focus efforts on emissions, as they can see financial gains for their work. One interviewee finds legislation easier to respond to than other pressures, such as an internal company pressure to address restricted substance use in the vehicle. They feel these customer and legislative pressures are reflected in their work with environment, as little or no focus is currently on restricted substances\(^{51}\).

When asked about anticipated directives on vehicles, electronics and brominated flame retardants, one company feels the End-of-life Vehicles directive is aimed at personal cars, and do not expect it will come to other vehicles sooner than 10 years from now. They are not working to meet demands in the directive, the proposed EU directive on restricting brominated flame retardants in electronics, or the Swedish proposals to ban these brominated substances. Another interviewee, who is involved in a process to address restricted substances in product design, still feels restrictions on brominated flame retardants are not reflected in their current work.

A company aiming to be ahead of legislation must find an important balance in order to avoid excess costs, as one interviewee describes. One example considers manufacturing an electronic component

---

\(^{48}\) The polymer PVC, polyvinylchloride, is currently the focus of much debate. It is suspect of a range of negative impacts on human and environmental health. Alternatively, there are studies to contradict these findings. Despite lack of consensus, PVC is in the public eye and under continuing scrutiny from consumer groups and possible restrictions on its use are being discussed by national and international regulators.

\(^{49}\) This actor states such a response is not observed in the USA where this type of direct legislation on brominated flame retardants is not anticipated.

\(^{50}\) These incentives are also focused on customers as emission and fuel consumption taxes. Producers in turn feel pressure from customers to reduce fuel consumption and vehicle emissions. One interviewee anticipates further deregulation of city traffic in Europe will increase demands on vehicle emissions and cites this and existing road emission taxation as incentives a company can respond to.

\(^{51}\) One interviewee states that as commercial products, trucks are under no pressure from customers in terms of restricted substances used.
without using brominated flame retardants. If a company demands a BFR-free electronic component from their supplier too early and competitors are not soon to follow, the BFR-free system will be too expensive, for too long. In the other direction, changes implemented after competitors, or just in time for legislation, do not provide any advantages such as image benefits in the market. Difficulty in finding this balance is regarded as a barrier to taking environmental decisions in product development, and in many respects, companies feel they are ‘guessing’.

There are organisational issues revealed as important drivers for addressing restricted substances in vehicle design not directly stated in the literature review (Chapter 2). For instance, ‘the best results come from work that a company itself identifies as important’. In this way, the company can focus on the most significant problems and work in a systematic way. This interviewee also states environmental initiatives identified and undertaken from within a company make overall environmental improvement easier.

Benefits from Environmental Design

The potential benefits for an organisation to implement restricted substances in product design where never explicitly mentioned during interview discussions, aside of ‘image’ benefits. In speaking with different levels of management, design, purchasing and upstream actors in the supply chain, the overall expression is that we have to. This appears to be tied to pressure actors feel from legislation and thus from producer to supplier. It indicates a striking absence of discussion on the potential returns from introducing a new aspect to the design process.

Top Management Commitment

The commitment from upper levels of management is felt by nearly everyone who commented as an essential factor for progress of reducing restricted substances, particularly during design and development decisions.

Interviewees link the spread of environment in the organisation to ‘top management’ commitment. They stated this commitment is important to secure environment in the organisation in general and to give it weight in the projects. Decisions in design that improve environmental performance of the vehicle despite higher initial costs demonstrate this commitment, according to different interviewees, and facilitate working with environment in product development. Two interviews give distinct examples of technologies adding costs to the project in which they were introduced, and feel these steps illustrate environment is ‘not only talk’, that management is putting money behind it.

One interviewee not working with environment commented instead on his experience with fire safety and testing. Safety is recognised as a high priority throughout the company which he states means he does not need to consider cost so much when developing measures to ensure and improve fire safety.

Several persons relate top management commitment to a personal interest. One top manager’s interest in environmental product development work is cited as an important support element, while other perspectives state that management not acting as though environment is important for the organisation is directly reflected in the way they work.
Personal Interest of Actors

Regardless of processes and tools in use, interviewees feel restricted substance issues are connected with personal interest and discussions revealed these issues often rely on key persons to establish profile and momentum. Interviewees provided different examples of this personal interest and its importance as they see it (Box 5). To summarise, examples included specific purchasing technicians, design engineers, strategy planners for new technology development and environmental contact persons for suppliers who are showing personal interest. Interviewees feel these persons are an influence in bringing environmental considerations into product development and in building momentum for restricted substance initiatives.

In the division for development of new technology at one organisation, persons responsible for developing strategies for new technology development are identified as highly environmentally aware. They are ‘doing extra’ to ensure environmental goals are considered in new technology strategy planning and in development projects. The interviewee feels it is because of these persons that environment is becoming a “strong discussion partner” in the planning of new technology development projects, where it was not considered in the past.

In another company, quality engineers and material engineers are working together in procurement, as is generally the case. Responsibility for ensuring supplier and product environmental performance formally lies with the quality engineers, but one interviewee felt a high environmental motivation and willingness in the material engineers. These material engineers have had no environmentally related training, but are taking initiative and looking for more “environmentally friendly processes”, for companies that are “good performers” and they are pointing out those companies that are poor performers or whom they suspect will not keep up with requirements.

The purchasing function in different companies was related directly to personal interest, where some purchasers “don’t bother,” others are more interested, and in one instance, a purchasing technician was asking for education to help understand the restricted substance lists and other environmental aspects related to the role. One interviewee stated that purchasing technicians are currently evaluated on their economic performance. Without environmental aspects included in this evaluation and given the time pressure that purchasers feel, economic aspects of purchaser-supplier relationships may be the only issues addressed.

Several persons identified the design engineers they work with as concerned and very motivated to work with environmental issues.

Box 5. Personal interest effects how restricted substances are considered in product design.

They also feel “if people are aware of a problem, they will try to solve it”, and that “no one wants to be “the person with mercury in their system” (Box 5).

One supplier company very much indicated that the types of questions and discussions they would initiate depend on the personal interest of their contact person in the producer company. This interviewee feels a contact working at the same level makes it easier to raise discussions about meeting environmental requirements.

---

52 Mercury is a heavy metal, well recognised for its hazardous effects on humans and the environment. The substances containing mercury have been restricted and removed from many applications.
Paying for Improvements

There is absence of agreement on where financial resources for designing out restricted substances should come from. In many interviews, the customer is identified as a barrier because the impression is that any increases in the cost of the vehicle for environmental reasons will translate to fewer sales. This lack of customers who will pay a premium relates back to low public awareness on restricted substances. One supplier states the producer is not prepared to pay for the environmental improvements that they are demanding. This interviewee’s experience is that regardless of restricted substance lists and requirements, the producer will choose another supplier if the cost of the component goes up.

Lack of Experience & Information

From interview discussions, it is apparent that restricted substance considerations are trying to be taken along with other considerations when deciding which system and which design solution to put in the vehicle. However, existing processes have not changed to consider all requirements in a new way, nor has behaviour of actors changed to address these considerations in many cases. Environmental considerations are often left out for not having experience and arguments to compete. A design process that is adapted to respond to continual time and economic pressures augments this.

One interviewee feels designers are interested but do not know how to integrate their concerns into their work. Designers cannot be environmental experts, so the role of environmental departments is to put environment in terms that designers can integrate into their existing routines and to provide support for this integration, according to one interviewee.

Environment as a consideration in vehicle design is new and not as experienced as other properties such as quality, styling and safety. Several persons identify this as a barrier to effectively balancing environmental with other requirements in vehicle design. For instance, persons working with safety have in some cases over 40 years of experience, it is a ‘natural’ consideration at all stages of design, and designers know how much value safety adds to the vehicle. The interviewee compares this to environment, which has been coming into design since the 1980’s where he is working, and after 20 years it is still not a ‘natural’ consideration.

In setting requirements for a project, there are few arguments for environmental requirements in terms of how much customers will pay or how much value they will add to the vehicle. Following on the integration of environment with other product requirements, design engineers speak a certain language in product development; “reach level x” and “test using method y”. According to these interviewees, environmental requirements not written in this language are a barrier for their fulfilment and for their full consideration among more traditional requirements. As it is, environmental requirements on each system will often have much description on how things should perform, which one interviewee referred to as ‘just fine language’ with no method to measure this. Developing such ‘measures’ to indicate when an environmental requirement is met can be difficult.

Overall, there were several interviewees who feel work with tools and environmental initiatives is not integrated into the product design process, even those who describe a specific process in place. Though processes are in place, they feel time is needed to reach real integration. One interviewee states that environment will never be satisfactorily integrated with other vehicle design considerations.

53 In a different interview, the case of the interior of the vehicle was raised to illustrate this point. The interviewee here said that persons working with interior could translate a deviation in the ‘smell’ inside the car to a value in terms of customer dissatisfaction.
For instance, when restricted substance or other environmental information is lacking for a component, the project will continue because of time pressures and changes will not be made. Quality, function and economics are more important to the design process than the possibility of restricted substances in a component, according to most interviewees.

Existing behaviour and mindset of actors along the vehicle design chain is stated as a factor hindering efforts to remove brominated flame retardants from vehicles. Internally, problems not identified early enough will face costs and possible disruptions to quality and function as reasons not to make any changes. When feedback pathways are established, there may still be barriers to effectively using this feedback. In testing vehicles for fire safety, there is a process to tell design engineers what problems were found in order to prevent the same problem in future. In discussion with one of these testing engineers, he explained that despite this process, the design engineers did continue to design in the same problem. He referred to inexperienced engineers that did not listen, or felt they could handle the problem in another way.

It is also felt that brominated flame retardants are overused, and interviewees attribute this to ‘the way we’ve always done it’ behaviour that guides the amount and type of flame retardant used. When adding flame retardant to a material, the attitude may be to add the same amount as last time, or a bit extra, to ensure it passes the fire test. Interviewees feel that materials do not need to be treated to meet the highest possible performance standard. Certain persons working with fire standards, fire testing and electronics commented that flame retardants are not necessary at all for several applications where they are currently used, but are added just in case or because they were once needed.

