An Assessment of the Potential for Waste Minimisation in Small and Medium Enterprises in the South African Metal Finishing Industry

By

Claire H. Jänisch

Thesis submitted for the degree of Master of Science in Engineering

Department of Chemical Engineering
University of Cape Town
Rondebosch
7700
South Africa

12 June 2000

Acknowledgements

I wish to thank a number of people who have contributed either directly or indirectly to this project:

Bas Kothuis for inviting me to join the Industrial Symbiosis Project and for his valuable supervision, input and help throughout.

All the members of Industrial Symbiosis Project team, especially Dick van Beers, Eckart Naumann and Daphne Hartney for their support and contributions to the project.

Dr. Harro von Blottnitz for his input, advice, editing, and comments, especially in the final stages when he had very little time available.

All the members and staff at the Department of Chemical Engineering for their friendly support, but especially the 'Greenhouse' members, and Helen Divey and Shireen Mjacu of the Main Laboratory for their efforts in analysing uncountable numbers of samples.

The managers and employees of the case study companies for their time, interest and enthusiasm.

Walter Barnett of the Hot Dip Galvanizers Association South Africa for his valuable knowledge and help, as well as the many other people, companies and organisations that contributed in gathering data for the Metal Finishing Industry Survey.

All the people and organisations with whom I met on the European Study Tour.

The Canadian Industrial Development Research Council for funding the Industrial Symbiosis Project.

The financial support of the National Research Foundation is also gratefully acknowledged.

Synopsis

The metal finishing industry has previously been found to be one of the most polluting industries of the manufacturing sector in South Africa.

South African environmental legislation has recently (1998) been updated. The National Waste Management Strategy (NWMS), has clearly identified waste minimisation as an important part of future programs aimed at making waste handling practices in South Africa more sustainable. The waste minimisation approach has been applied in several countries in various industry sectors, including the metal finishing industry.

The research presented in this thesis focuses on the identification and assessment of opportunities for waste minimisation within small and medium enterprises (SMEs) in the metal finishing industry. The potential for waste minimisation in the metal finishing industry in South Africa is assessed, based on the results of waste minimisation assessments carried out in two case studies as well as a comparison with the situation in other countries.

It was found that there has been significant potential for waste minimisation in the metal finishing industry in other countries, and it has been exploited cost-effectively in order to meet regulations or reduce treatment and disposal costs.

For a better understanding of the problems faced by the local case study companies, the current state of waste management in the industry in South Africa was reviewed and a survey of the size and nature of the sector was undertaken. It was found that outdated equipment, poor maintenance, poor worker skill and poor housekeeping practices lead to increased water consumption and the generation of unnecessary waste. In addition, few metal finishing firms in South Africa actively practice effective on-site effluent management, and where it exists, it is usually not well organised, operated or maintained in relation to compliance with existing by-law quality standards.

The similarities and differences between the local metal finishing industry and that in other countries where waste minimisation has been applied successfully, were also examined. The South African metal finishing industry was found to be similar to the metal finishing industry in these other countries in terms of size, structure, and processes employed. But, the waste management style typical of the industry in South Africa is significantly behind that of other countries, mainly due to the lack of effective enforcement of environmental legislation.

Despite this, some of the waste minimisation options applied in other countries to address well-known problems in this industrial sector, have been applied in the case study companies. Most of these are in the areas of simple housekeeping and process efficiency improvements resulting in reduction of waste volumes, hazardous nature, or both, as well

as attractive savings for the owners for minimum capital input. The economic feasibility of options requiring substantial capital investment was found to depend significantly on which waste management costs are currently not internalised at the companies. If the companies were made to treat their effluents and carry the costs (internalise the waste treatment costs), then the technology investments would look a lot more attractive. Future more stringent regulations, and higher water prices are therefore expected to improve the cost-effectiveness of such options. Without this, the potential for cost-effective options could be limited to low-cost or non-technology options.

However, experiences in the case-study companies indicate that there is much room for innovative solutions that allow for cost-effective exploitation of even technology options within SMEs, especially where there is interest within the company, supported by external assistance from key players in the industry.

The result is that potential for cost-effective waste minimisation was found, not only in the two case studies in the powder coating and hot-dip galvanising sub-sectors, but also in the electroplating sub-sector. These companies were also found to be representative of the South African metal finishing industry in terms of size, processes employed, key characteristics, waste management style, and barriers and incentives to environmental improvement.

Based on the results of the case studies as well as a comparison with the situation in other countries, it is concluded that there is potential for cost-effective waste minimisation in SMEs in the South African metal finishing industry. However, it is noted that the exploitation of this significant potential requires a clear understanding of the barriers and incentives for waste minimisation, and of the influencing roles that each of a number of key stakeholders in the industry has to play in this regard.

Table of Contents

CHAPTER 1: INTRODUCTION 1-1

CHAPTER 2: METAL FINISHING WASTES AND WASTE MINIMISATION OPTIONS 2-1

CHAPTER 4: THE SOUTH AFRICAN SITUATION 4-1

CHAPTER 5: CASE STUDY 1 – A POWDER COATING FACILITY 5-1

REFERENCES

APPENDICES

List of Figures

List of Figures

List of Tables

Glossary of Acronyms

Acronym	*Description*
AESF	American Electroplaters and Surface Finishers Association
BATNEEC	Best Available Technology Not Encurring Excessive Cost
CP	Cleaner Production
CWT	Centralised Waste Treatment
DEAT	Department of Environmental Affairs and Tourism
DTI	Department of Trade and Industry
DWAF	Department of Water Affairs and Forestry
EMS	Environmental Management System
EPA	Environmental Protection Agency
EU	European Union
GA	Galvanizers Association (UK)
GDP	Gross Domestic Product
HDGSA	Hot Dip Galvanizers Association South Africa
HMIP	Her Majesty's Inspectorate of pollution (UK)
ICPIC	International Cleaner Production Information Clearinghouse
IDRC	Industrial Development Research Council (Canada)
IPC	Integrated Pollution Control
IPPC	Integrated Pollution Prevention and Control
LCA	Life Cycle Assessment
MFI	metal finishing industry
NATSURV	National Industrial Water and Waste-Water Survey
NEWMOA	Northeast Waste Management Officials' Association (USA)
NGO	Non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
OTA	Office of Technology Assessment (USA)
ppm	parts per million (mg/L)
PRG	Pollution Research Group
RCRA	Resource Conservation and Recovery Act (USA)
SDV	Stichting Doelmatig Verzinken (galvanisers association in the Netherlands)
SEA	Surface Engineering Association (UK)
SME	Small and medium size enterprises
TRI	Toxic Release Inventory (USA)
WRC	Water Research Commission
UN	United Nations
UNEP	United Nations Environmental Program
UNEP WG	United Nations Environmental Program Working Group
WM	Waste minimisation
WMA	Waste minimisation assessment
WWT	Waste water treatment
yr	Year

Chapter 1: Introduction

'Metal finishing operations present some of the best and most classic applications of pollution prevention approaches' - U.S. EPA, 1996

1.1 BACKGROUND

The metal finishing industry has been identified as one of the most polluting industries of the manufacturing sector in South Africa. Although the contribution of the metal finishing sector to total waste in South Africa is not large (expressed in waste quantity per unit of GDP), more than 80% of the waste generated is hazardous (EMG, 1993). Not only does that in itself demand changes in environmental performance, but it is also highly likely that this particular industry will be subject to increasingly stringent monitoring by the authorities.

As regulations become tighter, and as the costs of waste treatment and disposal increase, the industry will have much to gain from adopting waste minimisation practices as a means to reduce waste and therefore the costs associated with the waste. The waste minimisation approach has been applied in several countries in various industry sectors, including the metal finishing industry, and in all cases has proven to be successful, in highly developed countries (Netherlands, U.S.A., U.K., Austria) as well as in countries in economic transition (South East Asia, African countries such as Egypt, Tunisia, Zimbabwe, Tanzania) (van der Meer, 1998).

The majority of metal finishing companies in South Africa are small and medium enterprises (SMEs) (EMG, 1993). There is a national development program in South Africa, supported by Department of Water Affairs and Forestry (DWAF), Department of Environmental Affairs and Tourism (DEAT), and the Department of Trade and Industry (DTI), to promote and support the establishment of SMEs in South Africa. SMEs form 41% of all South African enterprises and provide 35% of all jobs (DTI, 1998). They are therefore a vitally important part of the South African economy. However, international experience has indicated that there is a pivotal role played by SMEs in waste generation and their apparent inability to take on-board responsibility for waste management (EMG, 1993). Though the individual contribution of each SME to environmental degradation may be small, as an industrial collective, their impact is significant.

The high toxicity of many of the metal finishing industry's input material, and low degradability, necessitate the adoption of improvement options to 'clean up' the industry. It has been identified that stringent control through excessive penalties and restrictive practices may not be appropriate in encouraging the responsible handling of the wastes generated by industry (Cowan, 1998). Additional concerns as to the threat of more stringent limits to the economic viability of small scale operations and the possible consequent loss of employment opportunities counter the efforts of local authorities to enforce improved environmental responsibility. This points to a need for initiatives which intend to help increase environmental performance and help preserve a self-regulatory mode of operation. "An integrated approach to waste control through waste minimisation and on-site pre-treatment is believed to offer a mutually acceptable and effective mechanism for managing and controlling metal wastes whilst optimising resource utilisation and relationship between industry and control authorities" (Ibid.).

A process of drafting and enactment of environmental policies and regulating laws is taking place at national level. The potential for waste minimisation to improve the environmental performance of industry in South Africa is being addressed and several initiatives in this regard have been promulgated. The new National Waste Management Strategy for South Africa (1998), has clearly identified waste minimisation as an important part of future programs aimed at making waste handling practices in South Africa more sustainable.

The research presented in this thesis focuses on the identification and assessment of opportunities for waste minimisation within SMEs in the metal finishing industry in South Africa. Waste Minimisation Assessments (WMA) carried out at two metal finishing companies in South Africa are presented as case studies. Through these case studies, the thesis aims to demonstrate the advantage of waste minimisation as a proactive environmental management tool in SMEs in the metal finishing industry. For a better understanding of the problems faced by the case study companies, the current state in awareness and adoption of waste minimisation in the metal finishing industry in South Africa is discussed. The similarities between the local metal finishing industry and that in other countries where waste minimisation has been applied successfully are examined. The potential for waste minimisation in the metal finishing industry in South Africa is therefore assessed, based on the results of the case studies as well as a comparison with the situation in other countries.

1.1.1 Context in which the research was carried out

The research for this masters project forms part of the larger Industrial Symbiosis Project, currently undertaken by the University of Cape Town's Department of Chemical Engineering, titled: "An Industrial Symbiosis View of SMEs: Targeting Greater Eco-Efficiency Through Innovative Business Practice." The larger project commenced in February 1997 and will run for 3.5 years. It is concerned with optimising the economic and environmental performance, or "eco-efficiency," of South African SMEs, and is based on the existence of operational networks to which individual firms belong. It examines the SME sector by way of analysis of two critical sub-sectors, textiles and metal finishing, which have been shown in previous work to be two of the most polluting sectors of the South African economy (Kothuis and Petrie, 1997).

The symbiosis project looks at how companies function within their network and how this influences the overall economic performance of these networks. Analysis of the mass, energy, financial resources and information flows between companies and their networks, intends to demonstrate the potential for improvement in environmental and economic efficiency by cooperation between the company and its network partners. The project is set up around 10 companies within the textile and metal finishing industry sectors. For each of the companies, a waste minimisation assessment is required, followed by analysis of the networks.

1.2 PROBLEM STATEMENT

There is considerable information available on the environmental performance, waste minimisation opportunities and cleaner technologies for the metal finishing industry sector, from various international sources (Petrie, 1994). In Europe and the USA, waste minimisation in the metal finishing industry has been well promoted and there are many documented case studies where benefits have been gained. The acceptance of waste minimisation as a business consideration in these parts of the world is principally due to the very strict discharge limits and environmental regulations that businesses operate under (UNEP WG, 1998).

For South Africa, exposure to Cleaner Production has been very low to date, however, in the coming years, it is expected that the trends which are in evidence overseas will become a business reality here too. South Africa has an opportunity to learn from the mistakes and successes of developed countries regarding pollution and waste. The country is in an ideal position to incorporate foreign initiatives, together with its own ideas (EMG, 1998).

This thesis attempts to assess whether the waste minimisation techniques that have been used with success in other countries may be applicable to the South African metal finishing industry and/or if there may be other waste minimisation possibilities. The research goes beyond this to investigate the key influencing factors in the industries in different countries, which may have an influence on the adoption of waste minimisation in the industry. For potential to exist, one needs to determine whether the barriers can be overcome, and/or if sufficient incentives exist as drivers for waste minimisation for SMEs within the industry. Lessons learnt from the experiences of other countries in this regard are used in the assessment.

SMEs were selected as a focus for the assessment as, in general, SMEs lack the in-house waste management resources of the larger industry members, many of whom already have internalised environmental management systems. Moreover SMEs experience greater difficulties in managing their wastes cost-effectively and therefore are most threatened by demands for greater environmental responsibility. There is a need to facilitate improved environmental capability in SMEs (Coleman, 1994). Environmental improvement options for SMEs in particular, need to be cost-effective as, in general, they can only afford to invest in the environmental protection measures if it is economically beneficial (Kothuis and Petrie, 1997). There is a need to overcome these constraints to improved performance in ways which give due recognition to the need of SMEs to maintain maximum flexibility in their operations. This research therefore also addresses whether the potential waste minimisation for SMEs in the metal finishing industry is cost-effective.

In addition, there are very few case studies of waste minimisation in South African industry and, at the time of the start of the research work for this thesis, there was only one published case study from the metal finishing industry. The company was in fact a larger manufacturing company with an in-house electroplating line. This formed part of a thesis on waste minimisation in SMEs in South African industry (Coleman, metal finishing sectors other than electroplating. If these companies are found to be representative of the South African metal finishing industry, and if potential for waste minimisation is found, this thesis proposes that it indicates that there is potential for waste minimisation in the South African metal finishing industry as a whole. Once again, the key influencing factors will be included in the analysis of the potential and in determining whether the companies are representative of the whole sector.

1.3 THESIS OUTLINE

1.3.1 Thesis objectives

Specific objectives of the research carried out and presented here included:

1. To characterise the South African metal finishing industry in order to understand the processes used in the industry; industry structure; and the drivers towards and barriers against environmental improvement that affect the industry now and/or are likely to affect the industry in the future.
2. To examine the metal finishing industry in the U.S.A., Western Europe and Australia, for comparison with the South African metal finishing industry.
3. To review trends in environmental management and waste minimisation practices in the metal finishing industries in the U.S.A, Western Europe, and Australia so as to demonstrate the success or otherwise of waste minimisation in the metal finishing industry in these countries.
4. To formulate waste minimisation case studies for two companies in the metal finishing industry in South Africa, based on practical on-site assessments of industrial practice using real operating data, and to successfully carry out waste minimisation assessments in the case study companies.
5. To assess the potential for waste minimisation in SMEs in the metal finishing industry in South Africa based on analysis of the case studies and a comparison with the situation in other countries.

1.3.2 Thesis Key Questions

The research was planned in such a way as to answer the following key questions:

1. What are the similarities and differences between the metal finishing industries in South Africa and other countries?
2. What is the current state in awareness and adoption of waste minimisation in the metal finishing industry in South Africa and in other countries?
3. Have SMEs in the metal finishing industry in other countries implemented cost-effective waste minimisation successfully and do SMEs in the metal finishing industry in South Africa have the potential to do the same?
4. Are SMEs within the metal finishing industry in South Africa capable of conceiving and implementing cost-effective waste minimisation projects?
5. What were/are the obstacles and constraints for waste minimisation activities, and how have/can these been/be overcome?

1.3.3 Hypothesis

In answering the questions and satisfying the objectives set out above, the potential for cost-effective waste minimisation in SMEs in the metal finishing industry in South Africa may be determined. The premise for this dissertation has been that cost-effective waste minimisation has been applied successfully in the metal finishing industry in other countries. It is therefore hypothesised that:

"There is potential for cost-effective waste minimisation in small and medium enterprises in the South African metal finishing industry"

1.3.4 Assumptions and Constraints

The assumptions and constraints that were used in order to gather evidence to evaluate the hypothesis are set out below:

SMEs are companies with fewer than 250 employees. Medium sized companies have between 40 and 300 employees and some form of middle management. Small size companies have fewer than 40 employees and lack a formal management structure. (The definition of SMEs is the one used across all work for the larger Industrial Symbiosis Project). In researching SMEs in other countries it will be made sure that they satisfy these criteria.

For the assessment of potential for waste minimisation in the case studies, the companies selected should have *tractable problems* and be the cause of *significant environmental degradation* or the results will not have much standing. In addition, the state of environmental management in the company should be considered representative of the waste management style for the South African metal finishing industry in general.

The potential waste minimisation opportunities identified for the case-study companies must be environmentally beneficial. In other words, a waste minimisation option is considered successful if it results in:

a. a reduction in the total amount of waste generated by the industry
b. a reduction in the total environmental harmfulness of the waste
or both.

It includes any source reduction, or recycling activity undertaken by a generator, so long as the reduction is consistent with the goal of minimising the present and future threat to human health and the environment.

A waste minimisation opportunity is considered cost-effective if it results in reduced or equivalent operating costs for the case-study company, or if the payback period on a required investment is determined to be within five years from implementation and is within the financial ability of the company.

Apart from simple no cost options such as improved housekeeping, the cost-effectiveness of potential options is mostly company-specific. It is assumed that if it can be found that there is potential for cost-effective waste minimisation in case study companies, and that these companies are representative of the whole (in terms of processes and key characteristics), then it can be concluded that there is potential for cost-effective waste minimisation in SMEs in the metal finishing industry in general.

The assessment of the potential for waste minimisation in SMEs in the industry in general will be based on the results of the case studies and a comparison with the situation in other countries. A similarity argument approach will be used i.e. *if* all of the following are found to be true:

i) Cost-effective waste minimisation for SMEs in the metal finishing industry has been demonstrated in other countries through waste minimisation projects and case studies,

ii) The metal finishing industry in South Africa can be found to be similar to that in other countries where waste minimisation has been applied successfully, both in terms of processes, and in terms of key characteristics which affect environmental performance,

iii) Some of the waste minimisation options applied in other countries to address well-known problems in this industrial sector, are applied in the case study companies,

iv) There is potential for cost-effective waste minimisation in the case study companies, and

v) The case study companies may be considered representative of the South African metal finishing industry in terms of processes and key characteristics which affect environmental performance.

then the hypothesis may be assumed to be correct.

1.3.5 Scope of Thesis

This thesis will be focussing on waste minimisation in the metal finishing industry only. Where necessary, to set the background, general waste minimisation initiatives will be mentioned, but it is not the intention of this thesis to discuss the concept of waste minimisation in detail. It is also assumed that the reader is aware of many of the concepts of waste minimisation and Cleaner Production. In addition it is assumed that the reader has a general understanding of chemical processes. References to sources of detailed information (e.g. process descriptions) will be given, and in some cases, are included as Appendices.

There are many definitions of terms such as 'waste' and 'emissions', and 'waste minimisation'. It is not in the scope of this thesis to add to this discussion and hence, working definitions are provided in the Glossary. However, the use of these terms waste minimisation, Cleaner Production and pollution prevention in this thesis is considered for the most part interchangeable. It is not considered necessary for this thesis to undertake a comprehensive analysis of the specific terminology, but when using any of the above terminology, to refer to the concept rather than to consider whether the term used is the most appropriate term to describe it. For the most part, the term *waste minimisation* will be used, however, when referring to literature, it is necessary to apply the particular term used by the author to describe the concept, and if there is any additional idea implied, it will be noted.

The detailed case studies in this thesis are in the hot dip galvanizing and powder coating industry. These are only two sectors of the metal finishing industry. Electroplating is considered a major process in the industry. Therefore, published literature plus the results from the work of other Industrial Symbiosis Project members in this sector of the industry will be noted, in order to include this important sector of the industry, and widen the scope of the assessment.

1.4 RESEARCH PROCEDURE

This research presented here relies on an extensive literature review. The aim of the literature review is to survey the various concepts on which this masters project is based and to draw these concepts together into a unified basis for the ensuing data gathering and analysis. Primary information was accessed through books, journals, reports, surveys, publications, conference papers, and manuals relevant to the metal finishing industry, waste minimisation, Cleaner Production, and other related topics. A significant amount of this literature was obtained from Internet sources.

The practical research in the gathering and analysis of field data, is divided into three areas:

1. Meetings & Interviews (both in person and through correspondence). This helped to complement the literature review and involved contacting agencies, associations, organisations, and individuals with knowledge of the metal finishing industry both in South Africa and in other countries. A significant research activity in this area was the European study tour.
2. A survey of the South African metal finishing industry required for the first thesis objective owing to insufficient available data.
3. Detailed waste minimisation assessments in two local metal finishing companies to satisfy the fourth thesis objective.

1.5 THESIS STRUCTURE

Both the literature review and practical research are set out to cover the objectives of the thesis and to attempt to answer the thesis key questions.

Chapter 2 is a review of literature on metal finishing processes, associated wastes and waste minimisation opportunities. In Chapter 3, international initiatives in waste minimisation in the metal finishing industry are discussed. This includes both the results from the literature survey as well as the findings from the European study tour and other data gathering. Chapter 4 examines the South African situation in the light of waste minimisation in general and specific initiatives in the metal finishing industry. It includes both the literature review and the findings from the Industry Survey. Chapters 5 and 6 present the findings from the waste minimisation assessments in the two local case studies. In Chapter 7, the findings are discussed with the aim of testing the hypothesis against the success criteria, and the conclusions drawn from the work are set out.

Chapter 2: Metal Finishing Wastes and Waste Minimisation Options

---

"What we call Waste Minimisation often can be called something else in another profession. For instance: accountants call it loss control, process engineers call it an efficient process, managers call it total quality management, people unaccustomed to long definitions call it common sense"
– U.S. EPA, 1989.

2.1 INTRODUCTION

In order to gain a general understanding of the industry and to provide a context for the discussion of the waste minimisation opportunities available to the industry, this chapter provides a summary of processes falling under the metal finishing sector, as well as a summary of the general and specific wastes associated with these processes. The problems associated with these wastes and conventional waste treatment, and disposal options for metal finishing wastes are reviewed in more detail. Waste minimisation methods and techniques for the metal finishing industry are then discussed and a summary list of common waste minimisation options for the metal finishing industry compiled from various literature sources is presented.

There is an abundance of literature describing metal finishing processes, associated wastes, and waste minimisation options. For the purposes of this thesis, it is not considered necessary to review this literature in detail, and instead, overviews and summary lists are provided, and all references are cited.

2.2 AN OVERVIEW OF METAL FINISHING PROCESSES

The term "metal finishing" comprises a broad range of processes that are employed at some point during the manufacture of essentially all metallic products. The manufacturing industries where metal finishing processes are used predominately include:

- fabricated metal products (e.g. metal cans, fasteners, tools, metal furniture)
- common machinery (e.g. engines, farm equipment, construction equipment, manufacturing machinery)
- electronic machinery (e.g. computers, office equipment, audio and visual electronics)
- household appliances (e.g. washing machines, refrigerators, small kitchen appliances, air conditioners)
- automotive and water transportation equipment and components (e.g. automobiles, trucks, rail vehicles, boats)
- aerospace equipment and commercial aviation (e.g. aircraft, satellites), and
- miscellaneous manufacturing (e.g. jewelry, coins, musical instruments, toys)

(U.S. EPA, 1996).

A *finish* is any final operation applied to the surface of a metal article in order to provide protection for the base metal, or alter its surface properties to achieve various desirable characteristics or to improve the utility of the product in some other way (U.S. EPA, 1996). These characteristics may include:

- increased wear, corrosion or abrasion resistance
- enhanced appearance
- improved base for the adhesion of other materials (e.g. other metals, paints)
- enhanced frictional characteristics (lubricity)
- improved hardness
- improved solderability
- enhanced electrical properties
- enhanced temperature resistance

Processes used by the metal finishing industry involve the cleaning, hardening or softening, smoothing or roughing and conversion of the object's surface. Processes may be electrolytic, mechanical or chemical in nature. Most metal surface treatment and plating operations have 3 basic steps:

1. *Surface preparation* (pre-treatment) involves the use of solvents, alkaline and acid cleaners, abrasive materials, and/or water to clean the work-piece surface in preparation for treatment. Chemical additives may be present in the cleaner to make it more effective, easier to use, or less harmful to the metal surface. The surface of the metal is cleaned to remove unwanted matter such as carbon smut, welding flux, ink, oxidation products, oil, fingerprints, or other material.