Only one person interviewed felt that ‘non-traditional’ costs were considered in decisions taken on environmental options in the product’s development. For instance in the decision to accept a new part containing a restricted substance, one interviewee explained that under their EMS, work would now have to begin to draw up an action plan to remove the substance. When asked, the interviewee has not connected this as a cost associated with the decision, but then began to think of handling costs in the workplace, the dealership service centre and end-of-life handling as some further, but unconsidered, costs. Of those persons interviewed who were involved in the decision process, only one felt all relevant costs were considered and the others did not know of any ‘non-traditional’ costs that had been raised in discussions.

Box 6. Illustrating the lack of knowledge on financial advantages of environmental improvements.

The mindset of external actors can also influence a life cycle approach. For instance, persons originally involved in developing brominated flame retardants as the safe solution to reducing fire risks are lobbying for their continued use to ensure this safety.

Particularly regarding cost, several persons interviewed have a ‘feeling’ about benefits and cost saving of environmental improvements, but lack the same type of arguments that other considerations have come to establish to push the importance and possible value (Box 6).

### 4.2 Substitution & Substance Lists – Influencing Factors

Interviewees did not explicitly raise the benefits of working with substance lists. The interview discussions did mention the availability of alternative substances and other technical solutions, together with assessment of alternatives as influences to substitution of restricted substances in the vehicle design process. The influence to use substitution as method to reduce restricted substances in the vehicle, was discussed and it appears both process and mindset favour substitution in vehicle development in the companies. Following from this, interviewees were asked about the potential to consider a new design instead of an alternative substitute substance.
Many persons identified that having the restricted substance lists as a company standard are an important influence. Interviewees discussed a lack of information about the product in the early stages of design as a problem when trying to phase out a certain substance. This lack of information seems to characterise the process for all requirements, and not only environmental considerations. Difficulty in both sending the substance checklists to suppliers and receiving the completed checklists from them are important barriers to their use in vehicle development. There is also an expressed lack of aim and follow-up associated with using substance checklists.

A vailability & A ssessment of A lternatives

Availability of alternatives was identified as a driver for removing restricted substances from the vehicle, but one interviewee working in the environmental division of an automotive company states there are not usually alternatives in this industry, due to the highly specific components. Interviews with those involved in chemical assessment describe the difficulty to find information on alternative substances. Many of the proposed alternatives have not been tested for environmental and health effects, nor have they been evaluated in the technical applications they are proposed for.

One interviewee feels differences in the design of buses, trucks and cars mean flammability-test results on BFR-alternatives are not applicable to all vehicles. Thus alternatives must be tested for fire specifically in each type of vehicle to determine if they are acceptable. He feels that because companies cannot share results, the time and resources required from a smaller company to test alternatives presents a barrier to finding substances to replace BFRs.

A Process & M indset

The overall impression of interviewees is that ‘a process is in place’ for substituting a problem substance with an alternative substance. The infrastructure to develop and assess alternatives is in place and growing as new projects to find and test substitutes are taken. Interviewees also comment on an existing mindset regarding restricted substances, that a restricted substance can be substituted for another that is not identified as a problem. Certain actors can influence this, according to the findings. For instance, fire testing divisions can suggest particular flame retardants to polymer formulators. Though final decisions are made based on many suggestions and will usually be made on costs, interviewees feel.

Examples of design solutions that could eliminate the need for a flame retarding substance were discussed during this research in two instances. The first example is of a particular component – it is a series of electronics housed in a thick metal box and connected to the vehicle system by a cable. The designers feel the internal electronic components need not be treated with flame retardant at all, because the box is designed air tight and therefore the insides will not burn.

In a second example, an interviewee showed a new technology under development initially aimed to improve performance of certain electronics by keeping dust and moisture from the surface. This design is now recognised for preventing fire in the components it protects, with no flame retarding chemical.

Box 7. Design solutions to improve performance and eliminate the need for BFRs.

---

54 Differences include the location of the computer box, which is placed on the engine block in buses, but not in cars. Also, cars operate 4-5000 hours, while buses are in operation nearly a factor of four times as many hours.
A lternatives to Substitution

Taking the stated barriers to substitution and the aim of the restricted substance lists, interviewees were asked for their views on new designs instead of new substances, as a way to phase out restricted substances from vehicles. Several persons did not answer this, but their comments from the interview in general reveal interesting points that can be connected in the analysis (Section 5). Others had specific ideas on how they feel redesign could contribute to reducing restricted substances and most could think only of barriers to such an approach. Some persons thought immediately of isolated ‘redesign’ projects focused on weight reduction or materials use, but not of ‘redesign’ as an immediate consideration when faced with a problem, such as brominated flame retardant in an electronic component.

Interviewees were asked if they felt designers could consider changing a design when faced with removing a restricted substance, as opposed to replacing it with another substance. The following bullet points summarise some of the comments received.

• A restricted substance is used for a reason (or was) and thus it is easier to change to another substance;
• One interviewee states it “would be very good to have material or retardant that is similar or better than BFR” and this statement illustrates the mindset for preferring alternative substances;
• When there is a problem in a part, it is not redesigned, but “environment is considered in the next design”;
• To solve the problem of BFR use through a new design will require a long process to prove the new design meets existing and accepted fire standards;
• This approach is limited by things outside the scope of the company i.e. the existing fire testing procedure;
• This approach is limited by the existing systems, for instance the location of the electronic circuitry.

A Company Standard

Some companies have their restricted substance lists as a standing requirement for all product development projects, i.e. a corporate standard. This is identified by the majority of interviewees as a benefit and a driver for considering restricted substance use directly in the vehicle design stage\textsuperscript{55}. As a project begins, specific requirements are not always developed as they should be, but designers know the substances restricted from the product at the very earliest stages. As standing requirements, restricted substance lists are also perceived by new generations of designers in the same way as any other requirement to be set and met in product design. This helps drive the consideration of restricted substances in product development processes, as one interviewee specifically stated that new designers are receptive and proactive to addressing environment at early levels.

Certain interviewees are willing to rely on the current process of sending a restricted substances checklist to suppliers to adequately reduce these substances in the vehicle (though they expect this will take time). Not all interviewees agree, and a significant number feel existing processes will not be adequate to ensure suppliers reduce their use of restricted substances in the vehicle components and systems they supply.

\textsuperscript{55} Interviews support literature findings that to support efforts, environment cannot be treated any differently from the other properties in setting requirements for product and must be considered at the beginning of a project as all other requirements.
Lack of Information on the Product in Early Stages of Design

Though lists are a standing requirement the company, their supplier and sub-suppliers do not always have full information on product contents and interviewees do not feel suppliers fully understand whether their products contain restricted materials. Thus, it is unclear among producers which restricted substances their vehicles still contain. When information on use of a certain substance is lacking, prescribed action is often to send a request for more information to the supplier (see Figure 7, IMDS).

Restricted substance lists are not well understood. This is identified repeatedly as a barrier to using the lists in discussions with suppliers and thus a barrier to ensure brominated flame retardants and other restricted substances are not in vehicle components and systems. Design engineers, purchasing technicians and suppliers do not understand the substance names, or what components and systems they might be found in. Thus, designers and purchasers are generally not comfortable enough to go deeper with suppliers into questions about restricted substances in the supplied goods, especially when the suppliers first reaction is ‘we do not add that to our component’. Restricted substance lists should be used to start a dialogue instead of simply sending a list no one understands, according to one interviewee. They elaborate that in this way, lists can be an important driver for integrating restricted substance considerations into product development.

While lack of information in the early stages of vehicle development is a barrier to effectively using checklists for restricted substances, a lack of information on product content is also a barrier to keeping the list updated. One interviewee expressed difficulty in keeping a restricted substance list updated with substances that may pose a risk in future. If the company's list is not updated, they cannot ask updated questions to suppliers, as what the company can ask of its suppliers is limited to what it knows. This is identified as a main barrier to keeping ahead of new substance restrictions.

Automotive manufacturers have generally restricted the same substances, but their lists are not the same. This is confusing for suppliers who do not know where to work and must report differently for different producers. In the simplest sense, the supplier may just ask for a restricted material list they can work with. That is, a list with a 'manageable' number of substances, in an understandable format.

In companies where the list is not a standard and where there is no procedure to identify responsibilities, identifying a person to send the list to suppliers is a barrier. It is time consuming, and thus the request is not always sent. In these cases, ensuring the answer is received and then doing something with the information is stated as a further barrier to using restricted substances lists in vehicle design.

Aim of the Restricted Substance List

It is not always enough to just send a checklist of substances. One interviewee explains how some sub-suppliers do not understand the aim of the restricted substances checklist at all. Another interviewee states a barrier to using the restricted substances lists is communicating the aim of the list. For instance, “it is easy to send out a questionnaire on restricted substance use, but hard to tell what you will do with the results from it”.

56 Looking at a list of restricted substances, “you need to know more in chemistry than a designer (at our company) does” to understand it, according to one interviewee.

57 Several of the environmental and purchasing divisions within the companies are focusing mainly on EMS certification, and less on collecting information on product contents from suppliers by sending a checklist on restricted substances.

58 In one instance, responses included statements about the quality of the supplied components, and not their content.
According to persons working with chemicals and one raw material manufacturer, it is important to discuss individual BFRs, not all brominated flame retardants, or all halogenated flame retardants, or all chemicals in general, when talking about the problem (Box 8). Also, certain brominated flame retardants are more problematic in some applications that in others. However, no interviewees who were asked could offer a suggestion on how to effectively achieve this detailed communication.

Restricted substances are knowingly used in certain vehicle systems for the beneficial properties they confer. One interviewee feels it is 'impossible' to meet some of the current requirements without these substances. They feel designers do not understand the implications of design requirements in terms of restricted substances and thus are sending a "strange signal" to the supplier. One supplier supports this when he states, 'the main barrier to removing brominated flame retardants from the electronics in a car is that the customer wants them there'. Giving suppliers exemptions for restricted substance use eliminates pressure for the supplier to find alternative solutions. One interviewee states the most effective way to ensure suppliers meet environmental requirements is to show that the company is serious - no exemptions.