2. *Surface treatment* involves some change in the surface properties of the work-piece, such as application of a metal layer or paint. The final step in some processes is drying which may be simple air-drying or a more complex system such as forced air evaporation or spin dry.

3. *Post treatment* involves rinsing to remove any unwanted residual chemicals still present, or further finishing operations such as heat treatment (to relieve hydrogen embrittlement), colouring (using a dye) or anti-corrosion treatment (e.g. chromate seal) to produce the final product.

(U.S. EPA, 1994).

An overview of the most common metal finishing processes is provided in Table 2.1. A number of references were used in compiling this table. The main source for the list is the U.S. EPA (1996) guide on '*International Waste Minimisation Approaches & Policies to Metal Plating*', which provides a good overview of metal finishing processes. More comprehensive and detailed descriptions of each of the processes may be found in the '*Encyclopaedia of Chemical Technology*' (Kirk & Othmer, 1995). Metal finishing manuals such as '*A Cleaner Production Manual for the Metal Finishing Industry*' (UNEP WG, 1998) and '*Fabricated Metal Products Notebook*' (U.S. EPA, 1998) provide less detailed and more user-friendly descriptions.

The Northeast Waste Management Official's Association (NEWMOA) in association with the U.S. EPA designed a manual to provide environmental assistance staff with a basic reference on metal finishing (NEWMOA, 1997). The manual was specifically designed to be useful to assistance professionals with experience with metal finishing and for those who have never encountered metal finishing before. To compile the manual, NEWMOA reviewed over 700 books, articles, fact sheets, reports and guides on pollution prevention for metal finishing. The U.S. EPA funded the manual as a model of a comprehensive packet of information on a single industry. It is therefore one of the best references for a description of metal finishing processes, as well as associated wastes, and waste minimisation options. For a South African source, the report *'An investigation into water management and effluent treatment in the South African metal finishing industry'* (PRG, 1987) gives simple descriptions of metal finishing processes as background to the study. The reader may refer to any of the above sources for detailed descriptions of the metal finishing processes.

Table 2.1: Overview of Metal Finishing Processes

PROCESS (and inputs)	DESCRIPTION	FUNCTION
SURFACE PREPARATION		
Solvent Cleaning - Using methyl ethyl ketone, toluene, thrichloroethylene; or kerosene, mineral oil, and glycols dispersed in an aqueous medium	Applied by wiping, ambient-temperature immersion soaking, or vapour degreasing. Employing the natural solubilising properties of various non-aqueous solvents/ blends of solvents.	To remove unwanted oil, grease, and wax-based soils on metal substrate.
Alkaline Cleaning - Sodium phosphates, sodium silicates, sodium hydroxide, or sodium carbonate builders, with additives and surfactants (depends on metal substrate)	Done in heated soak tanks, and in some applications assisted by mechanical action, ultrasonics, or by electrical potential. Spray method also used. Additives promote better cleaning or affect the metal surface in some way (e.g. wetting agents, coupling agents, chelating agents)	To remove oils and other organic contaminants by saponification, emulsion, or dispersion.
Acid Cleaning/Pickling - H_2SO_4 HCL, HNO_3	Acid pickles may be applied by spray or immersion. Speed of the pickle reaction depends on the concentration and temperature of the pickle, the degree of agitation of the metal part or pickle solution, the alloy being pickled, and the acid used.	To chemically remove oxides and scale from metal surface. Pickling is usually used to remove scale from semi-finished mill products, whereas acid cleaning is used for near-final preparation of metal surfaces before electroplating, painting, and other finishing processes.
Abrasive (grit/sand) blasting - sand, plastic beads, and synthetic abrasive powders	A technique of abrasive cleaning or surface preparation using sharp particles (e.g. sand, cast iron shot, aluminium oxide).	A method to remove brittle materials such as millscale oxide, remains of paint, other surface films, etc.

Table 2.1 continued

PROCESS (and inputs)	DESCRIPTION	FUNCTION
SURFACE TREATMENT		
Plating Operations		
Electroplating - Ferrous and non-ferrous metal objects are plated with a variety of metals including: zinc, nickel, copper, hard-chrome, decorative chrome, brass, bronze, lead, platinum, tin, silver, gold, indium, cadmium.	Coating of one metal upon another by electrodeposition, achieved by passing an electrical current through a cyanide, acid, alkaline or neutral solution containing dissolved metal ions and the metal object to be plated.	To provide corrosion resistance, hardness, wear-resistance, anti-frictional characteristics, electrical or thermal conductivity, or decoration.
Electroless Plating - Copper and nickel electroless plating	The chemical deposition of a metal coating onto a plastic object, by immersion of the object in a plating solution, and utilising chemical reaction rather than electricity.	Widely used for industrial purposes, commonly used for printed circuit boards.
Immersion plating - commonly zinc or silver	Similar to electroless plating in that it uses a chemical reaction to apply the coating, however, the reaction is caused by the metal substrate rather than by mixing two chemicals into the plating bath.	Produces a thin metal deposit by chemical displacement
Chemical Conversion Treatments		
Phosphating - iron phosphating or zinc phosphating	Formed by the immersion of steel, iron, or zinc-plated steel in a dilute solution of phosphate salts, phosphoric acid, and other reagents to condition the surfaces for further processing	Applied as: preparation for painting, temporary corrosion protection, lubricant carrier in cold forming, friction improver for stamping and drawing, and as insulation on electrical steels.
Chromating - chromium phosphate (green chromates) and chromium chromate (gold chromates)	Solutions usually containing chromium and other compounds, react with the metal surface to form a layer containing a complex mixture of compounds consisting of chromium, other constituents, and the base metal.	To improve the corrosion resistance and performance of subsequently applied organic finishes (e.g. powder paints). Usually applied to aluminium substrates.
Passivation - nitric acid or nitric acid with sodium dichromate	The process of forming a protective film on metals by immersion into an acidic solution.	Stainless steel products are often passivated to prevent corrosion and extend the life of the product.
Metal Colouring - patina	Chemically converting the metal surface into an oxide or similar metallic compound.	To produce a decorative finish such as a green or blue patina on copper or steel, respectively.

Table 2.1 continued

PROCESS (and inputs)	DESCRIPTION	FUNCTION
Electrochemical Conversion Treatments		
Anodising - chromic acid, sulphuric acid, and boric-sulphuric acid anodising	Electrolytic conversion of a metal (usually aluminium) surface to an insoluble oxide coating. The part to be anodised is placed in a tank where a controlled direct current charge is applied. At the anode (the part), the aluminium is oxidised to Al_2O_3.	Provides corrosion protection, decorative matt finish, enhanced abrasion resistance, a base for painting and other coating processes, and special electrical and mechanical properties. The layer is colourless but pigment can be added to permanently colour the surface.
Other Processes		
Wet Painting - solvent-diluted formulations, and aqueous formulations	Most common application methods are spray painting and electrodeposition.	For protective and/or decorative purposes.
Powder Coating - epoxy, urethane polyesters, acrylics, polyethylene.	Dry powder paint is usually electrostatically sprayed onto part. Some form of heating or baking is necessary to melt the powder and ensure that the powder adheres to the metal.	For protective and/or decorative purposes.
Hot dip Coating - Galvanizing (hot dip zinc)	The coating of a metallic workpiece with another metal to provide a protective film by immersion into a molten bath.	For corrosion protection. Does not always provide a high quality finish.
Cladding - e.g. for coins	A mechanical process where the metal coating is metallurgically bonded by combining heat and pressure. The metal inside (copper) is heated and pressed between two sheets of molten metal alloy (nickel), bonding the materials.	Used to deposit a thicker coating than electroplating
Case hardening (diffusion coatings) - carburising (diffusion of carbon into a steel surface at elevated temperatures), nitriding (diffuse nitrogenous gas into steel), carbonitriding, microcasing - e.g. for samurai sword	A family of metallurgical process resulting in a hard surface, or case, over a metal core that remains relatively soft. A metal is heated and molded and then the temperature is quickly dropped to quench the workpiece.	The case is wear resistant and durable: the core remains strong and ductile.
Etching - ferric chloride, nitric acid, ammonium persulphate, chromic acid, cupric chloride, and hydrochloric acid	Controlled dissolution with chemical reagents or etchants (usually strong acids or alkalis).	Produces specific designs or surface appearances on parts.

Table 2.1 continued

PROCESS (and inputs)	DESCRIPTION	FUNCTION
Electropolishing	Metal surface is anodically smoothed in a concentrated acid/alkaline solution. Parts are made anodic, causing a film formation around the macro contours of the part	Film is thinner over the micro-projections and thicker over the micro-depressions.
Polishing and buffing	Abrading operations. Buffing is a specific type of mechanical polishing using a high-speed disc made from layers of cloth, leather or plastic impregnated with an abrasive.	To smooth out or remove surface defects (scratches, pits, or tool marks) that adversely affect the appearance or function of a part.
Tumbling	Work is placed in a barrel and rotated with or without abrasives, dry or wet.	To deburr, descale, polish, burnish or to dry parts.
Antiquing (Blackening)	Coating a workpiece with a black substance and mechanically relieving it so that only black remains in recesses. The black may be applied as a paint, an oxide coating, or as an electroplated deposit.	To create an antique finish (common practice in jewellery electroplating shops).
Metal spraying	Term applied to the spraying of one of several metals onto a metal substrate. The most common method is "flame impingement", where powdered metal is continuously fed into a high velocity flame. The flame atomizes the metal powder into a molten state and the particles are projected by flame energy onto surface.	Zinc or aluminium spraying on structural steel or aerospace high tensile workpieces for corrosion protection. Tungsten bearing materials, cobalt, nickel with small amounts of Cr for "hard facing". For salvage purposes on pieces exhibiting wear while in service.
POST TREATMENT		
Rinsing	Dipping finished part in water or demineralised water.	To clean of dragged-out chemicals that cling to parts.
Colouring	Part dipped in a dye after treatment.	To add colour to metal finish (e.g. anodised part).
Anti-corrosion treatment - sodium dichromate solution, or chromic acid	Part is dipped in a dilute chromate solution as a final treatment step.	To improve corrosion resistance.

Plating and surface treatment processes are typically batch operations in which metal substrates are dipped into and then removed from baths containing various reagents to achieve the desired surface conditions. The processes involve moving the object being coated through a series of baths designed to produce the desired end product. These processes can be manual or highly automated operations, depending on the level of sophistication and modernisation of the facility, throughput and the application (U.S. EPA, 1996).

Owing to the high cost of most new equipment and the relatively long lead time necessary to bring new equipment into operation, changes in production methods and products are made only gradually, and even new process technologies that fundamentally change the industry are only adopted over long periods of time (U.S. EPA, 1998). In addition, many establishments in the metal finishing industry are SMEs with limited ability to raise the capital necessary to purchase new equipment.

With the exception of leading edge technology, relatively few technological differences exist between the metal finishing processes used in different countries. The U.S. EPA (1996) suggests that this is due to the following factors:

- Simplicity of conventional metal finishing technologies and the limited requirement for skilled labour,
- Expansion of major chemical suppliers to a world-wide market,
- World-wide trade organisations and other forms of international co-operation, and
- Open access to major universities and colleges where research is conducted.

However, differences do exist in metal plating operations, depending on:

- The level of economic development across nations,
- Variations in demand for sophisticated plating applications,
- The availability of capital, and
- Environmental law and regulatory constraints.

It is further argued that over the past two decades, metal platers in developed countries have undergone a major technological shift from decorative finishes (such as nickel-chrome coatings on steel and zinc die-cast parts), to specialty finishes and more processing of aerospace and electronic parts. Metal platers in less developed nations have not been forced to respond to these changes and have, as a result, experienced far fewer and less rapid technological advancements. Similarly, developed countries have stable or decreasing needs for unskilled labour due to automation, these trends have not occurred in less developed nations (U.S. EPA, 1996).

Thus the core metal finishing processes tend to be the same from country to country, with the only real exceptions in some developed countries being the application of new specialty technologies, which are generally Cleaner Technologies (some are described below) and therefore not (or have already been) a focus for waste minimisation initiatives in any case.

2.3 *ENVIRONMENTAL IMPACTS OF METAL FINISHING*

As with any complex industrial activity, metal finishing processes result in a variety of wastes and environmental releases which have potential for human and environmental harm. However, the U.S. Environmental Protection Agency (U.S. EPA) has identified the metal finishing industry as one of the most significant contributors to environmental pollution and suggests that this is probably the case throughout most of the world (Hinton, 1991).

The metal-plating sector is one of the major industrial sources of heavy metals in wastewater (WRC, 1994). Both the industrial activities, as well as related disposal services, introduce heavy metal wastes into the environment. While all heavy metals occur naturally in the environment, most of them become highly toxic as soon as their concentrations reach certain limits. Some metals used as metallic coatings are considered non-toxic, such as: aluminium, magnesium, iron, tin, titanium, gold and platinum. However, metals like mercury, cadmium and lead can be bio-concentrated to harmful levels, especially in predators at the top of the food chain. Other metals such as silver, copper, nickel, zinc and chromium (the latter in the hexavalent oxidation state) are highly toxic to aquatic life (Kirk & Othmer, 1995). Metal finishing activities use large and highly concentrated quantities of these metals, and in general only a small portion of the input material are incorporated in the end-product (WRC, 1997).

The metal finishing industry is somewhat unusual among manufacturing industries at present because the vast majority of the materials used end up as waste (U.S. EPA, 1996). The current inefficiency of material use in the industry is due to the inherent characteristics of the processes employed where parts are immersed into concentrated tanks of chemicals and are subsequently rinsed in rinse tanks flowing with fresh water. The metal finishing industry relies heavily on the presence of fresh water for rinsing and bath make-up, and a high volume of waste water stems from inefficient use of fresh water and chemicals (van der Meer, 1998). The resultant wastewater makes up the greatest volume of waste material from finishing operations (U.S. EPA, 1996). In order to comply with environmental laws (particularly in the form of regulations on effluent discharge), the metal finishing industries initial response was the development of 'end-of-pipe' technologies, which in turn have given rise to the generation of toxic sludge, which requires careful disposal (van der Meer, 1998).

Wastes from metal finishing operations are generated by normal production activities as well as by accident. Accidental discharges can have highly acute impacts due to the concentrated nature of the hazardous materials in use, while normal processing wastes present more of a chronic problem due to the controlled and/or continuous nature of their discharge.

The following sections give an overview of metal finishing wastes and the potential fate of these waste products. In addition, conventional treatment and control methods that are commonly applied by the industry to these wastes are described. A summary table of major wastes typically associated with the processes described in Section 2.1 above is included for reference in Appendix B1.

2.3.1 Air Emissions

The air emissions of greatest environmental concern are chrome plating and anodising processes that use hexavalent chromium, and solvents from vapour degreasing. These emissions are frequently controlled by the use of wet scrubbers. Solvent emissions are presently controlled by management practices and carbon adsorption treatment systems (U.S. EPA, 1996). Emission of fumes (e.g. from galvanizing operations) and powders (e.g. from powder coating operation) are not as hazardous, but are still a concern.

Chromium is one of the most frequently electroplated metals, and due to health concerns for operators of chromium electroplating processes, forced air ventilation must be used. The mist is pulled into an exhaust system and wet air scrubbers and mesh pad mist eliminators can be used to remove the bulk of the chromium from the air stream. The industry has recently begun adding fume suppressants, wetting agents and/or foam blankets to the electroplating baths to reduce air emissions of chromium (U.S. EPA, 1998). These suppressants lower the surface tension of the bath, preventing hydrogen bubbles from bursting and producing a chromium laden mist. Fume suppressants are highly successful in decorative plating, but not as effective in hard-chrome plating.

2.3.2 *Wastewater and Effluent*

Wastewater is mainly generated during rinsing operations. The rinsing is necessary to remove the drag-out from racks/parts after removal from the process baths. Other sources of wastewater, which include scrubber blowdown, cooling water, floorwash water, and spent baths, typically make up only about 10 to 20% of the flow from a metal finishing shop (U.S. EPA, 1996). The composition of the wastewater will depend on the type of processes performed and the rinsing methods used. Rinse tank design and the rinsing configuration play an important role in determining the flow rate of wastewater from a shop.

Other more hazardous liquid wastes that cannot be discharged to the sewer are also generated from the industry. Process baths need to be discharged periodically when they lose their effectiveness due to chemical depletion or contamination (become spent). Solutions are subject to a variety of factors that cause them to become unstable. The key contributing factors are (Cushnie, 1994):

- Depletion of bath chemicals
- Chemical break-down of process chemicals or chemical side reactions
- Contamination from impurities in make-up water, chemicals or anodes
- Anodic/cathodic etching of parts and inert electrodes
- Corrosion of parts, racks, tanks, heating coils, etc.
- Drag-in of non-compatible chemicals
- Build-up of by-products (e.g. carbonates)
- Breakdown of maskant, fume supressant and wetting agents
- Errors in bath additions
- Airborne particles entering the tank

The most common spent process solutions are alkaline cleaners and acid etching/pickling solutions, which are discarded on a regular basis by many shops. The aqueous cleaning/degreasing solutions are usually strongly acidic/caustic and therefore require neutralisation before discharge to sewer. The spent process baths are regarded as hazardous because they are either toxic, accumulate in the environment because they do not readily biodegrade, and/or require special treatment prior to disposal (UNEP WG, 1998). Of particular concern are those that are highly toxic or contain carcinogenic ingredients that are difficult to destroy or stabilise, such as cadmium, cyanide, chromium, and lead.

Waste rinse-waters are discharged directly to municipal sewer systems or are first treated on-site using chemical/physical methods to remove metals to acceptable levels prior to discharge. Discharge of treated wastewater to the sewer is much more common than recycle or reuse. A high volume of rinse water dilutes the contaminants dragged from the process baths and results in a low concentration of contaminants. "Dilution as a solution for pollution" has been the easy answer for this problem, encouraged by concentration-based wastewater discharge limits. Unfortunately, dilution does nothing to minimise the impact of discharged wastewater contaminants that accumulate in sediment or enter the food chain (DNRP, date unknown).

The concentrated wastes are either treated on-site or are hauled to an off-site treatment or recovery facility. Treatment often involves neutralisation and/or fixation to render them inert. Plating solutions are typically rejuvenated and kept in permanent operation. Conversion coating and anodising solutions may become contaminated with the base metal being processed. When the concentration of dissolved metal reaches an intolerable concentration, the solution requires processing to reduce the dissolved metal concentration to a tolerable level.

Most metal finishing shops segregate their wastewaters into three streams: cyanide bearing, chromium bearing, and miscellaneous acid and alkaline. Cyanide wastes cannot be mixed with acid wastes owing to the potential formation of hydrogen cyanide. Cyanide and chromium wastes need to be treated by preliminary processes prior to metal precipitation.

Conventional treatment systems therefore consist of preliminary treatment of cyanide and chromium bearing wastewaters, followed by chemical precipitation (conventionally hydroxide precipitation), clarification and sometimes filtration/solids dewatering (U.S. EPA, 1996). The treatment generates a hazardous sludge that must be disposed of in an approved landfill or, if possible, sent to a recovery site for metals reclamation. Residual metals in wastewaters discharged to municipal sewer systems will be partially removed by the biological treatment process of the municipality (also generating a sludge) and the remainder will be discharged to a water body.

The heavy metals contained in industrial wastewater cause problems downstream at sewage treatment plants for a number of reasons. Firstly, they are not easily removed from the wastewater streams and will be present in the effluent that is discharged to waterways, possibly causing adverse impacts on aquatic life. Secondly, heavy metals can inhibit the biological treatment processes at sewage treatment plants, reducing the treatment efficiency of the plant (UNEP WG, 1998). Finally, the high concentration of metals, such as cadmium, which accumulate in sewage sludges can limit municipalities' disposal options and reuse options (such as composting). Sludges then become a liability for municipalities rather than an asset. Therefore, some local governments impose strict limits on the effluent discharges from metal finishing shops in order to meet discharge and disposal restrictions (U.S. EPA, 1996).

Contaminated liquid solvents are either recovered by distillation (on-site or off-site) or sent for disposal (incineration). When the cleaning ability of the solvent is diminished or it becomes contaminated, it needs to be discarded/replaced or purified on-site. Spent solvent can be recovered at a solvent recycling facility (U.S. EPA, 1996). Both off-site recycling operations and on-site purification use solvent distillation equipment to separate the contaminants from the solvent. During distillation, the contaminants are concentrated into still bottoms and the solvent is returned for reuse.

On-site treatment is not always possible. Electroless plating solutions can be difficult to treat as settling and simple chemical precipitation are not effective at removing the chelated metals used in the plating baths (U.S. EPA, 1998). Accidental spills may be too concentrated for on-site waste treatment. Also, some spent cleaning solutions contain chelating compounds that prevent the complete precipitation of heavy metals during treatment (U.S. EPA, 1996).

2.3.3 Solid Waste

Wastewater treatment sludge is usually the major solid waste type from metal finishing. It is formed by the conventional hydroxide precipitation treatment process. This is accomplished by adjusting the pH of the wastewater with an alkaline reagent (e.g. lime) to reduce the solubility of the dissolved metals, and settling and removing the resultant metal hydroxide precipitants. Flocculating agents may be used to cause the precipitated metal hydroxides to agglomerate and settle more rapidly. The wastewater is then clarified by allowing the precipitated solids to settle. The solids are removed from the clarifier and may be thickened and dewatered by mechanical/thermal means (U.S. EPA, 1996). Due to the high cost of hauling and recovery/disposal, it is often economically advantageous for shops to remove as much water from the sludge as possible.

The volume and composition of wastewater treatment sludge depends on the:

- Volume and composition of the wastewater treated,
- Nature and efficiency of the treatment process,
- Treatment reagents employed, and
- Dewatering process

Wastewater treatment sludge is generally disposed of in (hazardous) landfills or, if possible, may be sent to a metals-recycling facility (only available in some countries for very few waste types). Owing to land disposal regulations, the sludge must be stable (i.e. will not leach toxic metals) before land disposal. Therefore, some sludges may need to be processed before landfilling. Solidification (adding cement or cement-like materials to bind the hazardous metals and prevent leaching) is the most common method of stabilising sludges.

If it is possible to recycle the sludges off-site, the recovered metals may be used as feed material for manufacturing processes, e.g.

- Copper, cadmium, and zinc feed materials for primary metals manufacturing;
- Chromium for stainless steel manufacturing; and
- Wood treatment chemical reagents

(U.S. EPA, 1996).

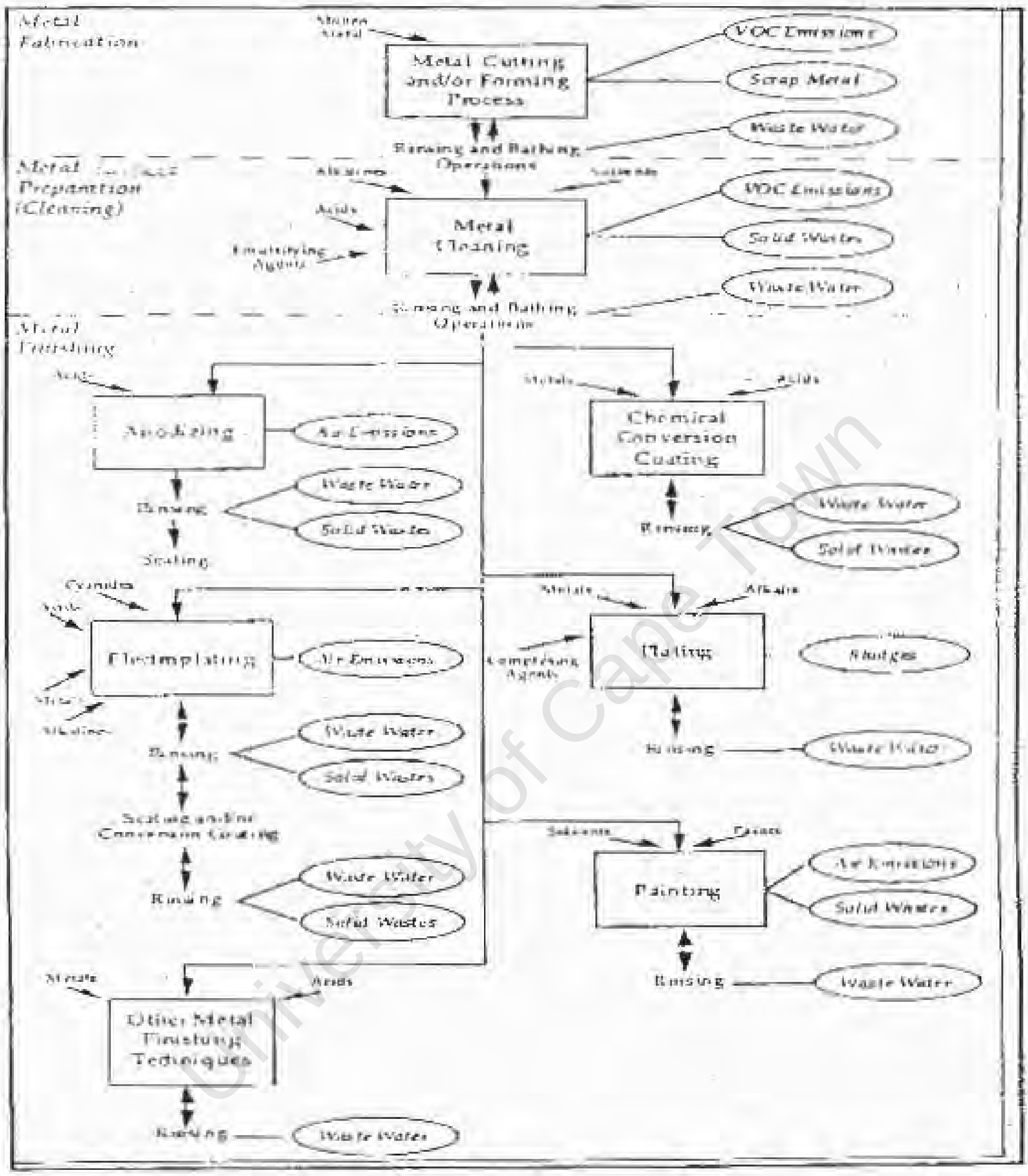
Another source of solid waste includes still bottoms from solvent recovery. Spent powder paint may also be solidified by oven curing to prevent it from becoming airborne when disposed. Metal finishing operations also generate other miscellaneous sources of wastes such as chemical packaging wastes, absorbents, filters, paint residue and abrasive blasting residue.

2.3.4 Summary of Metal Finishing Industry Environmental Impacts

Figure 2.1 overleaf presents a pictorial overview of the metal finishing processes and shows the typical emissions and wastes that are generated during production (source: NEWMOA, 1997).

Many of the chemical substances and metals used and handled in the industry are hazardous, both for workers and for the environment. There is a wealth of information available on the effects of these substances on humans. Environmental effects and human toxicity information for each of the heavy metals and chemicals used can be read up in the 'Encyclopaedia of Chemical Technology' (Kirk & Othmer, 1995). A good summary is provided in the 'Cleaner Production Manual for the metal finishing industry' (UNEP WG, 1998). This information for those chemicals in use at the case study companies is provided in Appendices E3 and F2.

Figure 2.1: Overview of the Metal Finishing Process and Associated Wastes



2.4 *WASTE MINIMISATION IN THE METAL FINISHING INDUSTRY*

This section discusses literature on the waste minimisation concept and methods, and the range of techniques and options available to the metal finishing industry. The reason for including this review at this place is that a discussion on the potential for waste minimisation in the South African metal finishing industry has to be informed by a knowledge of the possibilities identified elsewhere.

2.4.1 The Waste Minimisation Concept

Waste Minimisation can be seen to fit into a progression of waste disposal philosophy which originated as straight-forward discarding of waste, to end-of-pipe treatment of waste before it was discarded, through Waste Minimisation, and moving on to the emerging philosophy, which is Clean Technology, where no wastes are produced. It is an approach to decrease the environmental impact of industry by preventing or decreasing the origination of waste in the process line. The term, *Waste Minimisation* is an umbrella term that includes the first two categories of the U.S. EPA's preferred hazardous waste management strategy (CDTSC, 1993):

1. *Source Reduction*: Any activity that reduces or eliminates the generation of hazardous waste at the source, usually within the process.
2. *Recycling*: Reuse and recycling of wastes for the original or some other purpose, such as materials recovery or energy production.

Waste avoidance and reduction should be considered as the first options. Once all avoidance and reduction options have been eliminated, then options for on-site reuse and recycling can be considered. Only as a last resort should end-of-pipe treatment and disposal options be considered, and these are not really regarded as waste minimisation options. This waste management hierarchy was first outlined by U.S. EPA and is set out in full in the 'Waste Minimisation Opportunity Assessment Manual' (U.S. EPA, 1989).

The idea underlying the promotion of waste minimisation is that it makes far more sense for a generator not to produces waste rather than develop extensive treatment schemes to ensure that the waste stream poses no threat to the quality of the environment. There are a number of compelling incentives for minimising waste. While the main goal of waste minimisation is to reduce or eliminate waste, it may also bring about an improvement in a company's production efficiency. In the case that waste minimisation strategy has not completely solved the waste problem and end-of-pipe technology is still required, it is always observed that the end-of-pipe equipment is smaller, cheaper to operate and needs less investment than without waste minimisation (van der Meer, 1998).

A tremendous amount of work has been published in the environmental and chemical engineering literature on waste minimisation in general and specific to the metal finishing industry. This ranges from fairly complex techniques (often mathematically based) to examine the core processes which are creating waste; to 'how-to' articles on Waste Minimisation methodology; to reports on some of the successes of the application of Waste Minimisation studies to existing processes.

After reviewing the literature it can be concluded that there is a conceptual basis for designing minimum waste processes. Waste minimisation is essentially the application of familiar analytical, problem solving, and project management techniques to the reduction of waste in process operations (Conf, 1998).

2.4.2 Waste Minimisation methodology and techniques

In setting up a waste minimisation programme it is important to distinguish between the waste minimisation methodology and the waste minimisation techniques. The waste minimisation methodology is the procedure followed to manage the project i.e. to collect and process information and take decisions. The waste minimisation techniques are the creative methods used to generate waste minimisation ideas, possibilities, and options.

The USA Environmental Protection Agency (U.S. EPA) has produced the definitive waste minimisation assessment methodology, which is described in the Waste Minimisation Opportunity Assessment Manual (U.S. EPA, 1989). Many other organisations have produced waste minimisation 'how-to' guides, but they are usually based on the U.S. EPA manual e.g. PRISMA methodology (PREPARE, 1991). It consists of four steps, (1) planning & organisation, (2) assessment, (3) feasibility study, and (4) implementation. It essentially implies a comprehensive analysis of material flows that leads to the generation and implementation of a number of prevention options (De Hoo and Dielman, 1992). In selecting a methodology for the case studies in this study, some of the developments from this original methodology were reviewed.

The applicability and relevance of these established waste minimisation assessment (WMA) methodologies have been assessed in the local context, by Coleman (1994). A comprehensive review of alternative methodologies was conducted as part of this assessment. Coleman suggests that the U.S. EPA method of using worksheets as templates for data may be too inflexible to accommodate process & plant specific characteristics and that the methodology suggested by the United Nations Environment Program (UNEP) is more descriptive of the procedural requirements. Coleman (1994) also argues that an understanding of fundamental process chemistry & technology may be needed to clarify causes of waste, and obtaining such knowledge may require extensive information gathering and/or consultation with technology experts. In addition, the assessment may also be organised to focus on selected processes rather than the entire operating facility and prioritisation of waste streams or production sources may be done on the basis of a set of constraints. As a result of all these considerations, Coleman suggests a hybrid methodology combining the worksheets of the U.S. EPA methodology and the descriptive approach of the UNEP methodology.

Many of the suggestions from Coleman's hybrid methodology were incorporated for the WMA in this study, in particular, the procedural requirements and the need for compiling background information. However, a different specific WMA methodology (though in line with the ideas behind the hybrid methodology) was chosen for the case studies in this thesis.

The methodology chosen is that set out by the Dutch Institute for Applied Environmental Economics and IVAM Environmental Research in their '*Handboek voor Preventie van Afval en Emissies in de Metaalproduktenindustrie*' (MEZ, MVROM, 1992). The reason for choosing this methodology above any other was the recommendation of this method by the Industrial Symbiosis Project leader who was involved in developing the Handbook. Although there are manuals written specifically for metal finishing industry and might have been used instead, the work for the Industrial Symbiosis project covers more than one industry and it was necessary to use a single methodology for consistency throughout the Project.

The methodology selected is divided into 4 phases. The activities of these phases are described in the Table 2.2 below.

Table 2. 2: The selected Waste Minimisation Assessment Methodology

Phase 1: Planning and organisation

- Getting management commitment and convincing persons in the company of the necessity to minimise waste and emissions and the benefits that can be achieved by doing so.
- Defining the scope and boundaries of the project.
- Setting up a project team and defining responsibilities.
- Setting goals (quantitative or qualitative) and planning a time schedule
- Identifying sources of data and contact persons.

Phase 2: Pre-Assessment

The pre-assessment is an initial overview of the company's operations and waste streams and emissions to establish the WMA focus. The main activity is using worksheets to collecting information which is used to:

- Identify, characterise, and track the facility's waste streams
- Draw up process flow charts,
- Determine mass and energy flows,
- Start making rough mass and energy balances,
- Identify the main environmental costs, and
- Select the main focus areas.

On-site inspections cover all activities carried out on a regular basis in the relevant part of the company. An initial tour of the facility is required to form a good picture of how the company operates. More thorough/detailed inspections are carried out during the assessment itself.

Phase 3: Assessment

The objective of the assessment is to obtain a clear understanding of the sources and causes of wastes and emissions in the focus areas, resulting in the identification of improvement options. It involves a detailed study of the focus areas to establish as many possible suitable waste minimisation options. Activities include:

- Compiling background information on process operations, waste type & sources, process technologies, waste minimisation practices and environmental impacts (which forms part of the literature review presented in this thesis).
- Gathering additional data.
- Closing mass and energy balances which may require monitoring programmes to review processing conditions and to quantify losses or emissions previously unaccounted for.
- Generate options.
- Screen and select options for further study.

Generating waste minimisation options requires the following activities:

- Formulate a list of WM options from the available literature (literature review).
- Carry out technical reviews to compile information on waste minimisation alternatives and Clean Technologies (literature review and correspondence).
- Organise brainstorm sessions within the participating company to generate ideas.
- Discuss various options with suppliers.
- Consult local and international experts in the relevant branch.
- Examine all options with a view to the specific situation.

A pre-selection of options is then made to be studied in more detail as to their feasibility. Selection will depend on evaluation criteria which include (among others):

- Whether the option fits in with how the company is run.
- The environmental effect: reduction of amount and change in composition of the waste stream and any possible side effects on the environment.
- Whether it can be justified economically for the company.
- Availability of finances.
- Estimated technical feasibility.

Phase 4: Feasibility Analysis

To establish whether selected options are feasible.

- The technical evaluation covers installation and processing aspects plus any possible effects on quality and productivity. All affected groups in the facility should contribute to and review the results of the technical evaluation.
- The economic evaluation establishes the economic consequences for the company from the implementation of an option. It is carried out using the standard measures of profitability, such as payback period or discounted cash flow. The company uses its own economic evaluation procedure and criteria.
- The environmental evaluation quantifies the environmental benefit and ensure that there is no shift of effects (e.g. from water to solid waste) by performing a rough chain analysis (LCA-like)

The aim of these activities is to obtain a list of feasible waste minimisation options for presentation to the company's management.

Implementation

The implementation phase is primarily not a part of this project. However, during the project, more simple measures may be implemented within the companies

Lord et al (1996) suggest that the WMA methodology is merely process analysis for optimisation and pollution prevention. They argue that, reducing costs and improving products have always been incentives for process optimisation. However, employee safety and environmental protection have added new terms to the equation, making process analysis more complicated. The first step in pollution prevention and for process analysis is to completely understand the process, and this is the aim of the first phases of the WMA. They conclude by saying that optimising a process, whether for pollution prevention or any other reason, 'is evolutionary, not revolutionary', and through process analysis can be accomplished in an analytically sound manner.

The main aim of the WMA, whatever the methodology, is to identify and select waste minimisation options. The U.S. EPA 'Waste Minimisation Opportunity Assessment Manual' (1989) introduced the Waste Minimisation hierarchy discussed above. Although it is a useful way of classifying waste minimisation possibilities, the EPA Manual says very little on waste minimisation techniques. The waste minimisation literature however contains numerous examples of techniques. These techniques can be grouped into two types: Mathematical and Checklist.

The Mathematical techniques are sometimes sophisticated and require a good understanding of the chemistry and engineering of the process. Coni (1998) lists the following possible techniques: There are process modelling packages geared for waste assessment, which will optimise a pollution index using a multi-pollutant material balance and a process simulator; there is an approach called mass exchange network analysis; and also the application of pinch techniques to contaminant concentration and mass flow relationships. International experience has shown that mathematical techniques may need to be combined with checklist options.

The mathematical techniques most often used to generate options for metal finishing processes include material balances (Smith and Schurig, 1994), emissions modelling (Lord and Gallerani, 1998), alternative rinse flow calculations, drag-out calculations and efficiency calculations (Cushnie, 1994). These are mostly undertaken in conjunction with detailed measurements or a monitoring program in order to obtain the data needed for the calculations. Papers describing applicable techniques are often published in Journals, e.g. 'Application of Material Balance Concept in Waste Minimisation Assessment of a Metal

Finishing Process', published in the *Environmental Progress* Journal (Smith and Schurig, 1994), and 'Alternatives in Air Emission Modelling for Characterisation of Processes & Process Change', in *Plating & Surface Finishing* (Lord and Gallerani, 1998).

The *checklist* techniques are simply idea generators and can be used in conjunction with a brain-storming session with people who know the process giving rise to the waste and who can generate good ideas, or build on an idea (Coni, 1998). The checklist method is most suitable to SMEs who do not have the time or the personnel to carry out detailed assessments.

The waste minimisation manuals produced specifically for the metal finishing industry are obviously the best sources for identifying waste minimisation options. Classic examples are '*The Hazardous Waste Minimisation Checklist & Assessment Manual for the Metal Finishing Industry*' (CDTSC, 1993), the U.K. Metal Finishing Association's '*Checklist & Assessment Manual for the Metal Finishing Industry*' (MFA, 1992), and the Cleaner Production Australia '*Cleaner Production Checklists: Metal Finishing Industries*' (CPA, 1998). These are produced essentially as self-assessment guides for metal finishers to help them through the steps of a WMA.

There are also descriptive manuals (aimed more specifically at technical assistance providers), that attempt to describe in detail, the numerous waste minimisation options available for metal finishing shops. These can be used in addition to the self-assessment checklists to identify all waste minimisation options for a facility. The U.S. EPA '*Guide to Pollution Prevention: the Metal Finishing Industry*' (1992) is probably the original guide on which many of the other manuals are based (both in US and other countries). Often, industry organisations publish their own versions of these manuals, such as the Canadian Association of Metal Finishers' '*Metal Finishing Pollution Prevention Guide*' (CAMF, 1995). Often, the checklists are included as part of these manuals. For example, the CPA Checklists (CPA, 1998) form part of the larger '*Cleaner Production Manual for the Metal Finishing Industry*' (UNEP WG, 1998) which includes descriptions of general and specific process options.

The NEWMOA (1997) manual includes detailed descriptions of general improvement options to the more advanced clean technology options, and even discusses specific options for each of the metal finishing process. The chapters on Pollution Prevention Options in the U.S. EPA (1996) '*International Waste Minimisation Approaches & Policies to Metal Plating*', provides a brief summary of waste minimisation/pollution prevention techniques applicable to plating for a quick reference, followed by more detailed discussions on each option if required.

Most of these manuals also provide diagrams to illustrate process layouts for certain options (e.g. alternative rinse configurations), and set out tables to clearly illustrate alternative options for chemical/process substitutes (e.g. alternatives for cyanide-based electroplating). Case study examples of where some of these options have been applied successfully with resulting waste reduction and savings are included within the discussion of options, or as appendices to the manuals. In some cases, relative capital and operating costs for the maintenance, recovery and advanced technologies are provided. Lists of references where each of the options and technologies can be investigated in more detail are included in each case. The NEWMOA Manual includes over 100 of such references.

In addition to the longer manual-type sources, numerous short 'factsheets' are available specific to identifying certain waste minimisation techniques (e.g. drag-out reduction).

processes (e.g. rinsing, painting, etc.) or technologies (e.g. recovery technologies). These may be used by both industry members and technical assistance providers.

In some cases, the larger manuals have been directly adapted into shorter factsheets with a brief overview of numerous waste minimisation techniques e.g. '*Factsheet: Source Reduction and Metal Recovery Techniques for Metal Finishers*' (OhioEPA 1994), and the New Jersey Department of Environment's '*Waste Reduction for Metal Finishers*' (NJDE, date unknown) from the U.S. Factsheets for different areas of finishing are usually presented as series of factsheets which, together cover all processes (e.g. OEA Pollution Prevention Handbook Series of Factsheets: '*Degreasing Operations*'). These factsheets provide references and also indicate where further information is available. There are many manuals and factsheets from most developed countries available in a number of languages (some of the Dutch manuals and factsheets available are understandable for someone with a good grasp of Afrikaans in South Africa).

Additional sources for identifying waste minimisation options may be obtained from trade journals, many of which contain articles on case studies, current research, vendor information, and suggestions from industrial experts. *Plating & Surface Finishing* has published general overviews, such as 'Practical Pollution Abatement Methods for Metal Finishing' (Bishop and Loar, 1993). It has also published process-specific articles such as 'Recovery and Treatment of Plating and Anodising Wastes' (Kostura, 1990), as well as series of papers reviewing alternative process options, such as 'Comparing Substitutes for Cr and Cu to Prevent Pollution - Parts I and II' (Altmeyer, 1993a,b). Many new and therefore often 'cleaner' technologies are reviewed in these trade journals either on their own or as part of case-studies, e.g. 'Application of Ion Exchange Technology in Pollution Prevention' in *Metal Finishing* (Wilk and Capaccio, 1990).

Obviously the results obtainable from using these checklists and manuals are only as good as the ingenuity of the people using them. Metal finishers need to know not merely what options are available, but also under what circumstances a given technique or piece of equipment will be right for their particular shop, and what they must do to maximise the likelihood of success. A very useful reference for this is '*Pollution Prevention and Control Technologies for Plating Operations*' compiled by Cushnie (1994). The publication is a result of a survey conducted with hundreds of users and vendors in the US electroplating industry, to assesses the actual track record of currently available pollution prevention and pollution control equipment as a function of the process and the type of facilities in which each method is employed. Project results also cover trends in chemical substitution. The report describes the available options and summarises the survey results. (These results are reviewed and discussed as part of the international approaches to waste minimisation in Chapter 3 of this thesis). The report and associated database enables users to match their requirements and capabilities with the experience of survey respondents. Also included are the costs for purchasing and operating technologies.

A similar survey of waste minimisation options and assessment of their use and success in the U.K. metal finishing industry, was undertaken by the U.K. Surface Engineering Association (SEA, 1999) (this is discussed in more detail in Chapter 3). These option assessments are very useful indicators to those using the checklist approach as to which option is likely to work best for which application. They therefore serve a similar role as case studies, with the added benefit of being applicable in more than one situation.

Many of the U.S. manuals and factsheets are either available directly (may be downloaded) or indirectly (may be ordered electronically) on the Internet. For example '*A Pollution Prevention Resource Manual for Metal Finishers*' may be downloaded from the website for the U.S. Institute of Advanced Manufacturing Sciences (IAMS, 1995) (www.iams.org). This is also true for accessing or ordering manuals or factsheets from other countries (mainly from specific metal finishing organisations or projects that have their own website).

The various industry journals also have on-line versions, such as *Metal-Finishing.com* where articles may be accessed or ordered. The site also contains searchable databases for alternative product data as well as announcements for developments in technology (including Cleaner Technologies). The U.S. National Metal Finishing Resource Center (www.ncms.org/nmfrc) offers pollution prevention and compliance assistance information, a vendor database for alternative/substitute chemicals and equipment, and includes a forum for information exchange. Also easily available on the Internet are numerous case studies from a variety of sources including the UNEP International Cleaner Production Information Clearinghouse (ICPIC) Database of Case Studies for the Metal Finishing Industry (UNEP ICPIC, 1995).

Included in the References is a resource list of Internet sites related to waste minimisation in the metal finishing industry as well as the above and many other literature which serve as guides to carrying out WMA's, and sources for identifying waste minimisation options.

2.4.3 Overview of Waste Minimisation Options for Metal Finishers

A discussion on the potential for waste minimisation in the South African metal finishing industry has to be informed by knowledge of the possibilities identified elsewhere. In this section, therefore, an overview of the range of waste minimisation options is presented. In addition, a summary list of waste minimisation options for metal finishing processes has been compiled from an extensive review of the above-mentioned literature. It is included in Appendix B2.

2.4.3.a Improved Housekeeping and Operating Practices

General waste minimisation methods are non-capital intensive that can also reduce operating costs and improve the working environment of the shop (U.S. EPA, 1996). Good operating practices are often small changes that altogether can lead to a significant improvement in the operations and help avoid a major, one-step overhaul of the process (Gallerani and Brake, 1993). The implementation of these practices is considered the first step in an effective waste minimisation program (Cushnie, 1994). Some of the more obvious good housekeeping and production planning practices, which are applicable to metal finishing processes, are included in the summary table in Appendix B2. The simplest options require operator training, changes in organisational and procedural activities, or simple process changes. In the metal finishing industry, such changes can be implemented in the areas of drag-out reduction, counter-current rinsing, recovery rinsing, rinsewater control, and tank-side process management (Gallerani and Brake, 1993). Some of the most powerful waste reduction techniques, are the drag-out reduction and improved rinsing techniques (Cushnie, 1994).

2.4.3.b Drag-out Reduction Measures

Drag-out of various processing baths into subsequent rinses is the most obvious source of pollution in a metal finishing facility (Gallerani and Brake, 1993). The volume of drag-out discharged from a process is determined by many factors. Drag-out varies considerably among the various parts plated at shops. For example, the volume of drag-out in barrel plating is usually 10 times greater than typical rack plating (Cushnie, 1994). In addition to obvious effects of rack and barrel design and shape of parts, there are more subtle factors that affect the volume of drag-out. Some cannot be altered easily, (e.g. part shapes and process fluid concentrations), however, the effects of many other contributing factors are readily reduced by common techniques. These are usually employed to alter bath conditions or part withdrawal techniques. Drag-out reduction not only reduces the mass of pollutants reaching the wastewater stream but also reduces the amount of chemical loss suffered by the process. There are also simple methods of drag-out recovery that require much less capital and are simpler to operate than recovery technologies such as ion exchange and reverse osmosis. The list in Appendix B2 includes a summary of the wide range of potential drag-out reduction options. Drag-out recovery can reduce drag-out losses by 50% or more (Cushnie, 1994). After using the simpler methods and establishing new drag-out conditions, the applicability of additional recovery through commercially available units can be considered.

Actual measurements of drag-out are needed for accurate evaluations of pollution prevention options. The drag-out data are the most difficult and expensive to obtain (owing to the need for expensive analytical work). A well-proven method of generating drag-out data that uses conductivity measurements (provided a conductivity meter is easily available) is discussed by Cushnie (1994). The method is most suited to automatic operations. However, with manual operations and with job shops where there are a wide variety of products processed, as well as variable production rates, accurate drag-out measurements are difficult. Estimates of drag-out (based on type of part and surface area) have been presented in literature (Cushnie, 1994) but the values should be used only for gross estimates. Estimates based on related operating data (such as water and chemical replacement and evaporation rates) or the knowledge and experience of process operators, may be all that is possible for some facilities. Simple drag-out reduction methods can still be applied without accurate knowledge of actual drag-out rates.

Evaporation rates may also need to be determined for drag-out recovery options. Where evaporation is minimal there is little benefit from drag-out recovery tanks (as they are used to replace evaporation losses). Various formulae and graphs are published for estimating evaporation (Cushnie, 1994). Due to the relative ease of measuring evaporation rates, actual measurements should be used whenever possible.

2.4.3.c Rinsewater Reduction Techniques

Reducing rinse water usage offers several benefits including reduced water costs, higher waste treatment efficiency, size reduction of future waste treatment and recycle technologies, and reduction in the use of treatment chemicals (U.S. EPA, 1996). Rinse system design configuration has a major impact on water use. Equally important is the method of rinsewater control (Gallerani et al, 1993). Some of the possible rinsing improvement options are included in the summary table of Appendix B2. However, water use cannot be reduced indiscriminately without risking process problems. The required quality of rinse water is central to the reduction of rinse water use. Reduced rinse flow rate may lower the water quality, resulting in loss of plating quality or appearance, or causing contamination of the next tank (Cushnie, 1994). When more counter-flow rinse tanks are used, the process chemical and wastewater treatment operating costs are lowered, but water use costs are increased. The optimal configuration can be determined through mathematical means which must be supported by data collection.