The development of a new technology may 'require' the use of restricted substances in the vehicle. New technology development projects are usually driven by one parameter, for instance, to improve performance in engine fires. This means other properties are not considered and balanced when a new technology development project is planned. Thus, when the new technology is taken into the product development, problems may arise in terms of meeting requirements for restricted substance use and other properties. However at this point it is too late, and making changes at this stage are cited as costly and inefficient.

The purpose for using brominated flame retardant chemicals is to prevent fire and improve the safety performance of materials in a fire. According to one chemist, penta- and tetra-bromodiphenylethers are currently identified as the most problematic to health and the environment, while it is deca-BDE that is most often used. The interviewee states that while certain individual flame retardants should not be used for reasons of environment and health impact, it is unreasonable to refer to all "brominated flame retardants" because it would lead to a major problem with fires. The interviewee explains deca-BDE and many other brominated flame retardants beyond the PBDE group are not mentioned as a problem and are used a lot in computer cases and televisions to meet fire regulations. However, when asked, the interviewee did stated that these compounds have not been risk assessed in the way penta- and tetra-bromodiphenylethers have.

Box 8. Communicating the difference between flame retardants in different applications.

### 4.3 Teamwork, Suppliers and Testing – Influencing Factors

This Section describes the interview findings related to teamwork, supplier interactions and testing as they affect the consideration of restricted substances in designing the vehicle.

Teams in the vehicle design process are being adapted to include environmental expertise, and in other cases, new teams are being developed. The general impression from the interviews is that this team focus will draw on personal interest and improved communication to support restricted substance considerations in vehicle development. However interviewees only explicitly referred to the disadvantages that they currently face, with the exception of one case where discussion as a tool is identified as an important advantage.

---

59 For instance, by setting a certain quality or performance requirement (e.g. a level for fire testing performance) a company may be "requiring" the use of restricted flame retardant.

60 This interviewee subsequently acknowledged the difficulty of this in practice, reasoning that money is involved.
Confusion of Responsibility - Internal

Everyone is not aware of their role in terms of their responsibility and the scope of their work. Projects are characterised by ongoing discussion, balancing and evaluation and a specific barrier identified is the lack of leadership. Many designers, suppliers, environmental experts and purchasers interviewed feel actors are unsure of how far their boundaries for decision-making and influence extend when it comes to the project in general and environmental considerations specifically. Suppliers and producers state projects often lack a clear plan from the start, thus each actor along the vehicle’s development can have input that alters its course. This is a barrier to how environmental considerations are taken and followed in a project.

This confusion of responsibility for environment (and other) design considerations is also seen when environmental demands are put on many different parts of a product development project. In one case, restricted substance requirements are stated in the company’s overall environmental goals, listed in the project requirements and in requirements to suppliers. Several reporting routes and decision fora and too many persons responsible can mean no one is responsible. As the interviewee illustrated, “is it my responsibility to tell you or is it your responsibility to ask me?”

Reporting

In cases where the environmental person does not sit in on the project planning, it can take them some time just to locate the right designer to talk to about a particular substance in a particular part.

The purchasing department is responsible to test prototypes and manage testing results. There is little confidence that communication about testing results with the environmental department is regularly done and they do not know how many prototypes do not meet environmental requirements, which requirements are not met, or the frequency of these occurrences. This is described as a barrier to taking problems from one design and ensuring they are not repeated in the next design.

Interviewees indicate the purchasing function is ‘critical’ in communicating to suppliers that not only technical aspects but also environmental performance of the components are important.

Not operating under a hierarchy, but working very much with discussion as a tool is identified as a major driver for environmental work. This is mentioned especially for working at the design stage where engineers, designers, purchasers and other discussion partners are becoming more important to ensure environmental requirements are set and met.

In previous Sections of this paper, outsourcing design to suppliers has been identified as an important aspect in addressing restricted substance use. Thus, product chain pressures and industry associations are significant drivers to apply interaction with suppliers as a mechanism. Alternatively, it has already been stated that producer-supplier interactions can also influence efforts in a negative manner and the large number of actors, lack of consensus on goals and ‘secrecy’ are all recognised as possible barriers.

It is important to note that the effectiveness of ‘interaction with suppliers’ as a mechanism will very much influence the organisation’s ability to take a full life cycle approach.
Externally Designed Vehicle Systems

All interviewees were asked for their opinion on how out-sourcing full systems and in some cases, design of these systems, to supplier companies effects the environmental requirements for the project. Positions on this issue hit both ends of the scale. Some respondents are alarmed about their future ability to ensure restricted substance and other environmental requirements are met, given what they feel is a trend for designing systems externally. One respondent felt out-sourcing design “is a critical issue for environment” and how effectively it is taken as a consideration in projects. Another interviewee expresses concern that there is currently “no strategy to handle this matter”.

In the other direction, are respondents who feel a system designed outside the company is no different from one designed internally, as there are procedures and checks in place to ensure all requirements are met in any design. In the middle are those who recognise the systems in place, but feel sceptical about how well they currently function to support environmental requirements, let alone how these systems will function external to the company.

One interviewee states that possible increases in externally designed systems is his “biggest fear”, without hesitation. He explained that each year, the price of a vehicle model falls, which means incentives in the product chain are to reduce costs in each model. From experience in testing and with other companies, he gives an example where the quality of supplied parts decreased in successive years to save cost. This correlates to decreasing incentives for suppliers to meet environmental requirements as a project progresses. It is also a concern because testing to ensure that the supplied system is the same one that initially met agreed requirements is not done every year.

In one company, internal designers have support of the environmental division. But when systems are designed externally by suppliers, their designer only has communication with the company’s engineer responsible for that system. This increases the risk that information is not communicated to suppliers during design and development, according to one interviewee.

The overall feeling on outsourcing design is split because the majority of interviewees indicate that what should happen in theory may differ from what happens in practice. Theoretically, there are systems in place that ‘should’ ensure systems designed externally meet company internal environmental requirements. The company has to trust. But there is much scepticism on how well these systems will work in practice and in the learning situation of today “it is risky that something is missed”. All of the interviewees feel banned substances are still found in the vehicles, and most are aware of specific cases where these substances are present. ‘Of course’ there are restricted materials in existing components, as one interviewee put it. The example most often given is the presence of BFRs in electronics, though none of the interviewees at any of the companies knew specifically which BFRs. As one person exclaimed, “you always find something you didn’t know was there, though this is happening less and less”. While all acknowledge that the administrative routing is developed, few have confidence that this will be sufficient.

Externally designed systems may positively influence addressing restricted substances in the vehicle. Two specific benefits of externally designed systems are revealed during interviews. Systems designed by larger suppliers with their own environmental initiatives and research can mean improved environmental performance and restricted substance use. Also, one company indicated their suppliers of full systems are pressing for clearly stated requirements and reasoning on what requirements are aiming to achieve. One company specifically felt increased demands to be clear in their requirements and what they want to achieve coming from suppliers that design whole systems.
Suppliers interviewed state requirements must be received at the start of the project\textsuperscript{61}. Otherwise, the steps the supplier has in place to ‘check’ that they have met the producer’s requirements are met may not be effective. The interviewee states that when producers come with their requests at the end of a project, it is too late to change anything.

**Poor Supplier Cooperation on Restricted Substances**

Currently, interviewees feel the environmental initiatives from their company are not continuing along their chain of suppliers. In all the companies involved, some interviewees state suppliers are currently not fulfilling all the requirements they are asked. Regarding restricted substances checklists, one interviewee feels once a supplier reports restricted substance content in the checklist, no action is taken beyond that. This alarms some interviewees, who emphasise this is a major problem to be addressed further than it is currently.

A main criticism is that suppliers are working in their own interest, which one interviewee feels is to decrease costs. And this, he feels, is the case whether they sit inside the producer company or are completely external. Suppliers and purchasers of electronics support this feeling and state that components sell when offered at the lowest price and good quality. Additionally, a supplier selling to several producers increases the possibility that company-specific requirements to remove a restricted substance are lost. Ensuring commitment to the specific demands of one company is more difficult when the supplier is responsible for the whole design. In this situation, the interviewees here feel that the producer has less control when the supplier says they cannot meet certain restricted substance requirements. One interviewee states larger suppliers will stop supplying to the company before they will respond to restricted substances requests or other environmental demands.

In relation to the drivers and barriers identified from the literature, some see the International Materials Data System under development by European car manufacturers as a partial solution. Product chain pressures, lack of information in early stages of product design and a large number of actors are 1 driver and 2 barriers, respectively, that the IMD S is relevant to. Some interviewees feel the IM DS will coordinate the pressure producers are putting on suppliers. They expect this to increase the influence producers have on suppliers to fulfil environmental requirements and will also establish some common standards for requesting and reporting information on product content. Once established, the database is expected to be a source of detailed product information needed for conducting studies and decision-making.

**Figure 7. International Materials Database System & its potential to influence restricted substance use in vehicle design.**

As a specific example, plastics suppliers were identified as unwilling to disclose detailed information on additives, such as flame retardants.\textsuperscript{62} Thus, a lack of information on plastics is stated as “a big problem.” One interviewee is sceptical about the accuracy of responses. In one instance they sent a form with more than 100 substances (over 30 flame retardants) that was completed, signed and returned the following day. Another interviewee states they must point to exactly the information they want from suppliers, for example they cannot just ask about plastics, but must ask specifically about which additives, or they get no response.

When sub-suppliers respond that their systems do not contain BFR, but does not state what flame retardants it does contain it is hard for the supplier to then sign the restricted substances lists from

\textsuperscript{61}Thus, lack of information in early stages of projects is also a barrier to addressing restricted substance use in vehicle development in supplier companies.

\textsuperscript{62}After several years of requesting information from sub-suppliers on BFRs used in plastics, there are still some large companies not responding to checklists.
their customers. They do not know what their product contains, only what it does not contain. Also, this supplier must continually ask their sub-suppliers every time they receive a new request about a substance because they do not know full product content.

The issue of trust did come up in some interviews. One interviewee specifically stated that suppliers could not be trusted to fulfil design requirements in the company’s best interest. Persons working in purchasing are told not to trust suppliers, while others state that ‘you have to trust’.

**Producer-Supplier Interactions**

Despite scepticism on how well it is working, those interviewed feel the process of asking suppliers about restricted substances has the potential to begin effective dialogue between the company and supplier. Several persons stated that the best way to work is through cooperation, and one interviewee is trying to develop a forum for the company’s suppliers to interact and cooperate with each other. One supplier company states demands from the producers they deal with can be much stronger that demands from authorities.

Many companies who have systems and components designed outside their company do not know how suppliers handle their design requirements. One interviewee feels the best and ‘most natural’ way to deal with restricted substance use in supplier companies is for designers to talk to the suppliers, as they already have contact with the supplier and an established relationship for discussion.

Certain suppliers and some persons in purchasing who were interviewed describe the need to understand reasoning behind a certain requirement so suppliers can anticipate what else may be coming (Box 9).

**For instance,** one interviewee uses PBDEs as an example of potential benefits of communicating the full aim of vehicle environmental design requirements. Is PBDE the problem, or flame retardants in general? Suppliers do not want to phase out PBDE only to turn around and have to phase out its replacement one year later.

A second example provided is the requirement from several customers for all components to meet the highest level of fire resistance under the existing FMVSS302 fire testing method. The interviewee knows the FMVSS302 does not require the highest level in all applications or for all materials. Opportunities to reduce the use of flame retardant chemicals in components do exist. For instance, one particular component is a sealed thick metal box with a small amount of electronics and plastic inside. The interviewee states the oxygen inside the box would run out, extinguishing a fire. Thus, only the connection coming from the box need be flame-retarded.

**Box 9. Illustrating the benefits of communicating the aim of vehicle design requirements.**

There are a number of barriers to ensuring suppliers meet environmental requirements. Given these, interviewees were asked if a company could request its suppliers to work with restricted substance considerations in the development of their product.

The responses to this idea are as varied as the respondents themselves. Those in management and external consultant roles anticipate problems with resistance to and operational implementation of such an idea. Alternatively, persons in purchasing functions in all companies and one person working with supply chain issues in an industry association felt generally that companies should and “must” do this in the future.

One interviewee explains that the suppliers they deal with “should be receptive”, and another person states suppliers are often “interested in the ‘why’ behind requirements”. From one environmental
division, the perception is that it is “necessary, but difficult” to make such demands. Another interviewee acknowledges their company is not yet at the point where it can make these types of demands on suppliers.

When two supplier companies were asked this question, the responses were very different. One supplier felt they were already working this way 63. A second supplier opposed receiving requirements that stipulated how his company should work to design their product. Instead, preferring to receive a set of requirements the end product should fulfil, with no additional demands or unnecessary information. This respondent states that environmental considerations are not part of the day-to-day work in their organisation. Their focus is currently on formalising the process by which they receive product specifications in general from the producer and not on environmental requirements.

Receptive and proactive suppliers can be seen as drivers to integrating environmental considerations directly into product design at supplier companies. Barriers will include persons in the producer company whom are sceptical and suppliers who are not working with environmental issues beyond where their customer, the producer, pushes them.

Large Number of Actors

One interviewee indicated specifically that it is more difficult to track what substances are in a part from a whole system supplier. Another person attributed this to the fact that system suppliers have many tiers of suppliers themselves, and stated it will take time for the company’s suppliers to pass their understanding to lower tiers and to in turn, get information back. One statement illustrates the overall impression from the interviews: ‘it will be a challenge to involve everyone’.

Lack of Consensus

Internally, one interviewee feels consistency in the environmental department and consensus on what they want to achieve is important and that they can drive environmental issues in the design process by being consistent in communication with designers and engineers.

A barrier to carrying initiatives to phase-out a particular substance beyond the producer company may be differing incentives along the product chain. One interviewee feels incentives for the chemical industry are to phase out one substance and provide an alternative, then phase out the alternative substance and provide an alternative to it, as this way of working is ‘good for business’. The barrier here is the existing infrastructure for demand of function and supply of substances.

There is an economic incentive for plastics manufacturers to remove brominated flame retardants and participate in programmes working toward this. The more engineering that goes into a plastic, the more money that stands to be made from selling that plastic, and this new market may be attractive to forward looking manufacturers.

Communicating with suppliers, it is easy to express why a component should be of a certain quality, it is much more difficult to communicate that an environmental requirement holds the same importance as quality requirements. This is especially apparent when going to suppliers abroad 64 who are ‘not mature in environmental issues’ and hold different perceptions of environmental issues and what they

63 However, this interviewee states that environment is not integrated into their product planning of development and that the ‘bar’ for their environmental work is the demands received from their main customer. The interviewee anticipates that going beyond these demands (and in some cases, just meeting them) adds extra costs to the product and is ‘too risky’.

64 Companies may not choose suppliers in all cases. For instance, when importing a vehicle component manufactured in one country to an assembly plant in another country, a certain percentage of the value of the component must then be bought in local supplies. This is identified as a barrier, as environmental performance and awareness in countries is very different. Also, in this situation the company feels less able to make environmental demands.
mean. One person commented on the difficulty of communicating a ‘vision’ behind environmental requirements, and said it is much easier to communicate very specific environmental requirements. A second interviewee referred to the ‘challenge’ in getting all tiers of suppliers to understand why they are asking for certain information and why it is needed.

Designers from the supplier companies sitting inside the company, and working closely with in-house designers is one plan to align suppliers with the company in terms of restricted substances and environmental considerations. This suggestion was raised in more than one interview. This is being done by some companies and is agreed as a potentially effective solution by other actors.

Another suggestion from the interviewees to bring consensus between producers and suppliers is to involve suppliers in developing the requirements⁶⁵⁶⁶.

A second person presented the importance of making suppliers recognise a link between a company’s environmental requirements and successful sales of the vehicle in the market. This ties to risk sharing¹ as a possibility to provide all actors with incentive to understand and reach consensus on restricted substance use in the vehicle. That is, an incentive to share vision.

Secrecy

Actors in supplier companies and industry associations feel sub-suppliers do have the information about the contents of their products, but that getting this information is the biggest barrier. Suppliers of plastics and other polymer are identified as reluctant to disclose which flame retardants they use. Instead, they might request a form so they can indicate which flame retardants they do not use.

One interviewee explains the wide variation in reliability of the responses from supplier on restricted substances use in components and materials. Some respond to 2% of the substances, while others declare closer to 98%.

Just starting

Despite the high variability in how the companies involved are working with restricted substances in design, it is apparent that a majority feel work to get information from suppliers is ‘just starting’. All companies felt they were still learning, had much to improve and much further to go.

Confusion of Responsibility - External

There is conflict of opinion regarding who, along the vehicle production chain, is responsible for initiating reduction of restricted substances (an example is provided in Box 10). Some interviewees state that suppliers sign a form declaring they do not have certain materials in their component. Referring to brominated flame retardants, they feel responsibility for developing and testing alternatives should lie with the component suppliers. One interviewee did not see incentives for the vehicle producing company to be responsible for this type of research and development when they could put the demand directly on the supplier. Others are not confident that it is good enough if a

---

⁶⁵ This is recognised as a way to develop consensus between a producer and suppliers on quality standards in vehicle development.

⁶⁶ An additional way companies may try to develop consensus is to focus on one area important to the company, for instance the vehicle interior, work with suppliers to address restricted substance use in these systems. Then, they may move focus to another system and group of suppliers.

⁶⁷ Generally, a producer buys all components ordered from a supplier, regardless of the number of vehicles sold. In this way, the producer is taking all of the risk. In an agreement with risk sharing, components purchased corresponded to the vehicles sold.
supplier signs a paper. They feel suppliers do not know and thus it is ultimately the company’s responsibility to follow up.

**Who is responsible?** One interviewee explained this barrier in the polymer production chain. The raw material producer provides polymers to a formulator. The formulator adds additives to the polymer to confer certain properties and produce an end product, such as soft or rigid foam. However, the raw materials producer may also sell advice to the formulator, suggesting certain additives and mixtures for specific performance of the end product. Brominated flame retardants are a common polymer additive, to produce seating foams and rigid plastic components. The raw material producer interviewed clearly states it is not their responsibility to address this use of flame retardants.

Box 10. Actors along the polymer chain and responsibility for BFR issues.

Suppliers in some instances say they are waiting for the producers they supply to demand they take further action. Suppliers feel they cannot take the step to treat a component to less than V0 fire standard, but are waiting for their customer to say in no uncertain terms that there should be no PBDE or BFR in the supplied components. Though it is not required that materials be treated to V0 in many applications, one supplier feels no one wants to be responsible to decide to introduce a component less than this level, or to take a decision not to use BFR.

For instance, one supplier felt additional costs to develop a flame-retardant free component would be enough for their customer to choose another supplier. Thus, the supplier company is trying to prepare for a demand, but will not act until they are ‘told’, because they perceive it is too risky for their cost-squeezed business.

Factors Influencing Testing

None of the interviewed companies have a comprehensive system for checking up on suppliers to see “if they are telling the truth” as one interviewee phrased it. When a prototype is submitted to a producer just prior to product manufacture, a “sign-off” step occurs (as described in Section 2.3.3.3). But this sign off does not actually check whether a substance is or is not in the supplied system. Regardless, it comes at a point in development that interviewees state is too late to make changes.

### 4.4 Limit – the Case Tool

The Limit tool was developed for Volvo Car Corporation. It is introduced and described in Section 3.1.

This Section describes overall findings on Limit from the interviews. Analysis of Limit and suggestions are presented in the next Chapter, in Section 5.6.