Therefore, to evaluate rinsing alternatives effectively, drag-out and water use data as well as rinse quality criteria are required. In addition, equations that utilise these are needed. For example, Cushnie (1994) and Gallerani and Brake, (1993) (amongst others) discuss the use of an exponential equation that can be used to evaluate the effect of adding additional counterflow rinse tanks. As an alternative to using rinsing equations to perform these calculations, a modelling program can be written.

2.4.3.d Product Changes

Product changes (changes in the composition or use of the intermediate or end products) can be implemented to reduce the use of hazardous materials during finishing. Possible considerations for changes are included in the summary table in Appendix B2. Product replacement and similar approaches are largely driven by end users and consumer preferences. Captive shops have a greater opportunity for product changes than job shops because they control the design of the products. Job shops may however be able to provide customer education for part modification and design, and may choose not to bid on work that generates excessive pollution (U.S. EPA, 1996).

2.4.3.e Input Material Changes

Input material changes, such as using a less hazardous coating, can be implemented by either the manufacturer or metal finisher. Most input material changes made within the industry are focused on chlorinated solvents, cyanide, cadmium, and chromium. Environmental, health, and safety constraints have placed enormous pressures on their use, in most countries, and sparked a wealth of activity to develop alternatives for almost all applications. Some input material changes are restricted by specifications or aesthetic preferences (U.S. EPA, 1996), or may have adverse production impacts (Cushnie, 1994).

Cleaners in general have undergone extensive transformations, with emphasis on formulations having smaller amounts of chelating agents to improve ease of waste treatment. Other cleaners are designed with surfactants which displace oil for removal by filters or overflow, rather than surfactants for emulsification of oil. Longer cleaner life and a higher oil-content waste for energy recovery has resulted (Kirk & Othmer, 1995). A list of the more common alternative process and cleaning material options is included in the Table in Appendix B2.

2.4.3.f Process Solution Maintenance

Solution maintenance replaces the practices of using a fresh chemical solution until it is degraded and replacing it with fresh solution, or decanting a portion of degraded solution and replacing it with fresh solution. In either case, the spent solution is usually either treated on-site or transported to a treatment/disposal site. On-site treatment is not always possible because concentrated wastes may upset treatment facilities designed primarily for treating dilute rinse waters.

Cushnie (1994) identifies two major categories of solution maintenance:

1. *Preventive*: practices that avoid bath contamination or involve monitoring and adjusting of solution chemistry (i.e. *good operating practices*)
2. *Corrective*: practice of removing contaminants from the bath, whether they are dissolved or particulate, organic or inorganic.

A summary of both preventive and corrective options for extending bath life are included in the table in Appendix B2. Most shops use *conventional* corrective process solution maintenance methods (e.g. filtration) that extend the lives and reduce the disposal rate of cleaning and process baths. *Advanced* process solution corrective maintenance technologies, such as microfiltration and ion exchange, can indefinitely extend the life span of process solutions. These technologies do however have limited use and are generally only economically feasible in situations where either stringent environmental regulations or the cost of treatment/disposal of spent baths, are restrictive.

For most wastewaters, use of conventional *treatment methods* (neutralisation, reduction/oxidation of hazardous components, and metal-hydroxide precipitation) will provide sufficient pollutant removal to meet discharge standards. When conventional treatment is insufficient there are waste reduction choices for attaining compliance:

1. Use alternative treatment reagents and/or processes (waste minimisation)
2. Make internal changes (improve rinsing, drag-out reduction, segregate wastestreams), and/or
3. Use recycling/recovery technologies

(Cushnie, 1994)

2.4.3.g Material Recovery Technologies

Chemical/metal recovery technologies either recover drag-out and return in to the process (e.g. vacuum evaporation, electrodialysis, and reverse osmosis), or recover a constituent of the drag-out solution, usually a dissolved metal, and re-use/recycle it in another process (e.g. electrowinning, ion exchange) (U.S. EPA, 1996). Whereas many of these technologies are not really new, they have not before had the regulatory & economic justification for their use in metal finishing (Kirk & Othmer, 1995). Recovery reduces raw material costs by returning otherwise lost components to the process, and reduces contaminants in waste stream which lowers treatment costs and aids in compliance with discharge limits. The recovery technologies do, however, require at least some, and in many cases extensive engineering and planning. In addition, the feed stream usually requires complete characterisation. The level of customisation and engineering required for certain installations can represent a significant portion of capital costs and can make small feed stream volumes expensive to treat. Substantial process modifications or technology changes will require capital investment, however numerous case studies demonstrate that pay-back periods can be as little as months to 2 years (Gallerani and Brake, 1993).

2.4.3.h Closed-loop Systems

Recovery of metals/chemicals from rinse waters and spent process baths using technologies such as evaporation, ion exchange, and reverse osmosis can potentially be used so as to keep rinse waters in a closed-loop. However, 100 % recovery/reuse of all materials (process and other chemicals, water, sludge, etc.) is usually not practical, economically feasible nor efficient from an energy standpoint (Cushnie, 1994). With every technology or configuration there is some residual generated. For example, rinse water discharge can be eliminated, but the contaminant build-up in the bath will require purification of the spent solution which will result in some residual which will need to be properly discarded. Zero discharge is most likely to be achieved in the following stages:

1. Prepare a pollution prevention plan
2. Implement good operating practices
3. Minimise drag-out which causes waste water generation
4. Modify rinsing practices to reduce/eliminate flows to treatment
5. Implement bath maintenance and chemical recovery

6. Continuously reassess flowrates, process chemical/contaminant concentrations in recovered streams, costs, and benefits.

A negative aspect of zero discharge is the loss of flexibility that is provided by a wastewater treatment system/discharge.

Cushnie (1994) discusses problems associated with implementing certain technologies. He notes that international experience has shown that many installations of chemical recovery technologies and advanced bath maintenance have not been successful, with failure most frequently caused by:

- Maintenance problems (including inability to purchase replacement parts)
- Misapplication of the technology (due to ignorance on part of suppliers or shop personnel)
- Poor technical support by manufacturers
- Improper operation of technology by shop personnel (may be technically too complex)
- Chemical recovery causing a build-up of contaminants in process bath
- Recycled water of insufficient quality or chemical insufficiently concentrated for return to process bath
- High residuals generation

Examples of potential wastewater treatment and chemical recovery options are included in the summary table in Appendix B2. In some cases, a better option, if it is possible, is for metal finishers to make use of off-site recovery (in centralised waste treatment facility) or even recycling (where concentrated metal solutions and sludges may be processed into useful raw materials).

2.4.3.i Off-site Recycling/Recovery

In the USA there are a number of off-site metals recycling services (U.S. EPA, 1996). These were previously limited to spent solvents, precious metal wastes, and high purity common metal wastes, but now include services for a wider range of wastewater treatment sludges, and some facilities also accept spent chemical solutions. Companies that recycle metal accept limited types of waste, depending on their permit (issued by the U.S. EPA). Centralised waste treatment (CWT) facilities which accept metal finishing wastes are becoming more common in other countries (U.S. EPA, 1996). (Even in South Africa a CWT facility for regenerating spent hydrochloric acid for steel pickle, has been in operation for some years now, and is an excellent waste minimisation option for galvanizers who generate large volumes of spent HCl solution).

2.4.3.j Process Substitution

Alternative metal deposition methods are Cleaner Technologies that can replace some of the wet chemical processes that have inherent pollution control problems. In many cases, though, pre-cleaning and post-treatment processes are unaffected and, therefore, some conventional tank processing is still required. Many of the alternative processes have very high unit plating costs, and therefore, are currently used only for special applications where the cost of coating is not a major consideration (U.S. EPA, 1996). In general, the use of the advanced surface treatments (e.g. ion beam implantation, thermal spray) is more appropriate for treating small components because the treatment cost for these processes is proportional to the surface areas being covered. Some of these technologies are listed in the summary table in Appendix B2.

The U.S. EPA (1996) Guide to '*International Waste Minimisation Approaches & Policies to Metal Plating*', as well as the NEWMOA (1997) manual include discussions of the basic elements and process steps of these technologies, as well as their uses, relative cost, waste generation and safety considerations, which all need to be carefully considered when investigating these replacement technologies.

2.4.4 Summary

In summary then, the classification of waste minimisation options presents a wide range of solutions to the problems associated with a metal finishing shop's wastes and emissions, and because the categories are broad there will be some overlap. Some shops will be able to explore options in all categories; other shops may be limited to exploring only a few. In actual application, waste reduction techniques generally are used in combination so as to achieve maximum effect at the lowest cost (Freeman, 1990).

The selection of specific reduction techniques by an individual business must be based on accurate and current information on waste-stream generation and waste management costs. However, even reliable data would not reveal what actions, out of the broad range of possibilities, a specific industrial operation might reasonably undertake to reduce waste, because so much of what is technically and economically feasible is site-specific (Freeman, 1990). Therefore, although all identified options are possible, the potential for implementation of any option will depend on a number of site-specific factors which need to be investigated. This investigation forms part of the evaluation phase of the WMA methodology (Coleman, 1994).

2.5 CONCLUSION

The technology used in the core metal finishing processes tends to be the same from country to country. Metal finishing processes result in a variety of wastes and environmental releases which have potential for human and environmental harm. A wide range of potential waste minimisation options for metal finishing wastes have been reported in international literature.

While the above discussion of these options is not exhaustive, it does provide core information on pollution prevention opportunities for the metal finishing industry and gives an indication of the potential for waste minimisation within the industry. In the following chapter, the trend in awareness and adoption of these options (and waste minimisation in general) within the metal finishing industry in various countries is discussed. This discussion is set against the background of various influencing factors, including the characteristics of the industry, general and specific barriers and incentives, and the key role players in each case. These same influencing factors are then discussed in Chapter 4 for the South African situation and will help to assess the potential for adoption of this vast range of waste minimisation options in the South African metal finishing industry. In addition, the same list formed a vital starting point for the options generation phase of the case studies discussed in Chapters 5 and 6.

Chapter 3: Waste Minimisation Experiences in the Metal Finishing Industry in Other Countries

> *'South Africa has an opportunity to learn from the mistakes of developed counties regarding pollution and waste. We are in an ideal position to incorporate foreign initiatives, together with our own ideas'*
> *– EMC, 1993*

3.1 INTRODUCTION

The countries included in this review were chosen mainly due to the significant waste minimisation activities that have been undertaken in the metal finishing industry in each case. They are the USA, The UK, The Netherlands, Denmark, Germany and Australia. The metal finishing industry in each country is examined according to size, structure, and key characteristics that may influence environmental performance. This is to set the background for the discussion on trends in waste minimisation within the industry. Barriers and drivers to waste minimisation encountered in each country are also outlined, as are the roles of key stakeholders in spreading the waste minimisation concept within the industry.

3.1.1 Information Sources

In the USA, the metal finishing industry has been a focus for pollution prevention initiatives for almost 20 years. There is a considerable amount of documented information on the activities in the sector (U.S. EPA 1994, WRITAR 1995, NEWMOA 1997, etc.). The US Environmental Protection Agency (U.S. EPA) and a number of other sources, have produced a significant number of documents and factsheets on waste minimisation initiatives and programs in the US metal finishing industry.

Very little information on the Australian metal finishing industry was found in literature searches. The secretary of the Australian Institute of Metal Finishers was contacted, but was unable to provide even estimates of the size and structure of their metal finishing industry. A recent *Cleaner Production Manual for the Metal Finishing Industry* in Queensland (UNEP WG, 1997), suggests that the Australian metal finishing industry profile is very similar to that of the US. The manual also indicates that initiatives within the metal finishing industry in Australia are only just beginning to be implemented. The manual was written in 1998, but if any further progress has been made, information has not been made publicly available. Australian initiatives are interesting in that because they are more recent, they have also paid attention to the lessons learned from experiences in other countries and utilised this knowledge in local initiatives (ANZECC, 1998). This is evident by the approach of the UNPE WG Manual. The Manual also presents some Cleaner Production case studies from Australian metal finishing shops which form part of a national Cleaner Technology transfer initiative (EnviroNET Australia). Some aspects of these case studies have proven particularly useful in assessing options for the case studies presented later in this thesis.

General information on waste minimisation initiatives in other countries is obtainable from a wide variety of sources (e.g. demonstration project documentation such as the Dutch PRISMA experience (PREPARE, 1991b), but there is very little information on activities specific to the metal finishing industry apart from a few reported case studies. The U.S. EPA undertook an analysis of '*International Waste Minimisation Approaches & Policies to Metal Plating*' (U.S. EPA, 1996), which provides useful background information on the Western European countries, but not much on actual activities. The trend in adoption of waste minimisation within the industry is not documented and in most cases has to be assessed by comparing older literature with more recent literature, where it is available. There is also very little literature available regarding the demographics and characteristics of the metal finishing industries in other countries.

To add to the minimal literature information, therefore, an attempt was made to obtain quantitative and qualitative data from other sources. A number of international industry 'experts' were contacted via e-mail and fax mainly to obtain information on the metal finishing industry and waste minimisation trends in other countries. Amongst this group were researchers and practitioners associated with the UNEP Cleaner Production Programme, and specifically with the working group on the metal finishing industry, as well as industry association representatives. Apart from some qualitative information, the attempt was met with little success.

3.1.2 *European Study Tour*

An opportunity to travel to the UK lead to the idea of extending the visit to include a brief study tour of the UK metal finishing industry to add to the information gathered through literature and correspondence. The possibility of visiting other European countries at the same time was explored and the Netherlands and Denmark were chosen due to the Industrial Symbiosis Project leader's contacts there. In addition to the investigation objectives listed above, a further objective of the European study tour was to witness waste minimisation in practice through plant visits.

A questionnaire was prepared to ensure all aspects were covered in the various meetings and plant visits. Due to the visit falling in the European holiday session (June/July), there was some limit to time and to who was available for meetings, and it was not possible to meet with as many people as would have been liked. It was also not possible to meet with any government organisations. However, the meetings that were arranged were all highly successful and much valuable information was obtained.

In the UK, meetings were arranged with representatives of the Galvanizers Association (GA), the Surface Engineering Association (SEA), a general environmental consultancy (EnvirosMarch) and an international consultancy (T.Such International) connected to the UNEP Cleaner Production Metal Finishing Working Group. From these meetings as well as literature obtained from the meetings, a general idea of the present situation in the UK was obtained, as well as of the trends over the past few years. Time limits meant it was not possible to arrange any plant visits despite the enthusiasm of the Association representatives.

Meetings in the Netherlands were arranged via e-mail through previous contacts of the Industrial Symbiosis Project leader. A joint meeting was arranged with two separate industry associations associated with the metal finishing industry. The two associations were the Association FME-CWM (representing the metal and electrical engineering and allied sectors) and the national surface finishing association (Vereeniging voor Oppervlaetechnieken van Materialen or VOM). A separate meeting was held with the Dutch hot-dip galvanizing industry association (the Stichting Doelmatig Verzinken, or SDV). The SDV also arranged a plant visit to a hot-dip-galvanizing and powder coating company. In addition, a meeting was held in Rotterdam with an environmental consultancy (BECO) and an associated foundation for the promotion of waste minimisation within industry (Stimular).

Meetings in Denmark were arranged through the Danish Technical University (DTU). Johan Gregersen of the DTU's Institute of Product Development (IPU) arranged a plant visit to a hot dip galvanizing plant. Mr. Gregersen also organised a tour of the IPU's research laboratories for improved electroplating techniques. A meeting was also held with Henrik Wenzel of the Institute and with Kristian Loekkegaards of Ernst & Young (previously involved with UNEP projects in the metal finishing industry in Denmark and Malaysia).

In addition to the information gathered in interviews, a large amount of additional literature was obtained from the various organisations at the meetings. A report was written documenting the information gathered from meetings, interviews and plant visits. It sets out the discussions and findings from these and concludes the key findings and lessons learned (Jänisch, 1999). Literature collected during the study tour includes information on waste minimisation initiatives in the German aqueous metal finishing industry. Since environmental legislation affecting metal finishers in Germany is generally considered to be some of the most stringent in Western Europe, the developments are interesting, and have therefore also been included to some extent.

This chapter combines the findings from the literature review, the European study tour report, and other research to give an overview of international experience so as to satisfy the objectives set out above.

3.2 THE METAL FINISHING INDUSTRY IN OTHER COUNTRIES

3.2.1 Structure of the metal finishing industries

Accurate information regarding the size and structure of the metal finishing industries in each of the countries was not easy to come by. Only job-shop metal finishers are included in the statistical information that is generally available for the metal finishing sector in each case. Captive metal finishers are integrated into a larger manufacturing operation. These establishments, which both manufacture and finish products, are classified according to their end products and, therefore, are not listed. Therefore, figures for total number of metal finishing sites generally do not include the numerous captive operations. Where possible, estimates of the number of captive shops have been obtained based on the knowledge of key stakeholders in the industry, but the estimates of job-shop numbers are generally more reliable.

A summary of both qualitative and quantitative information for each country is included in the table below. An explanation of the sources of statistical information is included in Appendix C1. Information is not included in some cases as it has not been obtainable.

Table 3.1: Structure of the Metal Finishing Industries in Other Countries

	USA	U.K.	Holland	Denmark	Germany	Australia
Population	~350m	~60 m	~15m	~8m	~80m	~20m
Total no. of job-shop finishing sites	3,500 (25% of total)	700 (60% of total)	1800 combined (electroplaters: 35% are job-shops & 65% are captive)	350	700 (30% of total)	Total unknown (at least 150 in Queensland)
Estimate of no. of captive shops	10,000 (75% of total)	500 (40% of total)			1600 (70% of total)	
% SMEs (<250 employees)	99.5%	>90%	Almost all	>95%		
% < 50 employees	>90%	90%				
% < 20 employees	>66%	>50%	Typical shop	65%		
Electroplaters		32%	(350) 20%	(100) 30%		13%
Painters and powder coaters		44%	(700) 40%	(125) 35%		67% (powder coaters)
Galvanizers		3%	(30) 2%	(30) 8%		3%
Anodisers		8%	(50) 3%			3%
Other		13%	(650) 35%	(95) 27%		

(Danish EPA, 1997; SEA, 1999; Janisch, 1999)

Since information for all countries in each category is incomplete, it is not possible to make conclusive comparisons. However, some similar trends appear to exist.

A 1993 report on environment and competitiveness in the U.S. metal finishing industry noted that only 10-15% of the metal finishing companies in the USA are job shops, and that most metal finishing activities occur in captive shops within larger manufacturing operations (WRITAR, 1995). The 1994 Sustainable industries report (U.S. EPA, 1994) suggests that the figure is closer to 35% job shops (there are 3,500 independently owned metal finishing job shops, and estimates indicate that there are approximately 10,000 captive finishing operations). The latter figures seem to be in-line with the trend in Germany and Holland where the ratio of job-shops to captive is 30-35%:70-65% respectively (though the figures for Holland are for electroplaters only).

For the UK, there appears to be a higher proportion of job-shops to captive at 60%:40% respectively. This may be due to incomplete or inaccurate data gathering by the Surface Engineering Association (SEA, 1998). However, the source report for these figures states that the German job-shops represent a much smaller part of the sector than in the UK, the in-house shops being more than twice as common. Whilst the overall number of shops in Germany is three times that in the UK, the number of job shops is the same.

All in all it must be noted that captive metal finishing operations are difficult to assess, owing to the wide range of industry sectors to which such shops belong.

A definite trend found in each of the countries is that SMEs make up the vast majority of metal finishing shops. Generally, less than 5% of shops are large industries, the majority (>90% in some cases) have less than 50 employees, and more than half have <20 employees. This is not surprising considering the nature of the industry, and that SMEs usually make up the highest proportion of industry in general. SMEs comprise over 90% of the companies in Dutch industry (Gombault et al, 1999). SMEs are a vital and increasingly important part of the UK economy, accounting for 99.8% of UK business (Groundwork, 1995). In the US a typical metal finishing job shop is a small single establishment that employs 15 to 20 people (U.S. EPA, 1994). In the Netherlands, the average job-shop in the metal finishing industry has 15 employees (Uittenbroek, 1999). Hot dip galvanizing companies in the Netherlands are generally on the larger side, though still mostly SMEs with employee numbers ranging between 50 to 100 per company (RIVM, 1992).

Between 1982 and 1987, the number of smaller shops in the US declined, while the number of larger metal finishers increased. This development appears to signal a trend toward smaller shops closing down and medium and larger shops incrementally increasing in number (NEWMOA, 1997). Overall, there has been a sharp decline in the number of job shops. Similarly, there has been a decrease in the number of metal finishing shops in the Netherlands. In 1970 there were around 1200 electroplating shops in Holland, now the number is closer to 350. It appears the numbers are falling away because small firms in particular cannot exist with the increasing costs of operation. Increased environmental costs have been the most significant contributing factor (Uittenbroek, 1999).

In terms of the breakdown of process types, information for the US could not be obtained, however common trends are observable from the data for the Western European countries and Australia. Referring to Table 3.1 above, painting and powder coating combined, appear to make up the largest sector in terms of total numbers in each of countries. Electroplating makes up the next largest group, and is probably the largest group if painting and powder coating are separated. Other significant sectors are anodisers and galvanizers, though they are much smaller in number (<10%).

In the US, the number of metal plating and related facilities decreased by 4.3% over a ten year period from 1982 to 1992, while coating and related facilities increased 19.5% over the same period (WRITAR 1995). In Australia, powder coating has already made major inroads into liquid coating markets and has penetrated traditional decorative plating markets as well. The desirability of powder coating is based on the near elimination of wastewater streams and VOC releases as well as superior material use efficiency (UNEP WG, 1998).

For the US and the UK, further information regarding the most common electroplating processes was also obtained. This breakdown is included in Table 3.2 below. Overall it appears that the most common process types appear to be equally popular at between 30-40% usage each. The next most commonly used process in the US is tin acid plating at 27%. The accuracy of these figures cannot be determined. For the US figures it is believed that the non-cyanide and cyanide treatments have been under-reported in the survey (WRITAR, 1995).

Table 3.2: Most common types of electroplating processes in the US and the UK

Plating type	% of shops using the plating type (bearing in mind most sites employ more than 1 process)	
	USA	UK
Nickel	42%	40%
Non-cyanide zinc	39%	
Copper cyanide	38%	40%
Electroless nickel	30%	
Decorative chrome	29%	40%

(Sources: WRITAR, 1995 and SEA, 1999)

3.2.2 Characteristics of the metal finishing industries

Comprehensive information about the characteristics of the *U.S.* metal finishing industry is available in the literature. In a report entitled: *Sustainable Industry; promoting Strategic Environmental Protection in the Industrial Sector: Metal Finishing Industry* (U.S. EPA, 1994) the key industry and firm characteristics and trends that may influence a company's decision-making process with regard to environmental activities were identified. Information for the report was gathered from meetings and discussions with metal finishing industry members, trade association representatives, and industry experts, as well as data taken from the SIC records for the metal finishing industry.

Such comprehensive information was not found for any other countries. However, the US characteristics were discussed in meetings during the European study tour and it was mostly agreed that the characteristics of the US metal finishing industry may generally be considered representative of the characteristics of the sector in most countries. Where there is disagreement, this is noted below.

The US metal finishing industry is very diverse in terms of processes and size of operations within the industry and caters for many applications. Although geographically diverse, the industry is heavily concentrated in what are usually considered the most heavily industrialized regions in the United States. This geographic concentration has occurred in part because small plating facilities locate near their customer base to be cost effective (NEWMOA, 1997). A relatively small number of process chemicals, plant and equipment suppliers service a highly fragmented surface finishing shop sector made up of in-house contract and independent job-shops (U.S. EPA, 1994).

Job shops tend to be small and generally have fewer resources available to address environmental concerns. In addition, they are usually less specialised than many captive operations. Captive metal finishers tend to have greater access to financial and organisational resources and, consequently, tend to be more proactive with their environmental programs. Enough similarities exist between the independent and captive facilities that they can essentially be considered part of one industry. They use the same types of processes and fall within the same regulatory framework. In addition, the two segments have parallel ties with suppliers and customers (U.S. EPA, 1994).

Differences that do exist between the two segments can be used to understand more fully the drivers of the decision-making processes and the barriers to improved environmental performance in each segment. Captive operations may be more specialised, or focused, in their operations because they often work only on a limited number of products and/or employ a limited number of processes. Independent metal finishers, on the other hand, tend to be less focused in their operations because they may have many customers, often with different requirements. Independent and captive metal finishers do not ordinarily compete against each other since captive finishers seldom look for outside contract work. However, captive facilities may outsource tasks to independent facilities. This trend in outsourcing is becoming more common in the Netherlands (du Mortier, 1999).