Limit is intended as a ‘test’ to improve the phase-out of restricted substances by improving the awareness and knowledge about their use in the vehicle. The idea is that if designers, purchasers and suppliers understand where restricted substances are used and what design solutions require them, they are more able to work to avoid them.

---

68 The FMV SS302 fire testing standard and the V0 test level are explained in Section 2.1.3.1.

69 An interesting finding of the research is that electronics suppliers are not reporting the presence of PBD. TBBPA and ‘other flame retardants’ are declared in supplier reporting forms.
Since its introduction as a pilot phase, use of Limit and subsequently, feedback has basically been non-existent. The impression in the environmental, purchasing and different engineering departments is that Limit is not being used and interview discussions confirmed this. One opinion is that this is not because the purchasers aren’t interested, but because they are busy. Nearly all actors who were asked agreed on the need for such a tool, though many had not heard of it, and needed it described to them before they expressed this opinion.
5. ANALYSIS & DISCUSSION

It is beneficial at this point to revisit the initial research questions: What mechanisms are built into the vehicle design process to reduce restricted substance use? What main factors influence reducing restricted substances in vehicles? And, which factors are important to focus efforts, overcome obstacles and enhance driving forces?

The previous Chapters have described mechanisms that will affect the use of restricted substances. Within an environmental design approach, it is apparent there are two mechanisms organisations are using specifically for reducing restricted substance use in vehicles, namely substance lists and substitution. Chapter four then presented first hand insights on the factors that influence the effectiveness of lists and substitution.

There are strong external influences revealed in the interview, legislation and markets, which are briefly analysed in the first Sections of this Chapter. The analysis then, however, does not continue to examine all influencing factors. In light of what is already discussed in existing literature, the main content of the analysis in this paper focuses on the factors that influence using substance lists and substitution. Thus, the analysis centres on the new information revealed during the research.

5.1 Influence of Legislation

Legislation on a substance is perceived as the one force that can ensure a substance is not included in a vehicle design. This should be effective for new designs, which should not be designed to contain legislated substances. However it has been seen that this still occurs. There are also existing components and systems that contain restricted substances, as raised in interviews.

There is contradiction among interviewees and within interviews regarding legislation. It appears to come from the difference between existing and coming legislation. This is apparent in comments from several persons who did not see the Directives on Restrictions on the use of Certain Hazardous Substances in Electrical and Electronic Equipment or on End of life Vehicles reflected in their current work. Actors appear to be waiting for the implementation of legislation and the allowed phase out period to begin. There is also contradiction on whether substance regulations are an important driver for restricted substances issues or a hindrance to an organisations overall environmental strategy.

5.2 Influence of the Market & the Product Chain

Pressure from customers is obviously a potential driver for environmentally improved products. Hence the absence of customer pressure is a barrier for addressing the use of restricted substances.

The customer holds a powerful position of influence over the vehicle. As shown in Chapter four, companies invest a great deal of effort, time and money to determine exactly what the customer wants. In this way, the customer who demands specific environmental performance could have the ability to bring restricted substance considerations to each part of the producer company. This is currently not happening. It is apparent that arguments and priority will be given to brominated flame retardants, for example, if customers find a way to express that they do not want them in the vehicle. For instance, customer preferences for things like ‘smell’ in the vehicle interior can be determined and even related to how much a deviation in smell will cost in number of customer complaints. If the customer can give restricted substances enough importance, companies will devise a way to directly link phase-out initiatives to market benefits, as they have done for other details of a vehicle.

While power to influence real change lies with the customer, the information lies with the vehicle producers. In between are the suppliers who are glad of predictable (as with slow coming substance
bans) and incremental change, because slow but continuous change keeps business going. As is, this situation is not likely to push beyond incremental change or to provide real impact on the current situation. This can be likened to the situation in other points of the vehicle chain.

For instance, suppliers appear to be waiting for further directions from the vehicle producer who is in turn waiting for the supplier to phase-out a substance. It becomes unclear who is responsible to push this, especially in the absence of customer pressure. The example provided in the interviews is of certain BFRs in electronic components. A producer may ask their supplier to report which BFRs they use, who in turn asks their suppliers about the use of BFRs. Suppliers report the use of a certain flame retardant, and that is the end of it. Thus, the producer is waiting for legislation and the supplier is waiting for the producer. This returns to the question of who is responsible to push?

With polymers, for example, the brominated flame retardants that formulators choose are influenced both by the raw material manufacturer and by the fire testing engineer in the vehicle producer company. Both of these actors make recommendations to the formulator on how to meet fire requirements.

However, manufacturers do not appear to consider working with BFRs as their problem, but more a problem of the formulators. That is, they “leave it up to their customer” to research alternatives. The attitude of the manufacturers is that because they do not actually use the flame retardants that it is “not their problem”, and this is a barrier for cooperation. Again raising the question of whose problem is it? Raw material manufacturers appear to be the ones with the most possibility to affect the fire integrity of their product. Additionally, formulators are not currently tracking or responding to BFR issues, and instead are pressuring the raw material manufacturers to suggest more acceptable flame retardants. But in the end, the formulators may or may not take the advice given by the manufacturer. For reasons of cost or convenience, they may choose additives other than those recommended.

There is also the opinion that the problem belongs to the manufacturer of the flame retardant. But in this case the solution will likely be to develop an alternative. It has been stated that it is in the best interest of the BFR manufacturer to move from alternative to alternative. It is also seen as ‘good for business’. This situation appears to dampen the incentive to provide service solutions in place of chemical solutions along the entire vehicle chain.

If it is everyone’s problem (i.e. each actor in chain who is profiting from selling a product that meets fire and other requirements) then the optimal solution will come from tapping into the expertise of all actors. If each actor waits for the other, this will be a tremendous barrier to change. Unless the current producer of BFR is innovative and realises the business is to improve performance of a material in fire, then there may be no action beyond finding different alternative chemicals.

5.3 Substance Lists - Integrating into Vehicle Design

It is stated that the environment must be treated as any other property and must be considered at the beginning of the design process ‘like any other property’ is. This is not yet happening in most cases. Furthermore, looking into the design process and how it works, there is evidence that many considerations are left out of the beginning of the design process, not only environmental ones. When restricted substances are considered just as any other property, they are subject to the same barriers as the other considerations. With restricted substances, this can be amplified because environmental considerations are new to the process and lack the same arguments, experience and recognition that help to support other properties. This is not to indicate that they should not be integrated and considered with the other properties when choosing designs, but that it is important to recognise that they not only come up against ‘environment-related’ barriers, but also the barriers inherent in the design process. Thus, integration into a sub-optimal process can be an important problem for addressing the use of restricted substances.
Benefits from Environmental Design

“Without altering the product’s function, lifetime or performance” is an example of statements commonly describing the integration of environmental and restricted substance considerations into product development. While a vehicle with fewer restricted substances that no one purchases is not an improvement (Keoleian, 1994), changes in consumer values and behaviour and in the values and attitude of industry are necessary. The author of one study makes an illustrative statement; “the main issue for industry is to be economically profitable, not ecologically efficient, but if consumers demand and are willing to pay for environmentally adapted products, they will be provided” (Åkermark, 1999). Interview findings also reveal this overall resistance to change, despite recognition of the problem. It is this type of industry held attitude and values that will hinder making real changes in how vehicles and other products are impacting the environment.

Many are stating the inadequacy of the current FMVSS302 fire testing method used by vehicle manufacturers world wide. The environmentalists and the fire protection agencies are not content. Vehicle producers cannot please either of these groups within the current options70 and are not satisfied with the existing criteria for testing either. Yet the standard is used, influencing the design of vehicles and thus the use of certain flame retardant chemicals. If current discussion turns to action, a re-evaluation of the test method and the standard itself could change the way designs are evaluated for fire safety and thus address some of the current barriers for reducing the use of brominated flame retardant compounds. Reviewing the standard to determine where fire safety has been unnecessarily required, as well as where it has been inadequately addressed, will be important if this latter point is to be possible.

A Process & Mindset

When selecting materials, designers are very much relying on the way it has always been done and past experience. This can mean choices are made by routine as opposed to thought through decisions regarding the particular function in question. In a process under time and cost pressure, designers can more ‘safely’ choose what they know. In the past, a certain substance fulfilled requirements and performed well, so without understanding how the requirements are changed and why one substance doesn’t fulfil the new requirements, the designer is likely to choose it again. When quality and performance requirements are given more importance, there is less risk involved in choosing a known substance, even if it doesn’t fulfil the environmental requirements. This indicates the obvious need to give restricted substances a profile with designers that corresponds to their priority as a consideration. However, tendency for this behaviour also indicates why substitution is an attractive option when needing to remove one substance from a design. An alternative that can be substituted into place does not need to disrupt the routine.

This behaviour tendency and the existing structure to support substance assessment illustrate the way problems with restricted materials are traditionally approached.

Contradictions

A number of contradictions were raised during interviews. Those encountered rather frequently are described in Box 11. The reasoning for these contradictions appears related to actor’s perceptions versus the reality they experience. A very strong overall impression from the research is that what is described is not in place. This is not surprising, but observing it first hand is very interesting. People in discussions were never defensively stating how things are done. On the contrary, interviewees were open and straight forward, with very few exceptions. Thus, this contradiction does not arise from

70 Companies become frustrated working toward environment and then failing to meet expectations of fire protection agencies (NASFM, personal communication, Aug. 2000).
interviewees saying what they are supposed to say. Instead, there appears to be widespread\textsuperscript{71}, covert consensus that if a procedure is developed and spoken about, it will start to happen. This is very much reflected in the statements ‘it is coming’ and ‘it takes time’ that are reiterated by several actors throughout the course of the research.

Box 11. Contradictory interview results - three examples.

In order to take a new component or system with a restricted material, the decision must be approved very high up in the organisation, and thus, several persons in this organisation stated that it is ‘impossible’ to get a new component containing restricted material into the product. However, these same interviewees told how a component containing a banned substance was recently approved at this top level of the organisation.