There is general lack of technical knowledge amongst metal finishers which leads to reliance on external parties for technical advice and know-how (U.S. EPA, 1994). There is a great reliance on chemical and equipment suppliers for technical knowledge regarding even the day-to-day operations of processes. In addition, several trade associations play key roles in the metal finishing industry. Some of the better-known national organisations and associations relevant to the metal finishing industry in each country are listed in Appendix C2 along with a brief description of their main functions. Most of these associations have extended their activities to include environment-related services, especially in terms of the new environmental legislation requirements and how to meet them (i.e. pollution prevention options). For example, in the UK, ten years ago there was a sudden focus on environmental issues and membership to the SEA increased because of these environmental issues (James, 1999). Specific environmental committees have been established within many of these organisations in order to carry out these new roles. For example, the UK GA has appointed an Environmental Health & Safety manager and committee.

The U.S. EPA has stated that 'excellent plating quality and responsive service' are the two defining competitive variables within the metal finishing industry (U.S. EPA, 1994). However, the Dutch VOM and the UK SEA, believe that these variables are secondary as metal finishers compete on price first and foremost (du Mortier, 1999 and James 1999). In an Australian document it is noted that metal finishers view themselves as a service industry, responding to customer specifications and demands for quality products which, in some instances, limit their environmental options. In the US, where perhaps the most significant Cleaner Production efforts have been made, it has been reported that environmental performance now has a significant effect on the competitive dynamics of the industry. Firms that are able to keep up with compliance demands and accommodate increased costs of operation can be expected to reap some benefits from increased outsourcing activity and transferred business from defunct shops (UNEP WG, 1998).

Many other factors, both economic and environmental, affect the performance of each individual metal finishing operation. For the metal finishing industry, the nature and capital intensity of production and environmental technologies, the size of firms, the availability of substitutes for manufacturing inputs are some of the factors that are likely to affect both environmental and economic performance (U.S. EPA, 1994).

The scope and stringency of environmental regulations applicable to the metal plating industry are increasing. Such changes have forced nearly all metal platers to increase investments in pollution control equipment, employee training, and waste treatment and disposal services. However, the level of these increasing standards and the ability of platers to respond to them is not uniform. Even within developed countries, platers are faced with non-uniform requirements and enforcement (U.S. EPA, 1996).

More stringent legislation has lead to increasing environmental costs for companies to achieve compliance. This has had an initial effect in creating an unlevel playing field in which certain "rogue" companies are unable to take on the costs and have therefore had to operate illegally. However, the strict enforcement of the legislation, leading to increased environmental costs, has effectively driven these "rogue" companies out of business, causing them to shut down, thereby creating a more level playing field (du Mortier, 1999). For example, in Germany, many of the smaller surface finishing shops there had to close down, being unable to fund the capital investment necessary for new or additional equipment required to meet stringent environmental regulations (SEA, 1998).

While environmental concerns in the UK surface finishing industry are important, associated costs are low for most surface finishing sites (SEA, 1999). Environmental (treatment and waste disposal) costs in 1998 range between 1 and 5% of revenue, with the majority being between 1 and 2%. Electroplating and anodising sites have slightly higher costs. Specialist engineering paint and powder coating sites have the lowest costs with 27% spending <1%. According to a VOM document on the economic aspects of surface coating, the environmental costs at job shops in the Netherlands as a percentage of turnover are as follows (VOM, 1998): Electroplating: 15-30%, Industrial painting: 10-40%, Anodising: 5-10%.

A typical US job-shop operating cost breakdown puts environmental costs at around 5% in 1993 (WRITAR, 1995). Capital expenditures for pollution abatement by 1991 amounted to greater than 20% of the total capital expenditures for the industry. According to US Commerce Department estimates, 1992 pollution abatement costs and expenditures for the metal finishing industry totalled over a fifth of their budget (www.nmfrc.org).

3.3 TRENDS IN WASTE MANAGEMENT IN THE METAL FINISHING INDUSTRY

This section gives an overview of general trends in the adoption of waste minimisation in the countries investigated, to provide a background for understanding the current state of adoption of waste minimisation in the industry. Experiences in individual countries which are outlined below are considered indicative of general trends in the US and Western Europe.

Environmental concerns in industry began with concern for water pollution and the initial response to environmental pressure by industry was to implement end-of-pipe technologies for effluent treatment (du Mortier, 1999). Initial aspects of waste minimisation were introduced in the early 1980's, but the focus was mainly on the reduction of hazardous wastes. Air pollution was the next important focus after water, and this then shifted to soil/land pollution. The majority of environmental laws affecting industry, initially focused on end-of-pipe regulations, and on single-media pollution (U.S. EPA, 1996).

For example, in Denmark, in the period 1973-1990s, a company's process was treated as a black box, and the focus was on the emissions to air and water. The wastes and emissions were dealt with at end-of-pipe. Prior to the first Danish Cleaner Production programmes of 1987, environmental endeavours had primarily been based on dilution and abatement methods. Environmental regulations were based on a case-to-case approach and the central authorities' knowledge of environmental and production conditions in the enterprises mainly stemmed from the processing of complaints and appeals (Danish EPA, 1997).

In the late 1980's attention began to turn to encouraging the reduction of waste streams rather than just dealing with them and the popularity of pollution prevention as a strategy of preference of solving environmental problems, grew (Freeman, 1995).

Until the 1990's, pollution prevention in practice had been slow to catch on, despite all its advantages. Bresnan (1994) noted that perhaps the biggest impediment to industrial implementation of pollution prevention in the US was the current regulatory system, which required pollution abatement through installation of specific control technology. Once a company had invested in expensive control technology, the company felt compelled to use it rather than search out ways to avoid its use. Furthermore, very little information was available on no- or low-pollution technologies or on ways to change processes through pollution prevention techniques.

At the end of the 1980's, the metal finishing industry in the UK was, in general still very dirty and few shops had even implemented end-of-pipe technologies (UK DTI, 1991). These businesses exhibited very low profitability and their capacity for investment in new plant was minimal. Regulatory pressure and certain legislation had already driven some of the UK surface treatment companies to consider pollution prevention. Generally however, interest in waste minimisation was low because, at the time, the cost of waste treatment and disposal (where it did occur) was not significant. End-of-pipe technology was considered a satisfactory response to legislation. An additional factor that could not be ignored was that because the industry comprises many very small jobbing-type operations, enforcement of legislation was ineffective. Many companies found it very easy to throw restricted effluents down the drains without being caught (Ibid.).

Public pressure combined with the activities of both national and locally based environmental groups helped move pollution prevention legislation through State legislatures (Bresnan, 1994). Pollution prevention gained support relatively quickly because it enabled governments to pursue both economic development and environmental quality objectives – objectives which are usually seen as irreconcilable (U.S. EPA, 1996).

In November 1990, the US Congress passed the Pollution Prevention Act (PPA), which stated the nation's commitment to the concept: Congress "declares it to be the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible". Several pollution prevention initiatives and grant programs were implemented. The U.S. EPA signed a Pollution Prevention Policy Statement in June 1993 outlining the U.S. EPA's strategy for implementing the Pollution Prevention Act. U.S. congress reauthorized the Clean Water Act and reviewed the effluent guidelines and standards for Electroplaters and Metal Finishers in the early 1990's.

It was the UK's Environment Protection Act of 1991 that had the most significant effect on the uptake of waste minimisation by industry. Industry Associations such as the SEA and GA in the UK, had to take up environmental issues to help their member companies comply with new regulations (James, 1999). In Denmark at the end of the 1980's, consideration was given as to how environmental regulation could be organised to promote prevention in a more appropriate manner, and the Development Programme for Cleaner Technology was initiated in 1987 (Danish EPA, 1997). During the course of relatively few years from the introduction of the Cleaner Technology support scheme in 1987 to the amendment of the Environmental Protection Act in 1992, the Cleaner Technology concept became a well-established and institutionalised part of the Danish environmental regulation strategy. The Australian Environmental Protection (Waste Management) Policy (1994) included the requirement for nominated industries to implement a Cleaner Production plan.

Environmental policies initially focused on single-media approaches for environmental protection. The next phase of policy directions were based on a multi-media approach, recognising that pollutant releases to each environmental medium (air, land, and water) affect each other. Environmental strategies needed to identify and address these inter-relationships by designing policies for the "whole facility". Design of environmental strategies for similar industrial facilities, enabled environmental concerns that are common to the manufacturing of similar products, to be addressed in a comprehensive manner (OEA, 1998).

Pollution prevention has advanced from a concept to a proven, practical method (Oldenburg and Geiser, 1997). A wide variety of policy approaches to waste minimisation have now been adopted reflecting the differences in industrial profiles, environmental releases, business cycles, and the political climate in each country. These are outlined in Section 3.8, as part of the discussion of the influencing factors in the adoption of waste minimisation in the industry.

3.4 ADOPTION OF WASTE MINIMISATION IN THE INDUSTRY

In the countries investigated, waste minimisation in the metal finishing industry has since been well promoted and studies have been published showing the benefits that have been gained. It was found that many metal finishing shops have implemented one or a combination of waste minimisation techniques in order to meet regulations or reduce treatment and disposal costs. In the following section, an attempt is made to combine the results from studies undertaken in Denmark (1992), the USA (1994), the UK (1998), and Germany (1998) to obtain an indication of any specific trends for the metal finishing industry. More detail on these studies is included in Appendix C3. It must be noted that the studies in the U.S. and Denmark are from >5years ago, and it is likely that there has been further adoption in each case. Findings from general waste minimisation projects (such as the PRISMA project) are also included to show common trends and provide a context for the results more specific to the metal finishing industry. A summary table of both qualitative and quantitative results form the studies, is included in Table 3.5 after the discussion.

3.4.1 Improved Operating Practices and Process Control

International experiences with Cleaner Production indicate that the most significant gains have been made through improved operating practices and process control rather than through new technology (WRITAR, 1995). In general most attention has been given to improving the existing basic production technology through improvement of operating and maintenance practices and the application of more efficient equipment and monitoring and control devices (van Berkel, 1996). Studies undertaken on the diffusion of Cleaner Technology in Denmark show that within a few years, the use of Cleaner Technology had become widespread, but in general, housekeeping measures and substitution of materials have diffused more rapidly than changes and new investments in actual production equipment (Danish EPA, 1997). In Australia, as part of a UNEP Metal Finishing Working Group project, a number of businesses were visited to discuss the potential for Cleaner Production in the industry. It was found that for the few companies that have successfully implemented waste minimisation, it tends to be in the area of improved housekeeping or simple process modification (UNEP WG, 1998).

Cushnie (1994) states that widespread success in the US electroplating sector has been achieved using simple and highly cost-effective methods and techniques that reduce drag-out losses and rinse-water use. Rinsewater and drag-out reduction options appear to have been most widely adopted and successful measures undertaken by metal finishers in the countries investigated. The greatest interest and success for reduction of water usage in the US, UK and Denmark is cited as the use of more counter-flow rinse tanks. The use of flow restrictors has also been highly popular in the US. For those in the US survey that were able to quantify, average water flow reduction was 30% and some shops have even reduced flows dramatically by 90% or more (Cushnie, 1994). In the UK, techniques of using drag-out tanks and other simple drag-out reduction methods, have been the most popular and achieved the highest success level (SEA, 1999).

Where there is reliance on suppliers for process optimisation, as in the metal finishing industry, modifications to processes are less likely to be considered (Danish EPA, 1997). Careful control of process parameters (temperature, flow rates, contaminant concentration, pH, density, etc.) and process modifications (extending drain times to reduce drag-out, extending the life of cleaners, rinsing techniques, etc.) have been the key to waste reduction in the metal finishing industry. The 'technology' associated with these activities is usually quite simple and within the grasp of all businesses, including SMEs (WRITAR, 1995).

There is no data regarding the extent of adoption of options in SMEs vs larger companies. However, since over 90% of job-shop metal finishing companies in each country were found to be SMEs, it is may be assumed that the widespread success applies to SMEs in the metal finishing industry. It is likely, however that actual method implemented for achieving a waste minimisation objective, may differ depending on the size and financial ability of a company. The prevention of wastes and emissions is very much a company-specific activity. In many cases the areas of priority are characteristic of the branch of industry itself but the concrete solutions differ from company to company (PREPARE, 1991). For example, in the Dutch PRISMA Project, the same problem of water pollution and treatment sludge was identified in both of the 2 electroplating companies. The result was two entirely different sets of prevention options. An example of one problem that resulted in two different solutions was the reduction of drag-out by improving the drainage of work-pieces being transported from one process bath to another. For the one company where work is done manually, the prevention option was one of good housekeeping measures. For the other – a mechanised firm, the same option was realised through technical modifications (PREPARE, 1991).

3.4.2 Technology/Hardware Options

Where more complex technologies have been adopted in the metal finishing industry to reduce emissions, it is mostly due to specific regulations requiring significant improvements in process efficiency and hence the use of Cleaner Technologies. In the US, permits request the facility to adopt "Best Management Practices" under the Clean Air Act or the Clean Water Act. The permits set numerical standards for discharges and emissions, and in some instances may also specify the kinds of equipment and operating procedures that will be used (U.S. EPA, 1996). Although some shops in the US have had great success with chemical recovery technologies, such as ion exchange, they have generally been much less frequently applied than simple drag-out and rinse-water reduction efforts. In the US, 30-40% of chemical recovery and advanced bath maintenance technologies have not been successful, maintenance problems being the most common cause of system failure (Cushnie, 1994). U.S. experience has also shown that the most successful of the chemical recovery technologies are the least technically sophisticated technologies (e.g. atmospheric evaporation). Bath maintenance technologies are less frequently purchased than are chemical recovery technologies, but have generally been more successful.

The German metal finishing industry is subject to some of the most stringent environmental regulations in Europe. In particular, National Law requires that trade effluent can only be discharged if the life of process baths is the longest possible, process drag-out is minimised, and wherever possible returned upstream, and water for rinsing is reduced through counter-current rinsing and recirculation. Yet, on a trade mission to investigate Cleaner Technologies used in the aqueous finishing industry in Germany, the UK SEA found that the techniques used relied on readily available mature low cost technologies. The mission had expected to see "advanced" systems such as reverse osmosis, electrodialysis, etc. Instead, the use of conventional technology using standard chemical engineering principles for pollution control and monitoring, coupled with professional management was found to be the norm. Despite the fact the management has a good knowledge of effluent treatment and recycling techniques (including advanced methods in some cases), there is a strong preference to implement classical approaches due to their flexibility and success (SEA & UK DTI, 1998).

No single technology has since emerged as a significant replacement for conventional treatment. The most significant technology change with respect to end-of-pipe treatment for waste reduction in the US, is the use of sludge dehydration equipment (i.e. sludge dryers) to reduce the volume of sludge shipped offsite (Cushnie, 1994).

The SEA Trade Mission to Germany found that, unlike the UK where effluent treatment facilities were treated as end-of-pipe equipment, new German finishing plants have an integrated design with water reduction and materials efficiency as the core. Most importantly, the method showed attractive capital investment paybacks. The key elements in the integrated shop design included counter-current rinsing (minimum 3 stages), evaporation to maintain the water balance, ion exchange for re-circulation of rinse discharges, conventional metal hydroxide precipitation from the ion exchange regenerants, conventional batch filter-press separation, selective chelating ion exchange treatment for the effluent, and miscellaneous technologies such as oil separation for spent degreasers. Both process and engineering were found to have extremely rugged features and a high safety factor (SEA & UK DTI, 1998). The integrated design concept developed in Germany would be entirely viable for the UK, and therefore, probably for most countries, if the regulatory environment were comparable (Ibid.). Most of the technology, including evaporation, is established on an ad-hoc basis in a few surface finishing shops already. The technology base established in the German finishing industry, whilst meeting the environmental and waste minimisation requirements, has been mature for several years.

Closed-loop operation of metal finishing rinsing systems has not generally been successful. In Germany, closed-loop rinse water re-circulation is regarded as impractical (SEA & UK DTI, 1998). For Australia, the UNEP MetFin WG has found that the development of near zero discharge is uneconomic for most operators at this time, even if the technical know-how were available. However, it is considered that the concept will become increasingly attractive as full cost recovery for water and waste disposal are introduced, and as technologies for reuse and recycling become more widely available and economically attractive (UNEP WG, 1998). Of the US shops surveyed that have attained zero discharge (7%), these are primarily hard chrome platers where there is a high ratio of evaporation to drag-out (Cushnie, 1994).

The most common and successful Cleaner Technologies which have been adopted, are those which have been forced upon the industry by regulations specific to processes. Although many of these are 'pollution control' technologies, some have waste minimisation applications. For example, the requirement of the Environmental Protection Act in the UK for galvanizing baths to capture 95% of their particulate emissions has lead to the use of bath enclosures in most galvanising companies. Enclosure of galvanizing baths has resulted in zinc savings and improved process efficiency (Cook and Smith, 1999). The environmental legislation in the Netherlands is derived from European legislation, as for the UK. The trends in adoption of technologies as a result of legislation requirements are therefore similar as in the UK (e.g. hoods and fume extraction are in use in almost all companies owing to legislation requirements).

Once again there is no data regarding the adoption of technology options by SMEs vs. larger companies. It is most likely that the adoption of technologies depends on the constraints of the company. Since technology options require not only capital investment but also time and financial input for monitoring of process conditions and feasibility studies, this limits the potential for adoption in many SMEs. These constraints and how they have been overcome are discussed in more detail in the next section. However, it is noted that technology options have been implemented in the metal finishing industry, and where they have been successful is the application of simple low-cost technologies mainly to achieve process efficiency improvements.

3.4.3 Chemical and Process Substitution

The biggest impact of legislation on adoption of waste minimisation techniques has been by the banning of substances such as chlorinated solvents and cadmium, and the requirements for reduction in use of materials such as chromium and cyanide (e.g. U.S. MACT standards for hexavalent chromium). This has lead to the use of substitute materials and processes.

In Denmark, one of the focus areas of the Danish EPA's Cleaner Production programmes has been on the substitution or reduction of organic solvents. Although material use reduction or material/process substitution methods have mainly been driven by regulatory pressure, other reasons for change, offered by US survey respondents have included requirements to reduce the impacts of their processes on the environment and worker health, and to reduce operating costs (Cushnie, 1994). The European automobile industries, which are reputed to be the major market trendsetters, are also increasingly using water-based paints, and this is expected to have a decisive influence on the market in future (Danish EPA, 1997). In Australia, the use of solvents as cleaning agents in the industry is very limited. This has principally been a result of workplace health and safety and environmental requirements for limiting or eliminating the use of solvent based products (UNEP WG, 1998).

The Integrated Pollution Control (IPC) regulations in the UK have lead to substitution/elimination being taken up in a number of electroplating processes in particular. There has been an effort to find and implement cyanide-free plating processes in most countries. However, alternatives have not been very successful and there has therefore been little response. There is a need for better cadmium alternatives or control technologies. Cadmium plating is the only process that has been replaced by a greater proportion of sites than those still using it. Sites that have not replaced the process have just stopped its use (SEA, 1999).

Efforts in the US to reduce chromium usage have focused on non-chromium aluminium finishing and hard chrome plating substitution. Trivalent chromium is generally the preferred substitute for hexavalent chromium plating. Much research has been undertaken into chrome-free substitutes for chromium conversion coatings and the resulting alternatives have generally been successful (depending on the specific application). Although most of material input changes attempted in the US have been successful, there have been some failures and in many cases, even with successful changes there have been adverse production impacts (Cushnie, 1994).

The regulatory framework has also been the primary force in the gradual decline of classes of metal finishing like cyanide-based systems and cadmium plating (U.S. EPA, 1996). The result is often a renewed interest in new applications of older process technologies which, for example, has been a positive development for the nickel plating industry. Likewise, technical advances in powder coating technologies have not only captured painting segments but also resulted in inroads into a number of decorative plating markets as well.

In Denmark, elimination of VOC has lead to paint substitution as well as investigations into alternative application methods. These include electrodipping, electrostatic spraying or automatic object identification. There is not much information from other countries regarding the adoption of alternative finishing technologies such as vapour deposition.

3.4.4 Summary

In the countries reviewed above, most shops have implemented one or a combination of waste minimisation techniques in order to meet regulations or reduce treatment and disposal costs. Many shops have actually implemented formal waste minimisation programs, but these tend to be the larger shops or those which form part of a larger group of companies (e.g. Bammensgroep in the Netherlands). It is these typically larger shops that are now endeavouring to implement environmental management systems such as ISO14001. Many companies that adopted ISO9000 are now considering ISO14000 mainly due to international pressure. Industry associations, like the UK GA, are encouraging their members to implement at least simple Environmental Management Systems, and it is expected that these will be adopted on a wider scale even by small job shops in the future.

Table 3.3 below gives a summary of both qualitative and quantitative results from the studies. Figures for the U.S. represent the percentage of shops surveyed that have adopted the option (Cushnie, 1994). Qualitative comments are quoted directly from the reports mentioned above.

Table 3.3: Adoption of waste minimisation techniques by metal finishing companies in the USA, UK and Denmark

Waste Minimisation Technique	Adoption in the US	Adoption in the UK	Adoption in Denmark
Techniques of using *drag-out tanks* and other *simple drag-out reduction* methods.	>50%	"most popular and highest success level"	
Techniques for *Reduction of water usage.*	68% ("highest success for flow restrictors 70% use. rate 4/5 and counterflow rinsing 68% use with rate 4.2/5")	38% use more counterflow rinse tanks	"Interest greatest for counter-current rinsing"
Atmospheric evaporation for chemical recovery	Most successful		
Elimination/ reduction of *solvent use.*	68% in 1994	65%	Reduced by 30% between 1987-1992
Aqueous paints to replace *solvent paints*			46% in 1992
Substituting chromium (VI) with chromium(III) for *decorative plating*	Significant strides	16%	

Waste Minimisation Technique	Adoption in the US	Adoption in the UK	Adoption in Denmark
Replace *hard chrome plating.*		36% (mainly with electroless Ni)	
Substitute alternatives to *chromium conversion coating.*	Significant strides	17% (mainly with trivalent Cr, next with permanganate)	
Replace *cadmium plating.*		71% (48% with zinc plating)	
Cyanide bath replacement	There exists a technology transfer insufficiency with regard to non-cyanide finishing.	<40%	
Advanced wastewater treatment methods	10% adoption (ion exchange, evaporation and membrane technology most popular)		
Closed-loop wastewater treatment.	7% in 1994 (mainly hard Cr platers)		
Use of off-site metals recyclers	33%		
Number of shops that have implemented *pollution prevention programs*	51% implemented formal programs		73% by 1992

(Sources: Cushnie, 1994, SEA, 1999, Danish EPA, 1997)

3.4.5 Future Trends

Future trends in adoption of waste minimisation techniques have been predicted. The UNEP Working Group have identified probable short, medium, and long-term trends.

In the short-term, powder coating is likely to be an increasingly popular finishing technology for years to come. Advances in powder technology and delivery systems continue to open up new applications (UNEP WG, 1998).

The expansion of Physical and Chemical Vapour Deposition is expected in the medium term. Vapour deposition technologies are "dry" finishing processes for metal plating. Several technologies are currently available to transport metals in a vapour state to a part to achieve a solid metal coating. It is currently limited to accommodate larger parts and higher production rates hold the promise for a substantial reduction in wastewater streams in metal finishing operations.

Next Generation Technologies are only expected in the long-term. Advances in material science will one day allow for the finishing of parts by radically different methods, or reduce the need for finishing through alternative substrates. Four classes of emerging technologies are:

- Non-aqueous liquid baths which use solutions other than water (e.g. alcohol)
- Physical bonding where metals are deposited through physical rather than electrochemical means

- Nano-technologies which is the use of laser technology to place metals onto surfaces
- Alternative substrates such as ceramics and plastics which reduce the need for metal finishing

3.5 EFFECTS OF WASTE MINIMISATION INITIATIVES ON METAL FINISHING WASTES

It is difficult to measure waste reduction and as a result limited data has been generated documenting results of waste minimisation activities. The Cleaner Production projects have not been restricted to individual Cleaner Technologies and have tended to be used in combination with each other, depending on available space, bath composition and product quality. Therefore, it has not been possible to differentiate the reductions in environmental loading caused by the use of individual methods (Danish EPA, 1997).

Qualitative information indicates that reductions have been made, but as they have not bee quantified, are not very indicative of results that can be achieved. For example, the UK Galvanizers Association has stated that through waste minimisation and other techniques, the UK hot dip galvanizing industry has 'greatly improved its utilisation of process chemicals in recent years, reducing the volumes of acid used per ton of steel processed in particular' (GA, 1999). The Danish EPA has noted that in the hot dip galvanizing industry, 'the use of hydrochloric acid and flux has been reduced significantly and the amount of zinc ash generated has also been reduced substantially through mostly simple waste minimisation techniques and technologies' (Danish EPA, 1997).