While interviewees cite regulations on materials and products as drivers, very few persons say they are working toward them or see them reflected in their activities.

Interviewees also contradict themselves when speaking about trust. For instance, many state suppliers must be trusted, but also that suppliers cannot be trusted.

5.4 Substitution – Integrating into Vehicle Design

Two points are important under the concept of DfE and a LC Approach. First, a vehicle does not pose one environmental threat, but will have a range of environmental impacts across its life. Second, is that the best solution is to address these impacts during the vehicle’s design. These points seem obvious, but they must carry through in an approach to address restricted substance use. Approaches should reflect an understanding that the problem is not a fixed number of substances with negative environmental impacts. The approach should address the problem of a large number of poorly understood substances used in the vehicle.

When using a restricted substance, it is not always clear what stage of the product’s life cycle it will impact. For a company working with product development in a life cycle framework, this could be a driver to address restricted substances in design by designing problem substances out so they do not cause unexpected impacts later in the life cycle of the product.

Research findings indicate that brominated flame retardants are not required in all current applications. Thus, there are economic advantages to first assess whether the flame retardant is needed in a particular application before turning to an alternative.

It is also possible to change the design of a component or system to perform the same function without need for a flame retardant chemical. There are barriers to this type of approach revealed in the findings that may initially make substituting an alternative substance more attractive. For instance, a new design will require a lot of time, cost and testing to assess how it will perform, how it will effect the ability to meet other requirements and it’s environmental impacts.\textsuperscript{72} However, these arguments are also true for seeking an alternative substance. And the payoffs from a new design are arguably better. If a substance is replaced with an alternative, non-restricted substance, it can substitute into the component or system without changes. But in future it may need to be substituted again. If the system is redesigned, the entire component and system are evaluated for their function. This can potentially

\textsuperscript{71} “Widespread”, because this is found in the case study company, in supplier companies and in other producers.

\textsuperscript{72} Changing a design or developing a new solution to remove a restricted substance might impact energy use, natural resource use and risk to humans and the environment, which must be considered. The same holds true for changing substances as well.
result in improved function, combining functions and deleting obsolete or inefficient functions. Also, the number of substances can go down over time through such an approach.

If the tendency is currently to focus on substitution with an alternative substance to address restricted substance use, findings have also shown ‘lack of alternatives’ and poor quality of information on alternatives as barriers to substitution. To improve this situation requires resources to finding alternatives and to provide quality information (for example, on technical performance, environmental impact, and so on). When an alternative is found, it may not be exactly the same, and thus require other alterations to the design solution, or other substance changes. In the end, there is a lot of investment in this alternative substance. Phosphorous based flame retardants are proposed in some studies as alternatives to brominated compounds, yet some of these are compounds just recently listed for EU risk assessment (Section 2.1.4.2). If solutions had been developed around this ‘alternative’, for example, the work to find another alternative would begin again.

It may partly be a mindset that makes substitution of substances a more attractive option than redesign, but also that there is an existing process for this option. If a restricted material is found in product development, there are databases and persons available for information on alternatives. The system is designed to advise an alternative substance that can be used for making the change with minimal time delay to the project.

Traditionally, in many cases, projects for new technology development are undertaken with the aim to improve performance in one system of the vehicle. In new technology development, the lack of environmental considerations either completely or such that they are not in line with those of the main vehicle development project, was identified as an important barrier. It is seen that restricted substances, in an existing component will likely remain there until subsequent development projects are undertaken and even then it is not clear how requirements will be balanced and considered in the next design. If new technology development is not carried out with the same environmental requirements that will be applied at the vehicle development level, then the new technology will not meet these requirements when it is introduced into the project and may incur unintended use of restricted substances in the project. At this point, it will be too late to change.

Teamwork is mentioned in interviews as part of developing, communicating and assessing environmental requirements for the vehicle. Garcia (1999) introduces the way in which information on a product is lost as that product passes through each life cycle stage. This logic can be equated to vehicle requirements to illustrate additional advantages of working in teams to address restricted substance use. Specifications set at the initiation of a project are passed to designers of different systems, purchasing engineers, and then to suppliers and sub-suppliers. As information passes further from those who rationalised it, it risks losing meaning and importance to other actors (Figure 8).
way companies are involving these actors in the initial setting of requirements and in balancing different requirements and design solutions can lessen this effect.

5.5 Substitution and Substance Lists - Phasing out Substances

Substance lists appear to be inadequately addressing the problem of restricted substances in vehicles for a number of reasons.

Certain suppliers have started to demand more information about the producer’s environmental requirements. Not only do they ask the company to clearly state requirements, but also what it is they are meant to achieve. These two can potentially influence the way the supplier works in very different ways. It can be argued that only communicating a list of requirements can be more restrictive to how the supplier can work to fulfil them. This is because restricted substance lists are long and a supplier is left to guess where to focus efforts for the most return. While communicating what it is these requirements are meant to achieve can allow the supplier to optimise their product to achieve the company’s goal in the best way for the supplier.

Perhaps this logic is analogous to the comment from one interviewee regarding legislation, stating policy makers do not know the vehicle industry and thus legislation is made in a way that does not allow companies to find the best way for them. If the company can be seen as ‘legislator’ to their suppliers, putting requirements a way that is not too restrictive, liberates creativity\(^73\) and allows a holistic approach to issues that are most pressing in the supplier company may be ideal.

The broadness and lack of aim of restricted substance requirements may reflect that the producer does not know where to focus, and are themselves guessing. If the producer is very specific about requirements, a supplier may focus all efforts to meet them and all actors risk going down the same path. Leaving requirements more vague, the intent may be that suppliers take initiative which the producer can stand to gain from. However, if this is part of their intent, producers are not communicating it and suppliers are standing still waiting for direction, in certain cases.

A potential driver for producers to clarify the aim of substance lists is the evolution of knowledge on chemical substances and raising of company standards. Existing and proposed substance restrictions use phrasing similar to this example from Danish Order no. 540, which states one ‘hazardous’ substance cannot be used if an alternative substance that is less hazardous, non-hazardous or less irritant exists. These criteria are hard to define and hard to work with and the substances that meet such criteria will continually change with scientific knowledge and societal acceptance. As risk assessments are completed, new substances will be added to the priority substances lists of governments and companies. Also, as certain goals are achieved, companies will raise the bar of environmental performance, possibly targeting other substances for phase-out of their products. Encouraging suppliers to adopt an approach in their product development to deal with their use of restricted substances might keep them ahead of these changes and could decrease resources required from the producer to keep suppliers coming along.

The IMDS is anticipated to improve supplier’s understanding about what their customer is doing and assist them to report the right things. However, this doesn’t give the supplier information on why, or on how important one substance is over another, or on what to do next once they have reported the ‘right things’. The question of where to focus efforts and who should initiate them remains.

\(^73\) This is adapted from Geiser (2000), who states materials policy should “not be too restrictive but should liberate creativity” and applied by the author of this paper, to an approach for a producer to communicate restricted substance requirements and aims to suppliers.
Often, the information a vehicle producer has from suppliers tells only what substances are not in the system. In this way, the producer has little awareness about what substances their supplier is choosing as an alternative to a restricted substance. Suppliers are reluctant to disclose detailed product information and even if they did, the producer does not want to be working to evaluate the alternative substances their supplier is choosing to use. This situation supports another way of putting requirements to suppliers. If the producer asks suppliers to incorporate environmental considerations into the product development, it may promote decreasing the number of substances used. Requirements can be formulated to ask suppliers to eliminate restricted substances by looking to solutions that meet the same function in another way as opposed to simply choosing an alternative substance. In this way, the company does not spend resources to track the supplier deviation and work with them to phase-out a substance, and they may avoid having to do the same thing with the replacement substance in the near future.

This approach is supported by findings on new technology development processes. Actors conveyed the importance for environmental goals in the development of a new technology to be aligned with vehicle development goals. This means more planning and discussion at the planning stage of a new technology than has been traditionally the case. A supplier delivering a component or system to the vehicle is in some ways analogous to introducing a new technology. Thus, asking suppliers to work with design-for-environment initiatives follows the same logic that implements such initiatives in new technology development.

If a restricted brominated flame retardant is present in a component, a deviation will be allowed for a specified time (e.g. 3 months). However it may take much longer to develop and implement a solution while the supplier works toward (or is involved in working toward) a technological solution. If the producer demands his supplier work with environment in design, chances are better that when this new technology solution comes, it is not only free from brominated flame retardant, but still meets or goes beyond other company requirements.

On the other hand, are suppliers who want to know the company’s specific requirements, and no more. They are defensive about their customer company pushing environmental demands on them that go any farther than this. Another barrier to such an approach, revealed in the interviews, is the difficulty of communicating a ‘vision’ versus specific restricted substance requirements.

A producer’s ability to communicate their vision and the importance of their requirements also becomes important when speaking about risk sharing with suppliers. This is an approach raised in the findings intended to bring suppliers more incentive to follow vehicle requirements, from start to finish of a project. Risk sharing connects components purchased to the number of cars the producer sells. If the vision and reasoning behind restricted substance requirements is not successful, risk sharing could have a reverse effect. Involving suppliers might lead to a lowering of the environmental demands, as suppliers voice the barriers they will have to overcome to meet these requirements and the related costs to the project.

The importance of putting environmental considerations early in the design of a vehicle is mentioned in nearly all the current work and in these research findings. But there is little mention in the literature of communicating problems that occur in later stages of development back to the early stages of the subsequent design projects. A restricted substance found too late in development to solve is documented, often without further follow up. There is currently no consistent course to relay this information back to the beginning of the design process and thus no course by which lessons can be taken from which requirements have and have not been fulfilled (Figure 9). This might be a potentially important way to build the experience and supporting arguments for environmental considerations identified as lacking.
Further, the findings illustrate that an even an established process for feedback does not itself ensure effective communication. In product development where communication breaks down, other support for restricted substance issues become that much more important. Simply ‘putting them in’ to the existing process may work, but incorporating environmental concerns into product development can present opportunity to improve existing communication lines.