Some *quantitative* data is available for the US, from the national Toxics Release Inventory (TRI). According to TRI data for electroplating wastes in the US from 1988 to 1992, releases of TRI chemicals decreased 55% from 22 million to 10 million pounds released annually (NEWMOA, 1997).

Progress reports for the U.S. EPA's 33/50 program indicate that releases and transfers of so-called 33/50 chemicals from all US fabricated metals companies decreased by 31% between 1988 and 1991. Nine of the chemicals monitored by the 33/50 program are typically generated by metal finishing operations. For those fabricated metal companies (large proportion being metal finishing shops) that have committed to participate in the 33/50 program, this reduction was an even more significant 41%. The additional incremental reductions achieved by those metal fabricators participating in the 33/50 program suggest that a well conceived voluntary waste minimisation program can be effective in reducing toxic releases (U.S. EPA, 1996).

According to the chairman of the Dutch VOM, as a result of Cleaner Production in the metal finishing industry, it is estimated that associated environmental effects have decreased by up to 90% in the Netherlands (du Mortier, 1999). However, there is no data to verify this.

3.6 COST-EFFECTIVENESS OF WASTE MINIMISATION

The fairly simple technologies that add to or modify existing production technologies so as to improve environmental performance are what are generally referred to as "low hanging fruit." These waste minimisation options generally result in savings for minimum capital output (van Berkel, 1996). The results from experiences of other countries indicate that the greatest potential for waste minimisation in the metal finishing industry lies in "picking the low hanging fruit".

In the Netherlands, studies into the adoption of waste minimisation options in national and provincial pollution prevention projects have found that only a small number of generated waste minimisation options are actually implemented by the companies (PREPARE, 1991b; Bruijn et al, 1996). The most important factor influencing this decision is costs (Bruijn and Hofman, 2000). Options are generally only implemented when they have a relatively short payback period.

There are numerous published case studies of very successful waste minimisation projects in metal finishing operations, some with payback times of well under a year (PREPARE, 1991; UNEP ICPIC, 1995; UNEP WG, 1998). Financial and economic benefits from prevention differ enormously from one company to the next. Of the 2 metal finishing companies in the PRISMA project, one implemented 4 options all of which had a payback period < 1year, while the other implemented 4 options, all of which with costs neutral (PREPARE, 1991a,b). The results above have shown that the widespread success has been achieved using simple and highly cost-effective methods and techniques that reduce drag-out losses and rinse-water use. Both drag-out and rinsewater reduction measures have resulted in significant savings for minimum capital input (Cushnie, 1994). Improvements in process efficiency and control have been achieved through the application of technologies which allow for incremental change to the production process, which are easily incorporated into existing production processes, and which have low operating costs and set up times. Where Cleaner Technology has been implemented, readily available mature low cost technologies are used, and the resulting improvements in process efficiency have helped to off-set the capital investment (SEA & UK DTI, 1998).

However, pollution prevention projects do not need to generate a positive economic return to be successful. Because most pollution prevention solutions are cheaper than treating or disposing wastes, a greater emphasis on prevention can reduce environmental compliance costs, regardless of whether pollution prevention is profitable even in absence of regulatory requirements (OTA, 1994). Requirements for reduction in use of materials such as chromium and cyanide have lead to the use of substitute materials and processes. New more stringent emission limits have associated increased treatment and disposal costs. By incorporating waste minimisation options first, treatment and disposal costs are significantly reduced. In addition, the use of Cleaner Technologies enabling treatment with reuse also becomes increasingly economically feasible. The new more stringent legislation has meant that the options became cost-effective in comparison to alternatives (Cushnie, 1994). It can therefore be said that potential for cost-effective waste minimisation in the metal finishing industry in other countries has been identified.

However it is important to note that, environmental success does not come 'at a bargain'. The good results have required commitment, time and money (Bruijn & Hofman, 2000). The cost of undertaking the waste minimisation assessment itself in order to identify cost-effective options, therefore needs to be included in this analysis. Although the cost savings are an incentive for adoption of waste minimisation, SMEs may lack the time, personnel and finances to carry out the waste minimisation assessment in the first place. It is important to recognise that there are many barriers that need to be overcome before potential waste minimisation may be first identified, and secondly implemented, cost-effectively. In other countries, many of the barriers have been overcome with the help of a number of influencing factors and incentives. These are discussed in the following sections.

3.7 BARRIERS & DRIVERS TO WASTE MINIMISATION IN THE METAL FINISHING INDUSTRY

A number of barriers to adoption of waste minimisation for SMEs in metal finishing industry have been identified in the international literature and from meetings during the European Study tour (UK DTI, 1991; U.S. EPA, 1996; SEA, 1998; ANZECC 1998). A comprehensive list has been compiled and is included in Appendix C4. Of these the more commonly identified for SMEs are:

- Lack of capital and financial resources of company
- Lack of management time
- Lack of technical skills
- Lack of awareness, information and know-how of waste minimisation options
- Lack of clear environmental legislation
- Resistance to change due to associated risks

(Smaller companies are usually more constrained than larger companies in each case)
Of the drivers identified in the literature for other countries, the most common identified for SMEs are:

- Cost savings associated with waste minimisation
- Stringent environmental legislation and
- External assistance
- Proactive management attitude

These barriers and drivers are used as the basis for the ensuing discussion on factors influencing the adoption of cost-effective waste minimisation in the industry in other countries.

3.8 FACTORS INFLUENCING ADOPTION OF WASTE MINIMISATION IN THE METAL FINISHING INDUSTRY

The role of key players and other influencing factors in promoting waste minimisation in the metal finishing industry are discussed below, particularly the part they play in overcoming barriers and providing incentives.

3.8.1 The Combined Role of Government Policies, and Legislation

While it is the industry itself that ultimately must implement Cleaner Production, the role of government is to lead by providing a conducive environment and institutional frameworks (drivers) that will accelerate the process and encourage industry to initiate its own Cleaner Production programmes (ANZECC, 1998). The major role of government affecting adoption of waste minimisation in industry, has been the development, implementation and regulation of national waste minimisation legislation and policies. Numerous waste minimisation policy initiatives are currently being pursued at all levels of government in most major industrialised countries. The range of instruments used by governments trying to catalyse industry to adopt Cleaner Production is large but found to be in three main categories, namely: applying and enforcing regulations, using economic instruments, and providing support measures (U.S. EPA, 1996).

3.8.1.a Regulatory Aspects

The single biggest influence in adoption of Cleaner Production in the metal finishing industries in each of the countries investigated appears to be legislation and strong enforcement of the legislation. The metal finishing sector being a focus polluting industry in most countries, is subject to environmental regulations specific to its processes, and strict enforcement. Specific environmental regulations in each country that affect the metal finishing industry either directly or indirectly are included in Appendix C5.

In Denmark Cleaner Technology was introduced in legislation in 1996, and companies could be forced to use Cleaner Technology. It is a common belief among those involved that the metal finishing industry is the second most regulated sector in the US, following the nuclear industry (DNRP, date unknown). The German metal finishing industry has been subject to well-defined national, state and local regulations pertaining to environmental and waste minimisation for several years. This regulatory environment has ensured that Germany maintains the most stringent standards within Europe (SEA & UK DTI, 1998). National Law limits trade effluent discharge to lower levels than most of Western Europe (and subject to any more stringent local limits). Similarly, every effort must be made to avoid the production of solid waste and where this is not possible, to seek out uses for the waste (Ibid.). In the UK, the Integrated Pollution Control (IPC) statute regulations have directly affected the metal finishing industry. They apply to the release of pollutants to air, water, and land from certain processes including industrial cleaning and finishing (U.S. EPA, 1996). As discussed in Section 3.4.2, the effect of these regulations on the adoption of waste minimisation has been significant.

The enforcement of the regulations is made easier with the role of the environmental protection agencies that have the resources to serve as both enforcers and helpers for industry in adopting waste minimisation (Jänisch, 1999). The use of voluntary agreements, covenants or codes of conduct is now quite well established in other countries (ANZECC, 1998). Examples include the covenant approach used in the hot dip galvanizing industry in the Netherlands (Jänisch, 1999), and the U.S. Common Sense Initiative (CSI) in the Metal Finishing Industry (U.S. EPA, 1996). These put the administrative burden on industry and allow considerable flexibility in achieving negotiated targets. However, even though there is now a move towards self-regulation by industry in other countries, it appears that strict enforcement at first is a necessary step in the learning curve for the industry. The strict enforcement builds awareness in that the company is forced to implement changes, then sees the benefits of the changes and is then more likely to be willing to implement changes the next time (Uittenbroek, 1999). Once this awareness is there, co-operation between industry and regulators (co-regulation) becomes possible.

3.8.1.b Economic Instruments

Governments also use economic instruments as part of their policies in order to create incentives and disincentives for industry to adopt waste minimisation (U.S. EPA, 1996). Funding, taxes, and subsidies for waste minimisation projects and implementation of technology within industry have facilitated the adoption of waste minimisation, particularly in SMEs. The main purpose of these economic instruments is to create a behavioural change by creating a financial punishment or reward. Dutch (local) government has acknowledged the importance of stimulating SMEs towards Cleaner Production. These schemes are not always made use of owing to the bureaucratic method for applying for these schemes which discourages industries to make use of them (Versteege, 1999). In Denmark, financial instruments concerning waste minimisation are taxes, duties, and fees, as well as grants and subsidies. There is a duty on raw materials and several duties on wastes (not including materials for recycling or recovery) whether incinerated or landfill disposed (Danish EPA, 1997). Innovative technology generally is more expensive than older technology as developers need to recoup research and development costs, and new technology manufacture often doesn't have the benefit of economies of scale. In the UK and Australia, grants and tax deductions are available to support the development of clean technology.

3.8.1.c Support Measures

Internationally, numerous demonstration projects have also been initiated and funded as part of government policy to promote waste minimisation. These are mainly set up after new environmental legislation comes into practice and tend to focus on the problem industries/ materials (e.g. heavy metals). In both Denmark and the Netherlands, the metal finishing industry has been one of the focus industries for these government programs. By using pilot projects to develop technologies and demonstrate their environmental and economic results, it is hoped to be able to stimulate other enterprises to implement these technologies in their production (ANZECC, 1998). Most demonstration projects have been multi-industry projects, though a few have been directed specifically towards the metal finishing industry. The Danish government specially developed programmes for diffusion of technology within specific industry branches, including the metal finishing industry. These programmes have been highly successful (e.g. >70% of galvanizing industry implementing Cleaner Technologies), and are ongoing (Danish EPA, 1997).

The perceived risk associated with the new technologies also can be minimised through demonstration. Managers of SMEs in particular who are unwilling/unable to take risks with new technologies need to be shown that they do work in practice (Lokkegaard, 1999).

Overall the technique of demonstration projects has been proven to be highly financially viable to participants as well as being extremely environmentally beneficial for the companies involved. The funding has obvious effects on improving the cost-effectiveness of waste minimisation potential, particularly in SMEs. The Waste Minimisation Club concept as demonstration projects have also been funded by government and found to work well for SMEs in particular, as they cannot generally afford the cost of an outside consultant (Mercer, 1999).

3.8.1.d Providing Access to Pollution Prevention Information and Case Studies
Governments also fund the "marketing" of success stories (both economic and environmental) from these demonstration projects. A major outcome of these projects and other initiatives, are the published guidebooks and manuals for waste minimisation in general and for specific industries, including the metal finishing industry. These include case studies from the projects. It has since been discovered that these large and detailed guides were not generally used by industry. As a result these have been developed into shorter, to-the-point factsheets (more likely to be read and used) which were made obtainable from industry associations, environmental protection agencies, or specially developed information clearing-houses. Some factsheets are specific to certain industries, while others cover general topics like water saving techniques.

Some governments have funded, or set up self-sustaining, information clearing houses (both physical and electronic). The Internet is playing a more and more significant role in providing access to information on pollution prevention. The most well-known electronic information/technology transfer program is UNEP's International Cleaner Production Information Clearinghouse. It includes an electronic information exchange system which houses a vast number of international *case studies*, including a number for the metal finishing industry (UNEP ICPIC, 1995). The U.S. EPA Pollution Prevention Information Clearinghouse (PPIC) and EnviroSense websites, provide a vast amount of pollution prevention information which are applicable to the metal finishing industry. Australian government has established EnviroNET Australia, which is a network of databases, providing free information on research & development, environmental technologies, integrated Cleaner Production solutions, and industry expertise.

Such information provides companies, particularly SMEs with cheap and immediate access to a technological database that would otherwise be inaccessible. Database information ranges from being an initial tool to discover Cleaner Production, to providing technical information on specific techniques (NEWMOA, 1997). As a result, companies are able to assess their processes using the "checklist" waste minimisation assessment approach (discussed in Chapter 2) to identify obvious areas for waste minimisation. In this way, the time required for waste minimisation assessments may be significantly reduced, and most importantly, the cost of the "expertise" for identifying cost-effective options is effectively 'free'.

3.8.2 The Role of Consultants

As the majority of metal finishers are SMEs, they tend to have limited resources in terms of time and personnel to carry out waste minimisation assessments and research waste minimisation opportunities. Often they also do not have the technical expertise to implement waste minimisation.

The experiences of the PRISMA project show that intensive guidance and company-oriented consultancy can eliminate a substantial number of obstacles to prevention (PREPARE, 1999b). Consultants have built up their knowledge and expertise in giving waste minimisation assistance to industry through their participation in demonstration projects and through working with individual firms (Jänisch, 1999). The majority of the projects are funded and linked with government/ environmental agency initiatives. Getting the help of a consultant is not generally feasible economically for SMEs unless a number of them can get together and share the services of a consultant. For example, there are options for SMEs to form waste minimisation clubs and help each other approach waste minimisation together with the help of a consultant. The companies pay an initial amount to join up and their resources are "pooled" for outside help. The success of waste minimisation clubs has been proven in the UK and there is now a trend towards companies setting up their own clubs modelled on the format of the demonstration clubs (Mercer, 1999).

Much attention has been paid by consultants to adapting old and developing new methodologies to suit different types of companies in different sectors of industry (Mercer, 1999 and Versteege, 1999). The key lesson learnt from consulting experience, which relates particularly to the involvement of SMEs in projects, is to minimise the input time required by the management in waste minimisation initiatives. The conventional or 'PRISMA' waste minimisation assessment methodology usually requires a high level of involvement by companies, is a costly method and uses a thorough and comprehensive analysis if the environmental situation (Bruijn & Hofman, 2000). Consultants are adapting their methodologies to shorten the time taken for waste audits in order to cut costs and quickly identify options to get management interest quickly, and hence promote the adoption of waste minimisation.

The resulting 'Prevention Quick Scans' (PQS) have been found to be relatively cheap to implement, require little involvement of the company itself, and are focused on mapping the potential for pollution prevention (Bruijn & Hofman, 2000). The method is therefore particularly suited to SMEs. In addition to saving management time, the reduced time of outside involvement from consultants, keeps costs low for SMEs. The approach is to start with a few companies in a sector to find the relevant questions which need to be asked and then use this data to develop very branch-specific questions (Versteege, 1999).

Training has become an increasingly important tool in overcoming the barriers resulting from lack of waste minimisation awareness and know-how (Mercer, 1999). The emphasis is on learning to remove the obstacles perceived by the target groups (van Engelen, 1999). There is a now a major emphasis on training of employees to encourage waste minimisation in-house. They then help in setting up an environmental management system in the company to encourage continuous waste minimisation program once the consultant has left. Consulting experience has found that for most companies, the PQS in conjunction with a (simplified) Environmental Management System (EMS) in a company work very well together in achieving cost-effective waste minimisation programs in SMEs.

The experience and know-how of consultants is valuable to pass on to authorities involved in enforcing waste minimisation, for example through permiting. Therefore, In addition to training at companies, consultants have begun to offer training for policy makers and local authorities. Gombault and Versteege (1999) discuss the important role that local authorities and intermediary organisations in the Netherlands can play. The authorities have close links with private enterprises, citizens and other target groups, making them the most appropriate parties to stimulate ecologically sound behaviour.

3.8.3 The Roles of Industry Associations and Organisations

Metal finishers also rely significantly on the help of industry organisations and association for information on how to achieve compliance with the new regulations. Many of the metal finishing associations in each country had specific environmental managers and committees with permanent staff which could offer individual consulting to member companies regarding Cleaner Production issues, even beyond compliance only (GA, 1999; VOM, 1999). The committees may promote "best practice", raise awareness of environmental issues and worker health and safety, and provide extensive guidance and training for member companies (GA, 1999).

In some cases associations are actively involved in research and development of Cleaner Technologies and especially in dissemination of information regarding the best practices available. The Dutch galvanizers association (SDV) for example, serves as an information source for fact sheets regarding demonstration projects for Cleaner Technologies (Reimerink, 1999; NOVEM, 1998). The *National Association for Metal Finishers* (NAMF) in the US has set up a National Metal Finishing Resource Centre on the Internet with comprehensive waste minimisation information for all metal finishers (www.NMFRC.org).

The UK GA have published a guidebook with technical information regarding environmentally-sound day-to-day operation of plant (GA, 1999). The Dutch VOM published an updated handbook for wastewater handling and treatment in 1997 (van der Klis and Mortier, 1997). The handbook specifically promotes the use of waste minimisation techniques first, before treatment and includes a number of calculations and guidelines for estimating savings through waste minimisation and treatment techniques.

The Danish EPA (1997) found that enterprises appear to derive most of their knowledge of Cleaner Technologies from other enterprises, branch organisations and trade magazines, and only to a lesser extent from the authorities such as the Danish EPA.

To build up know-how and capacity within the industry, the Dutch VOM organises committees of a number of people within member companies to form task groups for researching new (cleaner) technologies and process techniques. The task teams produce reports for use by Association members. This saves on university research/consultancy costs and also ensures that the know-how remains in-house. This has served as a cost-effective means for companies to obtain technical help in implementing waste minimisation technologies (Du Mortier, 1999). The German DGO association organises conferences, seminars, training courses and symposia for the exchange of technical experience in Cleaner Technologies.

Associations have also worked closely with government in ensuring that environmental legislation matches the capacity of the industry, and through arranging covenants and voluntary agreements for self-regulation (Reimerink, 1999).

3.8.4 The Role of Chemical and Equipment Suppliers to the Metal Finishing Industry

Internationally, supply houses are developing Cleaner Technologies and chemical substitute alternatives (Such, 1999). New, more environmentally safe product development by suppliers is driven both by the metal finishing industry (in search of lower operating costs) and the suppliers (in search of product niches and avenues to sell know-how). There continues to be, however, a lack of understanding of the metal finishing process on the part of many metal finishers and a reliance on their suppliers to provide the right recipe. Suppliers, for their part, may be reluctant to suggest environmentally proactive process or product changes because it may mean lower product sales, at least in the short term (UNEP WG, 1998).

Some suppliers appear to be moving away from their historical sales commission incentive systems and toward a system that rewards sales of new, proprietary, and environmentally safer products. These same suppliers are also investigating profit-sharing relationships with more progressive metal finishers that want new products and/or are willing to try new products (U.S. EPA, 1994). Suppliers are selling a service and it is becoming more and more their responsibility to control process and product quality. It is therefore in their interest to reduce consumption creating a win-win waste minimisation situation through shared savings. When their only aim is to sell chemicals, there is no incentive for them to encourage waste minimisation which will indirectly lead to consumption of less chemicals (van Engelen, 1999).

Experience in the UK has shown that suppliers are often not aware that they supply Cleaner Technologies, or the reverse, is that industry is not aware of which suppliers offer Cleaner Technologies. Inventories of suppliers of Cleaner Technologies (through industry associations for example) have proven to be useful. These have been made accessible on the Internet (e.g. the US National Metal Finishing Resource Center www.nmfrc.com has searchable supplier lists).

3.8.5 The Role of International Co-operative Initiatives

Two International co-operative initiatives have specifically influenced the adoption of waste minimisation by the metal finishing industry.

The *Montreal Protocol* was adopted by more than 60 countries in 1989 and amended in 1992, and aims to protect the ozone-layer from man-made ozone depleting chemicals. Some of these have been traditionally used in the metal finishing industry, such as certain solvent degreasers. As a result of this, the metal finishing industry's widely used cleaning solvent methyl chloroform (1,1,1-trichloroethane) has been phased out and replaced with less-hazardous alternatives.

The United Nations Environmental Program, has a specific Metal Finishing Working Group in Cleaner Production (UNEP Metfin WG) which is a panel of international experts that provide technical expertise, advice and information regarding Cleaner

Production in the metal finishing industry internationally. Currently the working group comprises of approximately 120 members in about 30 countries. Members contribute case studies on practical waste reduction technologies that have proven economical viability and environmental advantages, and answer difficult industry pollution problems and assist in education and awareness raising in the industry through seminars, workshops etc. (Reeve, 1998).

3.9 CONCLUSION

There are some common aspects in the structure and characteristics of the metal finishing industries in each country investigated:

- Over 90% of the metal finishing shops are SMEs.
- The job-shop component is mostly smaller than the captive component.
- Painting & powder coating combined make up the largest segment in terms of number of firms, followed by electroplating, hot dip galvanising and anodising.
- There is general lack of technical knowledge amongst metal finishers, which leads to reliance on suppliers and industry associations for technical advice and know-how.

The metal finishing industry is a focus area for waste minimisation in each of these countries. Widespread success has been achieved using simple and highly cost-effective methods and waste minimisation techniques such as drag-out and rinse-water use reduction. Improved operating practices and process control measures have most commonly and successfully relied on readily available mature low cost technologies. Resulting improvements in process efficiency helped to offset the capital investment, thereby making the investment in waste minimisation equipment cost-effective. The greatest influence on the adoption of substitute or new technologies has been new more stringent environmental legislation that has meant that the option becomes cost-effective in comparison to the alternative.

There are a number of barriers to waste minimisation in the metal finishing industry, particularly for SMEs. Government policy and key stakeholders within the industry have had important roles to play in overcoming the barriers and providing drivers to waste minimisation in the metal finishing industry. International experience suggests that once the barriers have been removed, significant improvements are possible with relatively low cost implications for the individual companies.

The findings indicate that there has been potential for waste minimisation in the metal finishing industry in these countries and that it has been exploited cost-effectively. The next chapter addresses the investigation into the South African metal finishing industry and the potential for cost-effective waste minimisation in the local context.

Chapter 4: The South African Situation

'Cleaner Production is widely recognised at an international level as a tool for promoting and enhancing ecologically sustainable development. This international involvement in and support for Cleaner Production provides both drive and direction for continued activity at domestic level' – ANZECC, 1998

4.1 INTRODUCTION

In order to be better placed to offer conclusions regarding the potential for waste minimisation in the South African metal finishing industry, the objectives of the review presented in this chapter are to:

- Examine the South African metal finishing industry in terms of structure and key characteristics that affect its environmental performance, for comparison with the industry in other countries investigated;
- Investigate the current state of awareness and adoption of waste minimisation in the metal finishing industry in South Africa;
- Identify drivers and barriers towards and against environmental improvement within the sector ;
- Examine the roles of key players and other influencing factors in affecting the adoption of waste minimisation in the South African industry;

The chapter's structure is the same as in Chapter 3 since it covers the same topics as the investigation into international experiences.

4.1.1 Lack of data on the industry

There is little known about the actual structure and characteristics of the metal finishing sector in South Africa. A reliable estimate of the number of metal finishing installations is extremely difficult to establish. The task is made the more difficult as the majority of metal finishing work is performed in-house as part of an overall manufacturing activity, and of the remainder of the metal finishing shops operating on a contract basis, many operate small, backyard shops (NATSURV2, 1987).

In a report prepared for the Water Research Commission titled '*Investigations into Water Management and Effluent Treatment in the South African Metal Finishing Industry*' (PRG, 1987), the results of a 1982 survey of municipalities in South Africa receiving metal finishing effluent is described. The survey was sent to 118 municipalities, and 317 metal finishing enterprises were identified. However, it is unclear what proportion of the total number these represents, and what processes are undertaken at these sites. In addition, the data is almost 20 years out of date. The results cannot be considered to accurately represent the current state of the metal finishing industry, and can only be considered as rough benchmark figures.

A second investigation into water and waste-water management in the metal finishing industry, also for the WRC, was a national survey undertaken by consulting engineers, in 1987 (NATSURV2, 1987). The investigation studied only those metal finishing activities that were found to use substantial quantities of water or generate substantial quantities of effluent. The electroplating, anodising, and chemical surface treatment (phosphating) processes were found to be the most water-intensive, and the report deals exclusively with these. It is unclear how this survey was undertaken.

Naumann (2000) as part of the larger Industrial Symbiosis Project, has attempted an economic analysis of the metal finishing industry to identify economic potential for environmental improvement (e.g. for investment in Cleaner Technology). In his initial report he notes that inherent difficulties exist in determining the total size of the industry from existing data, due to the unavailability of data, as well as the fact that metal finishing is only classified to a limited extent as a sector on its own. The metal finishing industry is essentially a process/service rather than a product/output industry, meaning that it stretches across a very wide range of industries. Data on the size of the South African metal finishing industry, using the official industry classification SIC 35521, is not an accurate reflection of the entire industry, since it refers only to job-shop metal finishers. Captive metal finishing operations which form part of larger manufacturing companies are classified according to their output, and though considered part of the metal finishing industry, are not included in existing statistical data.

A database of metal finishing companies in the Durban metropolitan area has been established as part of a research project by the Pollution Research Group (PRG) of the University of Natal Durban (UND). This includes over 50 companies (mainly electroplaters) associated with the project. There is no quantitative data of this type for any other regions.

4.1.2 Survey

Owing to the lack of quantitative data it was decided to undertake a survey of the South African metal finishing industry. A survey questionnaire was compiled and a database was set up to capture all data for analysis. The database was compiled from company names obtained from researchers, associations, industry supply houses, and municipalities dealing with the industry, as well as through the electronic yellow pages (www.1023.com). A description of the method in which the survey was carried out is included in Appendix D1, and a copy of the survey questionnaire is included in Appendix D2.

The main objective of the survey was to obtain information on the characteristics of the companies (size, processes employed, and main product market). The survey also aimed to determine the type and amounts of wastes and emissions generated by the metal finishers as well as how wastes are managed by companies. However, due to lack of response from companies and hence difficulty in obtaining large amounts of data, it was considered sufficient to obtain data on company characteristics (location, size, products, processes, and captive vs. contract) only. An additional objective was to compile the database of metal finishing companies in South Africa in such a way that it could be used to determine the distribution of metal finishing companies according to province and according to process type.

have been liked to yield significantly representative results. Further effort to obtain a larger response and hence more representative results does not warrant the time required to obtain possibly only slight improvements.

The survey results are discussed in the following sections, along with other information obtained on the industry.

4.1.3 Further information sources

Meetings and discussions served as an important vehicle to add to this study both qualitatively and quantitatively. Interviews were conducted in person, over the phone or by correspondence with key stakeholders in the local metal finishing industry (association members, industry members, suppliers, municipal council members) to gain specific information regarding the South African metal finishing industry, and to assist with the survey.

Since the scope of the survey was limited, waste generation and management information for the industry had to be obtained through literature alone. The majority of the existing literature on waste management in the metal finishing industry in South Africa, is connected to studies prepared for the Water Research Commission (WRC) and focuses on treatment of effluent and related sludge waste only. The earliest reports found on these studies are from the late 1980's (PRG, 1987), the latest published so far is from 1998 (PRG, 1998).

In addition to these, the Environmental Monitoring Group (EMG) in South Africa, undertook an assessment of the need for the introduction of Cleaner Technology in some industrial sectors in South Africa (EMG, 1993). The Metal Processing Industry was one of the industries covered in the assessment and the results from the study include an analysis of waste generation in this industry. It was, in fact, the findings from this literature that lead to the metal finishing industry being chosen as one of the focus industries for the Industrial Symbiosis Project (Kothuis and Petrie, 1997).

In addition, Industrial Symbiosis project members have been closely linked to the preparation of the Danish Council for Environment and Development (DANCED) Project on Cleaner Production in the metal finishing industry, and have helped in compiling information for first-phase reports. Some qualitative information was compiled from meetings with industry members, association representatives, service providers, and regulators, which formed part of the preparation phase of this project. Access to findings from these investigations running in parallel to this thesis work has been possible even though the reports are not available to the public. Though qualitative information may be well informed, the findings from these meetings are based on opinions and experiences and offer no clear answers to questions regarding the true nature of the industry. In any cases where information from this source is known, it is included and due reference is given to the source of this information.

4.2 CHARACTERISATION OF THE SOUTH AFRICAN METAL FINISHING INDUSTRY

The characterisation of the local metal finishing industry draws on international experience in classification methods (e.g. job-shop vs. captive), as set out in Chapter 3 (Section 3.2).

4.2.1 Structure of the South African metal finishing industry

Different sources put different values on the number of metal finishing enterprises in South Africa. The official industry classification is given first, followed by a comparison of findings from a literature review and the survey results.

The industry code assigned to the metal finishing industry in South Africa is SIC 35521, known as 'Treatment and Coating of Metals'. It falls under Fabricated Metal Products in the manufacturing sector. The SIC definition according to Statistics South Africa (SSA, 2000) is as follows: 'This group includes plating, polishing, anodising, colouring, printing, hardening, buffing, sand blasting, cleaning, or other specialised activities in respect of metal and metal articles on a fee or contract basis. The units classified here generally do not take ownership of the goods nor do they sell them to third parties'. *Statistics South Africa* (2000) have captured approximately 255 *job-shop* metal finishers in South Africa which fall under this SIC definition. This corresponds to 1% of all manufacturing enterprises.

The results of the 1982 survey of municipalities receiving metal finishing effluent outlined in a report for the Water research Commission (PRG, 1987), indicated a total of 317 metal finishing firms. There is no indication as to type of firms (i.e. captive/job-shop). The number merely represents the number of firms recognised by municipal authorities as metal finishers in 1982.

Naumann (2000) states that various industry sources have contested these figures, and based on estimates from key members in the industry in Durban and Johannesburg, as well as discussions with national suppliers to the industry, concludes that the total number of job-shop metal finishing enterprises is closer to 500-600. As metal finishing processes are undertaken by a number of non-similar industries, it is impossible to gauge the total number of captive companies involved in metal finishing. An extrapolation from the job-shop estimate (based on the results of the survey and/or international proportions) can provide an estimate of the number of captive shops and hence the total number of metal finishing firms in South Africa.

As of March 2000, there were 316 metal finishing firms in the address database of the Industrial Symbiosis project. The majority (37%) of the companies in the database are located in the Western Cape area, owing to the ease of obtaining phone numbers and contact names in this area (UCT being located here). The number of companies in the Kwazulu-Natal region (25%) are boosted by the university of Natal PRG's database of metal finishers in the Durban region. The number of companies from the Gauteng area (32%) is limited to the few names obtained from municipality and supply-house sources.

Of the 316 companies, the total number which have been surveyed is 217. There are approximately 100 companies in the database for which information is yet to be obtained (missing contact details, no response). Additional company names may still be obtained from further sources (such as the electronic phone directory) for the Gauteng area in particular. Since data has not been obtained for the remaining companies in the database, it may be that they do not carry out metal finishing (i.e. they may outsource their finishing work), or they may have shut down. For this reason, only the companies that have been surveyed can be included in any analysis. The main survey results are set out in Table 4.1 below.

Table 4.1: Results of the survey of the South African metal finishing industry as of March 2000

	Eastern Cape	Gauteng	Kwazulu Natal	Western Cape	National
Total firms surveyed	5%	34%	32%	30%	217
% SMEs	88%	89%	87%	89%	88%
% job-shop	70%	48%	50%	42%	48%
% captive	30%	35%	41%	48%	40%
% both captive & job-shop	0%	17%	9%	10%	12%
% electroplaters	50%	42%	53%	37%	42%
% anodisers	0%	12%	9%	5%	8%
% powder coaters	20%	30%	36%	25%	28%
% wet painters	20%	23%	13%%	35%	22%
% hot dip galvanisers	20%	28%	6%	8%	14%
% other finishing types	0%	20%	22%	38%	25%

(% figures for each region, are the percent of total firms surveyed: 217)

Many companies were found to undertake more than one type of finishing (i.e. hot dip galvanizing and powder coating). For this reason, the totals do not add up to 100% or 217 companies. While information on processes employed, size and location could only be obtained for a small proportion (estimated 25% maximum) of all enterprises involved in metal finishing, the survey is assumed to give a fair indication of the nature of this South African industry sector.

It appears that there is a greater number of job-shop metal finishers than captive metal finishers at a ratio of 50% to 40% respectively (10% claimed to finish their own manufactured parts as well as outside contract work). However, it is unclear how representative the surveyed companies are of the total. There may be more in-house companies in the database as these tend to be larger and are more easily recognisable and/or it may be easier to obtain information from the larger companies. Results from other countries investigated in Chapter 3 vary from 10-60% job-shops. However the range of 30-35% job-shop is most common. No data was found for less developed countries.

According to a study undertaken by the Environmental Monitoring Group in South Africa in 1993, the *majority* of metal finishing work in South Africa is performed by *captive* metal finishers (EMG, 1993). It is unclear what the basis for this conclusion is. Naumann (2000) argues that the wide-scale lack of emphasis and institutional (as well as government) support for SMEs in South Africa may have lead to a situation where the job-shop component of the industry is relatively small, and the bias subsequently towards captive-shops. But that there is also the view that some of the captive shop enterprises are seeking to reduce their involvement in metal finishing and are tending towards effectively outsourcing such operations by contracting job-shop metal finishers to treat their products.

Since there are arguments either way and no real conclusion can be made with the data at present, for the sake of estimating a total number of metal finishers, the split between job-shops and captive shops is assumed to be approximately even. Therefore, if Naumann's (2000) estimate of 500-600 job-shops is assumed to be correct, the captive component will be approximately equal in size, and the total number of metal finishing sites in South Africa would be around *1000-1200*. This can only be considered a rough estimate.

The distribution of firms by region according to survey results is given in Table 4.2. Included with these results are comparative figures from other sources: Naumann (2000) offers a distribution of *job-shop* finishers based on suggestions from a leading metal finisher in the Durban region and leading suppliers of chemicals and metal (anodes) to the metal finishing industry. The results of the 1982 survey of municipalities receiving metal finishing effluent according to a report for the Water research Commission (PRG, 1987) are also included as benchmark figures. Although some uncertainties prevail regarding the reliability of the official data as generated by Statistics South Africa, the location of firms in the manufacturing sector are included in the table as it is likely that the percentage of metal finishers in each province is proportional to the manufacturing figures. These figures can therefore be used as a check against estimates and survey results.

Table 4.2: The distribution of metal finishing firms in South Africa by region

Region	*Total* firms in Industrial Symbiosis address database (January 2000)	*Total* firms surveyed (March, 2000)	*Total* firms identified by municipalities in 1982 (PRG, 1987)	*Job-shop* estimates (various industry sources) (Naumann, 2000)	*Total* manufact-uring firms from official statistics (SSA, 2000)
Eastern Cape	6%	4.5%	6%	4% (15)	6%
Gauteng	32%	35.5%	46%	45% (200+)	44%
Kwazulu Natal	25%	29%	20%	29% (130)	20%
Western Cape	37%	31%	26%	22% (100+)	18%
Other regions	–	–	2%	-	12%
National	**316**	**217**	**317**	**500-600**	**26,000**

Results other than this survey study appear to indicate that a significant majority of companies are located in Gauteng, and this appears to confirm the suspicion that the Gauteng proportion in the survey is substantially undervalued (i.e. closer to 45% than 35%). However, one can only conclude that the majority of companies were found to be located in Gauteng, followed by Kwazulu-Natal and the Western Cape (it is not clear which of these has a higher number, but the regions are close in number), with very few located in the Eastern Cape (~5%), and no data obtained for any of the other provinces. The manufacturing statistics indicate a remainder of 12% distributed between 5 provinces. The 1987 survey of municipalities identified no more than 5 or 6 metal finishing shops in regions other than the main metropolitan areas (PRG, 1987).

The number of employees in each company was also surveyed and it was found that almost 20% have <10 employees, close to 40% have <20, and approximately 60% have <50 employees. The overall results indicate that almost 90% of the companies surveyed are SMEs.

Table 4.3: Proportion of SMEs in the South African metal finishing industry

	Number of companies identified	Percentage of total
SMEs (<250 employees)	188	88%
Large companies (>250 employees)	24	11%
No data	4	2%

The conclusion from the survey results so far is that electroplating is the most common process, followed by powder coating and wet painting (combined painting would be greatest at 50%). Hot dip coating is third, followed by polishing, and anodising. The resulting distribution of the remaining process types is shown in Table 4.4

Table 4.4: Distribution of metal finishing firms in South Africa by process type

Type of metal finishing process	Percentage of total surveyed	
Electroplating	42%	
Powder coating	28 %	50% combined
Wet Painting	22 %	
Hot dip Coating	14%	
Polishing	11%	
Anodising	8%	
Electroless plating	2.3%	
Heat treatment	2.3%	
Etching	2.3%	
Metal Colouring	2%	
Metallic Coating	2%	
Case Hardening	1%	
Combined others	9%	

These results appear to be consistent with other estimates. Key stakeholders in the industry have estimated that the electroplating sector is expected to make up a significant number of sites (DANCED, 1999). There is not much known about the engineering painting sector, but judging from the size of the automobile manufacturing sector in S.A., it is expected to be quite a large sector. A report from the late 1980's states that painting is the most widely used finishing process in South Africa, and that plastic powder coatings have been finding increased usage and in many applications are replacing paint or metallic coatings (PRG, 1987).

The number of galvanizers is easier to determine due to high industry association membership. Thirty of the thirty-seven member companies of the HDGSA have been surveyed, and it is estimated that there are only about 6 others in the country. The proportion of galvanizers is therefore likely to be much lower than indicated by the survey. An estimate for the total number of electroplaters is in excess of 500 (DANCED, 1999), which Naumann (2000) states is consistent with estimates given by local suppliers and companies. Only 90 electroplaters (20%?) were identified in the survey.

For electroplating firms, zinc, nickel, and copper electroplating appear to be the most common process types at uses of 25%, 21%, and 16% respectively by the firms surveyed. Hard-chrome, brass, and decorative chrome plating are also widely used at around 11% each. Naumann (2000) quotes internal research by an industry source conducted during 1999, which attempted to quantify the volume of base metals consumption in the South African electroplating industry. This research found the most common metal used in terms of pure quantity to be Zinc ($Zn^{2/4}$ quality), followed by copper, nickel, and "pure zinc" (Zn quality) in the ratio 2.3:1.9:1.3:1. This appears to be consistent with the survey findings regarding most commonly employed electroplating types.

4.2.2 Characteristics of the South African metal finishing industry

The results of the survey have indicated that the vast majority of job-shop metal finishers operate in the main metropolitan regions of Johannesburg, Cape Town, Durban, Port Elizabeth, and East London.

Captive shops are usually much larger than job-shops, and are especially prevalent within the automotive and automotive components industry (Naumann, 2000). Job shops tend to be small and generally have fewer resources available. Often in small job-shops, the owner-manager is responsible for administration, accounting, marketing and production. There is little time for training the workforce and often the managers themselves are not sufficiently knowledgeable to provide skilled supervision. In addition, there is a great variety of individuals with very different, often non-technological, backgrounds, operating in the industry, and hence a general lack of technical knowledge amongst metal finishers (DANCED, 1999).

Suppliers involved with the industry survey have indicated that there is a great reliance on suppliers for technical knowledge and expertise. Many of the factory managers are not knowledgeable about processes that they operate and rely on the chemical suppliers to provide even day to day operational advice. There are a number of firms supplying chemicals to the metal finishing industry, although the bulk of the market (approx. 85%) is controlled by 3 large companies (DANCED, 1999).

Various industry organisations have been established to serve parts of the metal finishing industry. They serve the interests of firms operating in their specific fields, are essentially funded by their (industry) members and contribute mainly marketing expertise to the industry. There is little attention paid to environmental issues by these associations at present, but it is expected that these issues will be taken up more significantly in the near future (Barnett, 1999a). The only industry association in South Africa with a strong role at present in terms of offering technical advice as in other countries, is the Hot Dip Galvavanizers Association (HDGSA). No other associations have been identified with equivalent ability although a local electroplating association is likely to build-up capacity in the near future. The main national organisations and associations specific to the metal finishing industry in

South Africa are listed in Appendix D3 along with a brief description of their main functions.

The process of technology diffusion and dissemination is slow within the industry. In some cases, particularly for the jobbing factories, protection of market sensitive information is the cause but in most cases it is lack of communication. Diffusion of technology in the galvanising industry is more widespread than in the electroplating industry for example. This is since the galvanizing industry is a smaller and more coherent sector and is served with a well-established and cohesive industry association (DANCED, 1999).

Stakeholders agree that the primary competitive factor for most finishers is price (DANCED, 1999). Quality may be important in some cases though this depends on the product market (e.g. automobile vs. fencing). In general metal finishers have to meet minimum quality standards for a market sector in any case, and therefore price becomes the competitive factor.

While the cost of chemicals (especially proprietary cleaners) and metals (metal inputs are either traded in or directly affected by international price and currency fluctuations) is usually the greatest input cost, labour still accounts for approximately 30% of the production cost for a typical metal finishing operation. Hot dip galvanizers with their large quantities of costly zinc inputs, generally have a lower percentage labour cost component (Naumann, 2000). The cost of electricity and water is low in South Africa. Energy and water are relatively minor costs for the typical metal finisher at around 5% and 1% of operation costs respectively (Ibid.).

Standards of business performance vary greatly from one company to another. The approach to waste management by large versus smaller firms, differs. Environmental improvement initiatives that do exist are generally associated with the larger industries as these have the economies of scale and the technological and financial resources needed. This is not normally feasible for smaller companies where waste management entails a proportionally higher cost and so discharge of liquid effluent is to the local sewer system, and solid waste is disposed in landfill sites (Petrie, 1994).

4.3 CURRENT STATE OF WASTE MANAGEMENT IN THE SOUTH AFRICAN METAL FINISHING INDUSTRY

As mentioned in Chapter 1, the metal finishing industry has been identified as one of the most polluting industries of the manufacturing sector in South Africa. The most common areas of wastage are excessive water consumption and loss of chemicals due to drag-out and spillage. These problems are mainly a result of poor housekeeping practices (PRG, 1999). It has been found that much of the problem with poor housekeeping is often associated with low worker education and skill. In addition, outdated equipment and poor maintenance lead to increased water and energy consumption and the generation of unnecessary waste.

In general, industry is reluctant to invest in capital equipment not directly required by production and market needs. Thus capital will not be employed to replace old, less energy-efficient equipment with more efficient equipment. Similarly, capital required to reduce consumption of water or the generation of waste will not be invested as long as the costs and therefore potential savings are low (Naumann, 2000).

A national industry water and waste-water survey (NATSURV, 1987) found that electroplating, anodising and chemical surface treatment processes are the most water-intensive amongst the metal finishing operations in South Africa, and water is not used efficiently in most operations. The same study found that approximately 80% of the annual water intake of the metal finishing industry is used for rinsing. The cost of water is low, providing no financial incentive to reduce water use in the industry (EMG, 1993).

Dumping of cleaning solutions and acids occurs regularly (ranging from every week for some to once a year for others) and this provides the bulk of the salt load leaving a plating shop. Dumping of process solutions provides the major source of pollution from the metal finishing industry and is particularly harmful to local sewage treatment works where such toxic influent can bring normal sewage purification to a standstill (SRK, 1991).

While the larger metal finishing companies in South Africa generally follow acceptable disposal procedures, it has been found that many of the smaller operations do not, with effluent containing heavy metal concentrations in excess of the sewer regulations commonly being discharged to drain. The preferred solution is to prevent the discharge of the heavy metals to sewer as much as possible, although the use of penalties has not been successful in the past due to lack of enforcement personnel (Barclay et al, 1999).

A study undertaken on a number of metal finishing enterprises in the Johannesburg area (SRK, 1998) has indicated that "few metal finishers actively practice effective on-site effluent management, and that the rudimentary pre-treatment (where it exists) is usually not well organised, operated or maintained in relation to compliance with existing by-law quality standards, or disposal of waste sludges generated in the process. The systems are largely left to run themselves, with ad-hoc desludging to sewer, or via waste contractors on an irregular basis. Although several plant operators cited waste haulers as the remover of their waste sludges it is apparent that the amount taken by waste haulers represents a fraction of the metal wastes generated by the group, with the majority of metal load being discharged to sewer".

The diverse and intermittent discharges of heavy metals from SMEs metal finishing operations have a potentially detrimental effect on the operation of sewage treatment works and impact negatively on down stream water users (WRC, 1994). Naumann (2000), has reported that discussions with Johannesburg Metro representatives revealed that the problem with metal finishing effluent for most sewage works is associated mostly with the effect of heavy metal wastes on the composition of treatment sludges. The sludge from sewage treatment plants is traditionally sold off as 'Class D' sludge and used as a soil remediant (fertilizer) on farmlands, but this is often not possible due to this high heavy metal content, with the result that the sludge has to be disposed of to landfill.

Many of the government or privately owned disposal sites are overloaded and local authorities are concerned about a shortfall in capacity leading to costs for treatment upgrades, site remediation, or the development of new sites. There is particular concern over wastes containing heavy metals in disposal sites. Leaching and mobility rates of heavy metals in these dumps are potentially accelerated by strongly acidic rainfall – a common occurrence in much of South Africa's industrial heartland (Petrie, 1994).

A particular problem is evident in the province of Kwazulu-Natal, where at present, no disposal site for hazardous wastes exists in the province (only two low-hazardous waste sites), which is effectively encouraging illegal storage and/or dumping of hazardous wastes (Daily News, 1998). Metal finishers are forced to engage in transportation of hazardous wastes to disposal sites in Gauteng, which is technically illegal, very expensive, and fraught with risks (the final legal responsibility is on the metal finishing firm, as opposed to the transport company).

It is suspected (based on conversations with several industry members through the telephone survey) that the use of solvents, cyanide, and chromium is still widespread within the industry, and that little attempt is being made to reduce their use mainly since metal finishers are unaware of the alternatives. At least three companies contacted for the survey however, indicated that they had stopped their cadmium plating line rather than deal with the complicated waste disposal requirements.

4.4 ADOPTION OF WASTE MINIMISATION IN THE INDUSTRY

Waste minimisation initiatives that have already been undertaken in the South African metal finishing industry have yielded both successful and unsuccessful results. Some of these have been individual initiatives, while others have been results of co-operative initiatives. These are reviewed in the following paragraphs.

4.4.1 Waste Minimisation Club

The formation of a Waste Minimisation Club in the metal finishing industry in the Durban area in 1998 has so far proven successful, with a number of waste minimisation options having been identified in the various companies, and reported combined savings being in the region of R340,000 (Barclay et al, 1999). Savings have only been quantified by 6 (20%) of the companies participating in the club, therefore the actual total club savings will be in excess of this amount. In most cases, payback period was immediate and in others a matter of months. Of the waste minimisation options implemented, over 90% involved simple housekeeping options such as fixing water leaks, shutting off water supplies that were not essential, hazardous waste segregation, ensuring that the correct amount of chemicals were being used, and reusing rinsing or chemical baths. Other options identified included improved operating practices through process modification (e.g. replacement of overflow rinses with counterflow rinses and installation of drag-out tanks) and using alternative input materials (PRG, 1999). Some companies implemented waste minimisation options without quantifying the results and many other options were identified for implementation in the future (Barclay et al, 1999). Environmental savings have not been published. Of the companies involved in the Club, 90% are SMEs and 50% have <50 employees.

It appears that potential for cost-effective waste minimisation has been identified in a few of the companies (6 reported) so far. The Waste Minimisation Club is ongoing and it is likely that savings in other companies may be attained over time. However, Barclay et al (1999) have noted that it is only where waste minimisation is made a priority in the company, that substantial savings have been achieved. "It has been found that some companies lack the commitment to continue with waste minimisation programs, largely a result of lack of time available for environmental management activities" (Ibid.). It therefore appears that there are barriers to identifying whatever potential may exist in such companies.

4.4.2 Off-site recovery scheme

A successful Centralised Waste Treatment (CWT) initiative in South Africa has been the implementation of a facility for the off-site recovery of hydrochloric acid used in the hot dip galvanising industry. Once the iron level in the acid solution reaches above 10% it has to be discarded regardless of acid concentration. Since 1975, the acid (which previously was discarded in the sewers) is collected by a commercial company which regenerates it and sells it back to the galvanising companies. This project was initiated by the chairman of the HDGASA. The Gauteng based organisation, collects the spent acid from all provinces, tankers it away, regenerates it and resells it to the users at the equivalent price as new acid. This has proven to be highly cost-effective and has been successful not only for galvanizers but also for other users of hydrochloric acid, e.g. companies which pickle steel to remove scale for a variety of reasons other than galvanising (Barnett, 1999a).

4.4.3 Published waste minimisation case studies

The results from completed waste minimisation assessments carried out in electroplating companies as part of academic research connected to the University of Natal Pollution Research Group and the University of Cape Town Industrial Symbiosis Project, are presented briefly here as published case-studies.