The growing efforts to collect information on components and their composition will potentially improve this feedback. If this information is gathered too late to make changes in the current project, it is still available for the start of the next project, and the problem can then be addressed. It may also in future decrease the time it takes in the beginning of a project to determine if a component contains a restricted material. To gather this information requires sending supplier requests, collecting, documenting and communicating the results and will have to keep pace with the speed at which new components (especially electronics) are introduced to the vehicle’s development.

Though new tools and mechanisms are developed, many companies have described a process in place intended to address restricted substances. There does not seem to be effective feedback needed to focus on making the exiting process operate well. Though the routing for this communication is described, there is confusion about different roles and it is not actually happening. Most specifically, suppliers are reporting deviations on restricted substances to the purchasing division. These deviations do not appear to be communicated to designers or to those who initially set the requirements. Currently this may be happening for the initial detailed design, but so many changes are made before the component is finalised that restricted substance requirements can fall off in these final stages. Thus, feedback is not received on the actual component or system chosen.

“If people are aware of a problem, they will try to solve it” and “no one wants to be the person with mercury in their system.” This does not also seem to be the case in the purchasing departments; probably not due to lack of concern as much as lack of awareness or feeling that this is important in their working routines. More so, persons in purchasing departments felt environment is not integrated and is not adequately addressed in their work. The overall impression is that purchasing systems in place are not working yet and as the company tends to outsource full vehicle systems and design of systems, this role will become more and more important.
5.6 Case Tool - Limit

Though an in depth analysis of Limit is not appropriate here given the lack of information available on the tool directly, the interview findings provide a basis for more broad analysis and suggestions.

There are factors to be aware of when launching Limit to designers and purchasing technicians. DfE is still in its infancy and emerging, so Limit is being introduced into a way of working that is still developing. This can be a limitation. It can be also an opportunity, as introducing a new tool at this time can improve that it becomes incorporated as part of the ‘routine’ along with other tools, in time it will be a natural consideration.

- Limit is meant to enable design and purchasing engineers to make intelligent questions to suppliers about material content. Thus, it should focus on preventing design solutions that rely on restricted substances and their alternatives. The information columns in the booklet that identify each component and restricted substances expected in that component could include a column of ‘questions’ for redesign – to ensure dialogue aims at the level of design and not only at the level of substance alternatives.

- As findings indicate, it will be important to improve participation of the purchasing function74. Issues may be relying heavily on whether they push issues with suppliers and feedback unsolved problems to the environmental division to bring to the table in setting requirements for the next project.

- Limit can be explored and potentially adapted to help purchasers not only to initiate discussion with suppliers, but to provide them feedback on their performance.

- There may be potential for Limit to compliment existing tools to improve the use of the restricted substance lists. For example, in Volvo Car a Quality Assurance Document File is already in use by purchasers. It provides guidance and a checklist for purchasing technicians to ensure quality in the products and processes of suppliers. Though this document has not been within the scope of this research, it may be worthwhile to assess whether Limit could be integrated with this existing tool and still accomplish its goals.

- It will also be important that Limit is updateable. A lot of work can be required to keep up with substances and arguably it makes more sense to compliment the tool with a way of thinking that will accomplish the goal of restricted substance lists in another way (i.e. will address the problem of too many poorly understood substances and mixes). One person referred specifically to the time required to keep such a tool updated at the rate of changing information and feels it may thus be unrealistic to ask designers to use such a tool (i.e. new component designs, new declarations from suppliers).

74 Currently focus of environmental work may be on implementation of an ISO certified EMS. Thus, restricted materials cannot simply be ‘added’ to this job.
6. CONCLUDING REMARKS & SUGGESTIONS

Chemical substances are effective solutions to many design constraints. But they also cause unwanted impacts and these are increasing. In light of this, the vehicle industry has begun to remove certain hazardous chemical substances and materials from their products. They are responding to legislation, information from authorities and are also taking their own initiatives. However, this research concludes that the restricted brominated flame retardants and those banned by legislation are not yet out of vehicles. In part, this is because the industry does not feel that suitable alternative solutions exist for all applications in vehicles and components. Also, it is partly because vehicle producers and suppliers of components, such as electronics and textiles, do not know all cases where BFRs are used. Likewise, they are not aware of which BFRs are used. The situation is similarly unclear for many other restricted substances.

More information is becoming available and more substance restrictions are expected. The work that the industry still has to do should account for this and should ultimately focus on reducing the number of substances in use.

**Restricted substance lists** are presently the main mechanism to address the issue of restricted substance use in vehicles. **Substitution** of one substance with another is the prevailing strategy in the industry. This means actors in vehicle design look for substitutes instead of taking a step back to consider the necessity of a substance or the possibility of a different design.

There is current focus and effort to develop tools to integrate environmental considerations into design. Many factors hinder integrating restricted substance considerations into vehicle design decisions (Section 6.1). But it is key to recognise that integration into a process that is geared to time and cost pressures may still not adequately address restricted substance use.

Two points are proposed to begin to improve this situation. First, actors should not default to substitution. The approach should take real consideration of intended function and necessity of function of a substance. For instance, the acceptance of flame retardant chemicals in the past has built in certain designs. Changes to these designs could eliminate the need for flame retardant.

The second point is to allow the integration of restricted substance considerations to bring changes to the design process and to the product. Performance, business and environmental improvements will result, and this research provides examples of this.

These two aspects will also have to be extended outside the organisation in interactions with suppliers.

Detailed discussion of these conclusions focuses on the importance for organisations to emphasise organisational aspects of vehicle design and development. This is not meant to take away from the idea that technical aspects (i.e. tools such as a list of alternative substances) are important for an organisation to operationally integrate restricted substance considerations into vehicle development. Such technical aspects might include databases of product contents or alternative substances, support to balance trade-offs in design decisions, help to understand substance lists, design guides and perhaps a toxicity index if LCAs are to more accurately value restricted substance use in vehicles.

Organisations are increasingly developing these types of technical aspects or, tools. The important point is that these efforts and the resulting tools can leave actors with the impression that the tools alone are the solution. For instance, lists are seen as a tool to substitute one substance with another, instead of a tool to remove restricted substances from the vehicle (which may or may not be achieved by substitution). Thus, it is important to distinguish between the aim and the tools to support reaching that aim.
6.1 Concluding Remarks

Despite the voluntary nature of much of the existing processes, legislation on a substance is perceived as the only existing factor that can ensure it is consistently given a profile in vehicle design decisions. Market pressure could match and even exceed this influence, as it does with many other vehicle design considerations, but this pressure for restricted substances and brominated flame retardants is currently inadequate.

Improving the consideration of restricted substances in vehicle design can **improve the design process itself**. However, this will not be realised if environmental considerations are included with the intent of minimal disruption and change.

For instances, integrating environmental targets into new technology development processes may not only lead to environmental improvements, but can improve the planning and discussion of the project. This brings new technology development projects more inline with vehicle development. Requiring **suppliers to integrate environmental considerations into their design processes** could have potentially the same effect and bring supplied components more in line with vehicle development.

Producers are sending restricted substance lists to suppliers and putting resources into collecting responses. But this is not reducing restricted substances in the vehicle. In fact, it may leave suppliers expecting more direction and follow up on their response and give them an excuse to wait. On the side of the producer, just mailing a list to suppliers may fail to realise improvements in overall supplier communication. Thus, the **list should initiate dialogue and two-way communication** - the type of relationship that is of increasing **strategic importance**.

Designers and suppliers need to understand the **aim of restricted substance lists** and thus, the real problem. The problem is not a fixed number of substances with negative impacts, but is a large number of poorly understood substances used in the vehicle. The problem can then be approached with a new way of thinking.

Beyond communication and behavioural changes, new thinking will also require examination of existing **structural constraints**. For brominated flame retardants, these include the FMV SS302 fire testing methods and the mindset that make flame retardant chemicals an established element in design solutions. Neither the method or the mindset are optimal. Together they allow only incremental changes rather than improvements toward reducing the use of restricted brominated flame retardants.

There is current focus and effort surrounding the development of new tools to ‘integrate’ environmental considerations into design processes. The process for integration is developing and seems to be on a track that will continue to improve with time. However, the term ‘integration’ might be misleading. Tools and processes for integration will fail if those involved do not recognise that their intent is to **change the current way of working**.

6.2 Suggestions

Designers should **step back** and consider the function that is really desired from the substance, the designed system and from that system within the vehicle. This should be done before a substitute is considered. **Look for bad design** that was done because flame retardants were available and acceptable (Figure 10). For instance running wires across the heater is the best solution, but is only possible because a flame retardant can be added. It is likely the same opportunities apply for uses of other restricted substances.

This does not imply such an approach is appropriate in all cases, but it should be the first consideration. Designers can use this thinking to approach day-to-day problems, balancing between
properties and in discussions. Perhaps it is here where new concepts and ideas are generated and can prepare the organisation for bigger changes to come in the vehicle industry.

The organisation should not limit themselves to the current designs because they may inherently be the root of the problem. A framework of cooperation, feedback and a clearly communicated problem supports this.

![Diagram](image)

Figure 10. Identifying designs made possible by the acceptability and availability of brominated flame retardants.

New design considerations should be ‘allowed’ into the existing vehicle development in a similar way that a ‘process’ for substitution has become recognised.

Focus should be on informal and intuitive elements of product design. These are as much a part of product design decisions as the formal and technical elements of the process. Recognising this during the development and use of environmental tools seems to be overlooked and will be essential to the success of any changes.

Vehicle producers should focus on cooperation with suppliers. Actors in the product chain are all uncertain - they can cooperate to avoid counteracting efforts and to reduce the risks associated with change. Cooperation should improve the overall performance of the product. It should improve the lines of communication between producer and supplier regarding all vehicle requirements, not only environmental ones. Cooperation should address a restricted substance so that the same problem does not need to be addressed again in future.

If the vehicle producers aims to reduce the use of substances overall, communicating this aim can pressure suppliers to test the substances they produce and use and to clearly communicate this information. This aim provides incentives for suppliers to be less secretive about their products.

Vehicle producers can require suppliers to address restricted substance use in early stages of product design, in order to decrease their use of substances overall.

Producers should develop supplier requirements in the way they would like legislation to be developed for them. Thus, requirements are not restrictive but allow a systems approach to environmental issues by the supplier.

Ideally, a designer-supplier relationship should be two-way. That is, the producer does not only hand down requirements, but the supplier tells how they want these requirements structured. Suppliers can be involved in the development of requirements.

Substitution or redesign are often not possible. Feedback of the problems encountered in the project must go to the stage at which requirements are set and components are chosen. It should tell purchasers, suppliers, designers and the person in the environmental department responsible for the project which requirements the design did not meet. In this way, environmental requirements can be improved and recurring problems can be identified.
External to the vehicle producer, authorities also look for opportunities to influence the issue. Incentives for reducing brominated flame retardants can focus on raw material manufacturers and vehicle producers. This has the potential to effect response because the name of the raw material manufacturer is on the polymer that goes into the vehicle and the vehicle bears the name of the producer.

Vehicle producers, fire protection agencies, producers of polymers and electronics, product designers and fire safety testers have potential to cooperate for a fire testing method that enables synergies between vehicle performance, fire safety and environmental protection. They should all be involved in any re-evaluation of the FMVSS302 or vehicle fire testing methods.
Bibliography


ENDS Environment Daily. 2000b. E.U. should not restrict flame retardant. 29/05/00. www.endsdaily.com


Finkbeiner, M. et. al. 2000. Life cycle assessment as a tool for design for environment. DaimlerChrysler AG. Society of Automotive Engineers. USA.


Appendix I – Interviews


Appendix II – Life cycle assessment

When choosing tools to implement a product focused strategy, an organisation may choose LCA as one of many operational tools.

The International Organisation for Standardisation (ISO) specifically defines LCA in the 14000 series of standards. The LCA tool measures the impact a product will have on the environment through its life. Specifically, an LCA begins with an inventory of all energy and material flows associated with the product or product system under assessment. The impacts of these flows are aggregated and valuated in some way, to indicate the total impact of the studied system (ISO, 2000). The results can be used for a wide range of applications and thus, the LCA itself will have a different scope and data requirements depending on this use. To address environmental criteria in product development, LCA is used to examine and support decisions (Young and Russell, 2000). It can provide a profile of the environmental impact from each product, or different systems and components, which may help designers to focus when trying to minimise the life cycle impacts of the product.

Results of a complex LCA conducted on a whole product can be used to identify ‘hot spots’ of environmental impact, possible spots to focus actions for improvement. A less complex LCA may be used to generate results for comparing one solution to another, and thus support decision making. For instances, a vehicle producer may use results from such an LCA to compare a new concept for an upcoming vehicle with a concept used in a current vehicle.

Currently, the results from an LCA do not show a pay off for reducing the use of restricted substances in product design, the way they do for changes in energy or material use. This is because LCA conducted according to the ISO standard must be based on quantitative data and a globally accepted environmental impact category. Such a category is not currently agreed for restricted substances. This is directly linked to the lack of risk assessment data described previously in Section 2.1.1. Thus, LCA as a tool currently does not support reducing restricted substance use in the products, and is not included in further discussion in this research.
Appendix III – Example Restricted Substance List

A company develops or adopts a restricted substance list for several reasons, and these reasons are usually reflected in the substances that appear on the list. Given these different reasons, it is common practice for a company to develop two lists - one for substances that are not to be in the product and a second list for substances that are a rising concern, and should be reduced and removed when feasible. These lists will often include levels at which a certain substance can be present, as well as certain applications where exceptions are made.

Presented here is illustrative information adapted from the 'black' and 'grey' lists, developed by Volvo Corporation restricting the use of certain substances. The lists are currently adopted as a company standard in Volvo Car Corporation, Volvo Bus Company and Volvo Truck Company.

Example:

Chemical Substances Which Must Not Be Used Within The Volvo Group

VOLVO Corporate Standard STD 10091 (Volvo’s Black List)

“Scope and field of application – According to a decision by the Volvo Group’s Environmental Council, restrictions have been introduced with respect to the use of certain chemical substances. This standard lists those chemical substances, which must not be used in Volvo’s production processes, nor must the be included in Volvo’s products in unreacted form. The Volvo Group’s Environmental Council initiates the updating of the standard.

“New products containing one or more of the chemical substances listed in this standard must not be put into use. Phase-out plans with final date of use are required for those listed chemicals substances, which have not been fully phased out.

“The prohibition refers to each deliberate use of the chemical substances specified in the standard. However, the prohibition does not apply in those cases a chemical substance occurs in the form of impurities in a specific product, that is, non-desired occurrence in very low concentrations, or when it is handled in small quantities by trained staff at laboratories.

“Exceptions may also be made for chemical substances used in processes controlled by legal requirements or safety regulations where it is not possible for Volvo exclusively to prohibit the use of the substance in question. In situations where exceptions have to be made, special precautionary measures shall be taken to prevent injurious effects on humans or the environment. Any exceptions shall be decided upon by the respective Volvo company.”
Table of Substances Restricted on Volvo’s ‘Black List’, Corporate Standard.

<table>
<thead>
<tr>
<th>Group</th>
<th>Substance name</th>
<th>Example of type or area of use</th>
<th>Risk*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amines</td>
<td>Phenyl-β-naphthylamine</td>
<td>Antioxidant</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Methylenedianiline</td>
<td>Hardener in paints</td>
<td>C</td>
</tr>
<tr>
<td>CFC Compounds</td>
<td>CFC 11</td>
<td>Cooling agent, freon</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>CFC 113</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>CFC 114</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>CFC 115</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>CFC 12</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>Fibres</td>
<td>Asbestos</td>
<td>Insulating material</td>
<td>C</td>
</tr>
<tr>
<td>Flame retardants</td>
<td>Polybrominated biphenyls</td>
<td>Textiles, plastics</td>
<td>E, N, C</td>
</tr>
<tr>
<td></td>
<td>Polybrominated diphenyl ethers</td>
<td>Textiles, plastics</td>
<td>E</td>
</tr>
<tr>
<td>Rubber Chemicals</td>
<td>Aminobiphenyl + salts</td>
<td>Dye</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Benzidine (+ salts)</td>
<td>Dye</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Thiocarbamide</td>
<td>Rubbers and plastics</td>
<td>A, C</td>
</tr>
<tr>
<td>Halons</td>
<td>Halon 1211</td>
<td>Fire retardant</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Halon 1301</td>
<td>Fire retardant</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Halon 2402</td>
<td>Fire retardant</td>
<td>O</td>
</tr>
<tr>
<td>Chlorinated hydrocarbons</td>
<td>HCFCB</td>
<td>Blowing agent, solvent</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>PCB</td>
<td>Insulators, oils</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Hexachlorobutadiene</td>
<td>Solvent</td>
<td>E, T</td>
</tr>
<tr>
<td></td>
<td>Carbon tetrachloride</td>
<td>Solvent</td>
<td>O, C, T</td>
</tr>
<tr>
<td></td>
<td>Methylene chloride</td>
<td>Solvent, in fuel</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>1,1,1-Trichloroethane</td>
<td>Solvent</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Tetrachloroethylene</td>
<td>Solvent</td>
<td>C</td>
</tr>
<tr>
<td>Metals</td>
<td>Lead chromate</td>
<td>Pigment</td>
<td>C, A, E, N</td>
</tr>
<tr>
<td></td>
<td>Cadmium + Cd compounds</td>
<td>Pigment</td>
<td>C, E</td>
</tr>
<tr>
<td></td>
<td>Mercury + Hg compounds</td>
<td>Electric equipment</td>
<td>N, E</td>
</tr>
<tr>
<td>Lubricants</td>
<td>Chlorinated paraffins</td>
<td>Oils, fire retardants</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Mineral oil with PAHs</td>
<td>Base oils, lubricants</td>
<td>C</td>
</tr>
<tr>
<td>Surface-active agents</td>
<td>4-Nonylphenol</td>
<td>Used as ethoxylates</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Nonylphenoletheroxylates</td>
<td>Cleaning agent</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Octylphenol</td>
<td>Used as ethoxylates</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Octylphenoletheroxylates</td>
<td>Cleaning agent</td>
<td>E</td>
</tr>
<tr>
<td>Solvents</td>
<td>Benzene</td>
<td>Solvent</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>2-Ethoxyethanol</td>
<td>Solvent</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>2-Ethoxyethanol acetate</td>
<td>Solvent</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>2-Methoxyethanol</td>
<td>Solvent</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>2-Methoxyethanol acetate</td>
<td>Solvent</td>
<td>R</td>
</tr>
</tbody>
</table>

*) A = Allergy; C = Cancer; T = Toxic, E = Environmentally hazardous; N = Neurotoxic; O = Ozone depletion; R = Reproductive hazards.

The table is adapted from the table that appears in the Volvo ‘Black list’ - Substances which must not be used, Volvo Corporate Standard. The actual list of substances in the standard also contains a column for the Chemical Abstract Number (CAS no.) for each substance AND footnoted exceptions. The flame retardant chemicals are highlighted for emphasis here.
Vehicle producers are recognising the need to reduce the hazardous substances and materials used in vehicles. To do this, some focus on early decision-making in the vehicle design process. This research investigates the vehicle design chain to reveal how restricted substances, specifically brominated flame retardants, are being addressed and what main factors influence this.

Results show that restricted brominated flame retardants are still used vehicles, and the situation is similar for many other restricted substances. The thesis examines the use of restricted substance lists and the method of substitution, as the most common mechanisms to address the issue. Discussion focuses on how using lists and substitution will integrate restricted substance considerations into vehicle design decisions and on how effectively they reduce restricted substance use.

Conclusions are based on information gathered from interviews with a range of actors in the industry and in the field. Volvo Car Corporation served as case study and the Swedish Chemicals Inspectorate provided full financial support.