The waste minimisation results from a job-shop electroplating firm in the Durban area have been published as a particular success story from the Waste Minimisation Club project (PRG, 1999). The company may be considered a typical small-scale electroplating job-shop offering a wide range of electroplating types, including the most common process involving zinc, nickel, copper and chrome. The main focus area for improvements has been the large volumes of wastewater arising from rinsing. Waste minimisation options have included reducing inefficiencies, improving housekeeping (particularly in the areas of drag-out reduction) and implementing an on-site water recycling plant. As a result, water consumption has been reduced by 75%, with savings of over R65,000 p.a., and a payback period within months of being commissioned (PRG, 1999). This is particularly significant, since the company is a small company. Other improvements have included the dewatering of waste sludges.

In another electroplating company in the Durban area, a WMA was carried out by a postgraduate student in the University of Natal Pollution Research Group (PRG). Though the results have not been published, through interaction between the PRG and the Industrial Symbiosis Project, it has been established that drag-out reduction through extended dripping time and fixing of leaks has resulted in savings close to

R30,000 p.a. for a minimal investment (Reimer, 1999). The company is however, not strictly an SME as the metal finishing operations are in-house of a larger (non-SME) manufacturing company i.e. captive metal finishing operation.

The hard-chrome plating operations captive of a larger (SME) automotive component manufacturing plant have been investigated twice by University of Cape Town affiliated researchers during the last five years. The company can be considered representative of larger-sized SMEs and captive metal finishing facilities, as there are fewer restrictions for the company in terms of management time and financial ability. The company also employs an effluent treatment plant, identified as waste management practice for larger companies in the South African metal finishing industry. As a result of the first assessment, most of the potential for pollution prevention was realised in the rinse section through a simple drag-out recovery system where the first rinse tank was used to replace losses in the plating tank (Coleman, 1994). Since the chrome content in the exiting rinse water was still high, the main aim of the second assessment was to investigate the possible installation of a closed-loop chemical recovery system for the dragged-out plating chemicals in the rinse water, in order to reduce the need for effluent treatment (Meuser, 1999). Ion exchange or evaporation systems were identified as the best technology options for the site. Payback calculations for the technologies (~5years) showed that it would not be economically feasible to install either system at present. Though, it was noted that with expected water price increases in the future together with the improved plating quality and environmental improvements (no chrome-containing sludge waste), the zero-discharge system would be potentially cost-effective. In the meantime, the further investigation revealed that by redesigning some of the jigs in the plating area to reduce their surface area, the drag-out could be significantly reduced and related cost savings for water treatment and lost raw material could amount to R6,000 p.a. (Ibid.)

The cost of undertaking the waste minimisation assessment in all of the cases discussed here was significantly reduced (almost 'free') by the use of (donor funded) students for carrying out the waste minimisation assessments. The cost of employing a consultant to do the job instead (and there are very few with waste minimisation experience in South Africa at present) is most likely to have been prohibitive, particularly for the job-shop. In addition, without the external 'push' the companies would most likely not have considered waste minimisation options. Therefore, although cost-effective waste minimisation has been identified for representative job-shop and captive companies in the electropating sector, the method of identifying the opportunities is not potentially achievable for the typical metal finisher. Lack of awareness of waste minimisation options, and financial constraints of SMEs for employing expertise are but two of the barriers to waste minimisation in the metal finishing industry in South Africa. Other barriers and incentives to waste minimisation in the industry are discussed in the following section.

4.5 BARRIERS & DRIVERS TO WASTE MINIMISATION IN THE SOUTH AFRICAN METAL FINISHING INDUSTRY

From the review in Sections 4.2 through 4.4 above, the following barriers to environmental improvement for SMEs in the metal finishing industry were identified:

- Lack of in-house technical knowledge and reliance on suppliers for technical know-how and process-optimisation expertise.
- Financial and time constraints, particularly for job-shop SME metal finishers
- Lack of awareness of waste minimisation principles and options
- Low worker skill and education
- Low cost of water, electricity and waste treatment (sewer charges)
- Lack of enforcement of legislation

Petrie (1994) reports that the South African industrial base is subject to constraints which make it unique. Its status as both a developed and still developing economy is likely to impact on the ease and pace with which it can introduce Clean Technologies, and the rate with which it can move to more responsible environmental management. Of the barriers identified above, the last three may be considered more applicable to South Africa's status as a developing country.

The lack of enforcement of environmental legislation in South Africa is a particular concern that is often cited. In fact, Petrie (1994) argues further that while South Africa is not short of environmental law, it is short of effective environmental law. In addition to certain gaps in the law itself, this ineffectiveness has two fundamental causes: the first is inadequate enforcement of environmental law and the second a lack of effective administration and management of environmental quality. With regards to enforcement, environmental law is ineffective, not only because the penalties for environmental damage are seldom severe enough to discourage polluters but also because the existing body of environmental legislation is weakly wielded. Effective administration, including development of the law and improvement in the quality of its enforcement, has been hampered by a lack of clear policy direction by government (Ibid.).

This, coupled with the low cost of water and electricity have resulted in a situation where there is little incentive for metal finishers to improve on the current unacceptable waste management practices. However, South African environmental legislation has recently (1998) been updated. The new Integrated Pollution and Waste Management (IP&WM) Policy for South Africa represents a paradigm shift in waste management that focuses on pollution prevention rather than primarily on impact management and remediation (EMG, 1998). In addition, the National Waste Management Strategy (NWMS), a derivative of the IP&WM Policy, follows the waste management hierarchy that promotes waste minimisation as the first step followed by recycling, treatment and finally disposal (EMG, 1998). The policy includes legislative tools which are expected to act as drivers towards waste minimisation within industry. The role of government policy and legislation in affecting waste minimisation potential in the industry is discussed further in the following section.

The review of cases where waste minimisation has been adopted in the industry in South Africa so far (section 4.4 above), indicates that external assistance has been the main driver, supported by the associated cost savings for the companies. The external assistance served a number of purposes including raising awareness of waste minimisation options, providing technical expertise, and reducing financial and time constraints. These influencing factors, and the role that key stakeholders may play in overcoming barriers and providing drivers to waste minimisation in the industry, are discussed further in the following section.

A summary of the most significant barriers and drivers to waste minimisation for SMEs in South Africa has been compiled by Kothuis et al. (1999) and is included in Appendix D4.

4.6 FACTORS INFLUENCING ADOPTION OF WASTE MINIMISATION IN THE METAL FINISHING INDUSTRY

This section follows the same outline as the equivalent discussion in Chapter 3. The roles of key players in the metal finishing industry are examined, particularly the part they play in both providing and overcoming the identified barriers to adoption of waste minimisation methods and technologies.

4.6.1 The combined role of Government, policies and legislation

It is the government's role to both regulate and support industry, and ensure compliance with a wide range of legislation. This is a difficult role, especially in the light of the often-cited situation of inadequate manpower. Pollution control is administered by a number of national, provincial and local government departments. This organisational structure is outlined in Appendix D5.

4.6.1 a Regulatory Aspects

To date, the South African environmental legislative framework has been very fragmented, with no consolidated national statute on waste management. Instead it relies on several statutes that can influence waste management and several provincial ordinances and local by-laws control waste management. However, the NWMS of Integrated Pollution Control addresses the fragmented administration of pollution management (Lazarus et al, 1997). The table below summarises in broad terms the key elements of the existing waste management approach as currently practised in South Africa, compared to the proposed future situation after implementation of the NWMS.

Table 4.5: The key elements of the existing and proposed waste management approaches for South Africa

Existing waste management approach	Strategic objectives for integrated waste management
Limited focus on control mechanisms	Focus on environmental protection and sustainability
Inadequate waste collection services	Adequate waste collection services for all
Fragmented approach with single media focus	Consolidated multi-media approach
Conflict of interest	Transparency and conflict resolution
Insufficient information	Integrated waste information system
Inadequate environmental planning	Holistic integrated environmental planning and capabilities
Inadequate research and development programs	Focused research and development crosscutting implications
Fragmented regulatory approach	Integrated regulatory approach
Regulations inadequately enforced	Enforcement facilitated
Full waste management costs not realised	Total cost accounting and polluter pays principle

Source: (ReSource, 1999).

In order to develop a practically implementable strategy the priority initiatives were categorised into short- (by the year 2004), medium- (by the year 2008), and long-term (by the year 2012) priorities. A phased approach over the twelve years is proposed for the full implementation with initiatives set out for institutional, legislation, capacity building, and financial requirements (Resource, 1999).

The two main legislative tools that will influence environmental management are the new National Water Act (1998) and the National Environmental Management Act NEMA (1999). The latter seeks to resolve the present confusion of environmental roles and responsibilities between various inter-governmental departments and within differing levels of government (EMG, 1998).

The New Water bill has replaced the Water Act 54, of 1956. Under the new Water Bill, management must accept total responsibility for waste and pollution arising from their industry. The Bill places responsibility on the user to purify effluent to an acceptable standard so it can be returned to its original source (Lazarus, et. al. 1997). The Bill also makes way for a more sustainable demand-management water pricing approach. Water pricing will now be set to value the resource according to its scarcity, and will also be geared towards full-cost recovery to a much greater extent than was done previously. This means that all the costs in the provision of water will be incorporated into the water price (and related effluent charge), including capital, operating, social and environmental costs (Naumann, 2000).

The price of water will therefore rise significantly over the next years, not only to help finance existing (and future) water infrastructure where necessary, but also to act as a deterrent for inefficient and wasteful water use. The increases should be an incentive to use water more sparingly, encouraging source reduction, particularly in those industrial processes which use significant amounts of water such as electroplating, anodising and conversion coating in the metal finishing industry.

With the shortage of engineered approved landfill sites (discussed above), disposal methods used for industrial waste will be increasingly closely monitored, and the costs involved will take account of the environmental burden to a much greater extent. It is generally accepted that the cost of waste disposal is going to increase significantly over the next few years. The cost of waste disposal in the Western Cape has risen 700% since 1991 and the trend is expected to continue in the future (Dittke, 2000). If the metal finishing industry is unaware of waste minimisation, they will face rising costs of pollution control which might put them out of business or might force them to operate illegally.

Central to the adoption of Cleaner Production is a need to ensure that whichever mechanisms are employed, they are properly monitored and enforced. This is likely to be a primary concern in South Africa. Already understaffed departments responsible for enforcement of these new laws are unlikely to be able to enforce more stringent requirements without more staff and bigger budgets. The result of this is that unless significantly greater financial resources are allocated to the departments concerned, there is likely to be a greater level of self-regulatory legislation, and a continued absence of consistent enforcement (Peart and Patel, 1998).

4.6.2 The Roles of Industry Associations and Organisations

Associations have the ability to negotiate with government on regulatory issues on behalf of the industry. Although there is potential for this to be used to aid waste minimisation initiatives in the industry, in the past it has been used in opposition to achieving waste minimisation. During the last drought in the PWV region, local government introduced water restrictions. The SAEA made representations to local government to be exempted from these restrictions, as it would have had serious consequences for electroplaters (Zalk, 2000). This does however indicate the strong influencing role that associations may play in affecting environmental change in the industry. The need for raising awareness of waste minimisation in the industry as a whole is however evident.

The chairman of the HDGASA has indicated interest in setting up an environmental committee/manager (Barnett, 1999a). They have also been included in the DANCED project preparation committee for the Cleaner Production Project in the metal finishing industry, and it is likely that the Project administration may be based at the HDGASA. In addition they have offered significant help to this project both directly (through sharing of information and offering advice for the case study company) as well as indirectly (through lending their support to the industry survey). No other associations have been identified with equivalent ability, although the AESF is likely to build-up capacity in the near future.

4.6.3 The Role of Chemical and Equipment Suppliers to the Metal Finishing Industry

Suppliers as service providers have an important role to play as the long term means for transferring Cleaner Production know-how and technology. Many of the local suppliers are either directly or indirectly inked to international supply houses. Therefore, within the field there is a great deal of knowledge of Cleaner Production advances that have taken place in other parts of the world. The lack of application of these in South Africa mean that the practical experience necessary to adopt them is lacking and potential service providers are not able to fully service the industry. At present, probably due to low awareness in the industry, there is very little demand for Cleaner Technologies, and therefore no incentive for international suppliers to access the market here (Bibber, 1998).

Approximately half the chemicals sold by suppliers to the metal finishing industry are sourced from overseas (especially from Europe and the Far East) (Naumann, 2000). As new chemicals are developed internationally, these then become available to South Africa (e.g. new improved degreasing chemicals which operate at lower temperatures – saving energy), and owing simply to their cost and quality benefits, may be adopted in industry here, even without environmental considerations. The same trend may be observed with the phasing-out of the use of some chemicals (e.g. solvents).

One South African supplier of chemicals is presently investigating possibilities of changing from supplying 'products' to supplying a 'service package'. One of the main drivers for this is likely to be the fact that the industry as a whole is said to be shrinking which has necessitated an increase in the emphasis on service. What suppliers are effectively doing is 'nurturing' and 'maintaining' their target market (Naumann, 2000).

4.6.4 The Role of Research Institutions

There is a need to build-up local capacity in South Africa, especially in terms of consulting expertise, and technology know-how. This is being addressed through research institutions and academia who train engineers, scientists etc. on environmental management, research pollution prevention methods and encourage implementation, and encourage research that realises practical application.

In particular, academic research into Cleaner Production is conducted by academic institutions such as the Environmental Process Engineering Research Group of the University of Cape Town (UCT), and the Pollution Research Group (PRG) of the University of Natal Durban (UND). Research is often in collaboration with the industry and semi-governmental organisations (such as the WRC), and have international co-operation (such as the European Union at UND) or international funding (such as the Canadian IDRC at UCT). Academic research has provided the current metal finishing case studies of successful waste minimisation applications, which may serve as demonstration examples to encourage waste minimisation in the wider industry.

4.6.5 The Role of International Donor Organisations

International donor organisations have the potential to contribute strongly to the development of waste minimisation programs and technology transfer in the industry.

International assistance was provided for the UND Waste Minimisation Club Projects by the European Union in the form of funding of consultants from the UK with experience in managing waste minimisation clubs.

The Danish Environmental Aid Agency (DANCED) intends to play a number of roles in promoting the adoption of waste minimisation in South Africa. They have so far provided substantial support for the development of the new IP&WM Policy. Furthermore support is provided for training activities and development of action plans in specific industrial sectors in order to implement Cleaner Production. A potential Cleaner Production project for the metal finishing industry is in the project preparation phase. The project idea is to support the adoption of Cleaner Production in the metal finishing industry in South Africa by transferring technology from Danish Industry and the experience of the Danish Cleaner Production Program. If approved, the support is likely to take the form of awareness raising within the industry, the provision of limited subsidies on a demonstration basis, and support to the process of technology diffusion, dissemination and training (Jensen et al. 1998).

4.6.6 The Role of the Private Sector

The Industrial Development Corporation (IDC) has developed a specific finance scheme for the implementation of Cleaner Production technology for the protection of the environment. It is available to industrialists for the acquisition of fixed assets to control / abate pollution in order to protect the environment, save costs and safeguard their exports. The scheme provides financing for the modernisation of existing plant and equipment, the expansion of existing industries and the establishment of new ventures aimed at Cleaner Production technologies (PMG, 1998).

Awareness of environmental issues amongst the community in general is very low in South Africa. Consumer pressure is unlikely while focus is still on price. It is only when quality and origin become a more dominant factor in affecting purchasing decisions that the production of 'cleaner' products will increase (Petrie, 1994).

4.7 CONCLUSIONS

It has been difficult to determine the size and structure of the South African metal finishing industry accurately. Results from a survey, combined with estimates from industry sources and literature indicate that:

- There are approximately 500-600 job-shop metal finishers
- It is unclear whether the captive or job-shop segment is more prevalent as there is argument either way. Owing to this and the survey results, the split between job-shops and captive shops is assumed to be approximately even, and the total number of firms is roughly estimated to be between 1000-1200.
- The vast majority of the metal finishing job shops are SMEs (~90%)
- Electroplating makes up the largest number of firms (~40%), though if powder coating and painting are combined they make up the largest sector. Anodising and hot dip galvanising are also significant sectors in terms of number of firms.
- Few firms actively practice effective on-site effluent management, and where it exists, it is usually not well organised, operated or maintained in relation to compliance with existing by-law quality standards, or disposal of waste sludges generated in the process.

The main barriers to improved environmental performance by the industry (particularly SMEs) are identified as:

- lack of awareness and understanding of Cleaner Production principles
- lack of finance
- unclear legislation and ineffective enforcement
- low input material and waste treatment costs

The main drivers to adoption of waste minimisation are expected to be:

- Cost savings associated with waste minimisation
- Regulatory pressure
- External pressure (such as environmental specifications)
- Improved environmental performance

Key role players have in some cases been responsible for creating barriers, but have the ability to provide incentives and other means to overcome them. The new National Waste Management Strategy intends to address the regulatory problems and includes waste minimisation as a focus area. In addition, increases in water and effluent charges as well as waste disposal costs are expected in the near future.

In some individual electroplating companies, cost-effective waste minimisation potential has been identified with the help of external assistance through participation in larger research projects.

In Chapter 7, all these aspects will be compared with the international experiences that were described in Chapter 3. In the next two chapters, the waste minimisation assessments in two local case study companies are described in detail. The companies are *job-shops* in the powder coating and hot dip galvanising sectors of the industry, and both are true SMEs.

Chapter 5: Case Study 1 – A Powder Coating Facility

'Minimise waste and emissions at their source rather than handle or treat them after these have been generated' – van Berkel, 1996

5.1 INTRODUCTION

In order to gather evidence in support of the hypothesis that there is potential for cost-effective waste minimisation amongst SMEs in the South African metal finishing industry, case studies were carried out in two local companies. This chapter describes the waste minimisation assessment carried out in the first of the two case study companies. The company is a small powder coating factory specialising on aluminium products. The process uses simple painting technology that is not highly efficient and results in a significant waste of powder paint. Powder that is emitted as a fine dust, settles within and around the factory, and the company has received complaints from neighbours regarding this dust settling on walls and cars in the area.

Another environmental concern to the company management is the use of hexavalent chromium in the pre-treatment section of the process. The hexavalent chrome process bath is hazardous and when spent requires expensive treatment and disposal. In addition, hexavalent chrome is carried over into the rinsewater. This was identified as a potential problem waste in the initial pre-assessment which had previously been performed by Dhliwayo (1998). The work completed by Dhliwayo included the location of sources of waste in the plant and the identification of the current disposal and treatment methods, as well as the selection of three focus areas for prevention of wastes and emissions. However, the pre-assessment had not been adequately completed, and additional work was needed, specifically in quantifying the amounts and costs of wastes and emissions. The work for this company therefore involved completing the pre-assessment and re-evaluating the selection of focus areas, before moving on to the assessment and selection of options. A brief assessment involving monitoring of certain streams and more detailed mass balancing was also performed by Dhliwayo. This information was tested and used where necessary.

The waste minimisation assessment methodology used has been outlined in Chapter 2, Section 2.4. The company's laboratory technician was involved in the assessment, and the Manager was included in this assessment team by adding necessary input as time allowed. All phases of the waste minimisation assessment were carried out as part of this project over a period of 18 months. The results of the assessment are presented in this chapter as a list of feasible waste minimisation options which may be/have already been implemented by the company.

5.2 COMPANY PROFILE

The company is a small-scale powder coating factory for architectural aluminium (window/door frames). The factory was commissioned in 1989 as an offshoot of a related company. It is privately owned and managed and currently employs 25 people.

The main activity at the plant is applying a protective coating onto a variety of aluminium parts from its customers. The plant operates for approximately 250days/year, with 2 shifts per day. Variability of work tends to be seasonal with the building market.

Their competition includes two other companies in the Western Cape area which anodise and powder coat aluminium. Their market share is approximately 1/3 despite their small size. Financial considerations are the primary constraints acting upon the company. The second constraint is the limited technical expertise readily available within the company, resulting in a dependence on suppliers. Its coating has an SABS approved quality system which has benefits, but is also a constraint in that it cannot easily allow for product or process changes which may affect the quality or not meet with SABS specifications.

The company is a member of the Aluminium Federation South Africa (AFSA) and the Association of Architectural Aluminium Manufacturers South Africa, for which they receive general marketing information and newsletters/journals.

5.3 PROCESS DESCRIPTION

The company operates a typical aluminium powder coating system with the principle process operations at the company as follows:

- Pre-treatment
- Powder Coating
- Curing

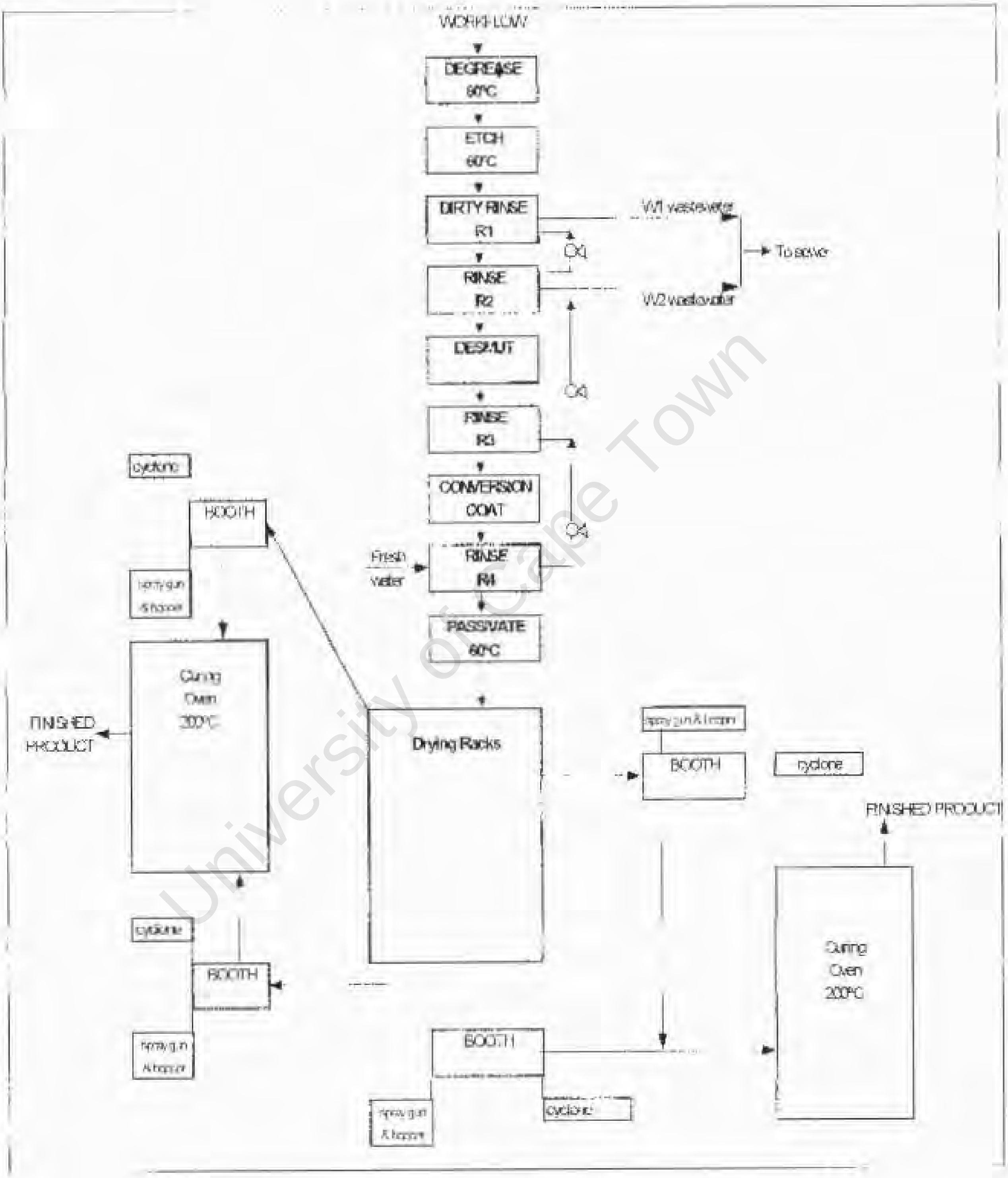
A process flow diagram for the company has been drawn up and is included in Figure 5.1. The pre-treatment tanks are 8m in length and 0.75m wide. All tanks are above the floor surface at a height (depth) of 0.62m. A significant amount of floor space is used for drying pre-treated parts prior to painting.

5.3.1 Pretreatment

The pre-treatment is the process of cleaning and preparing the surface to enable a good coating of paint. The larger aluminium profiles are lowered and raised into and out of the baths by a manually-operated crane. Small parts to be pre-treated are placed in the stainless steel immersion baskets where they are separated by aluminium strips and tied down with nylon rope. These baskets are suspended on the manually-operated cranes.

The pre-treatment system and control specifications have been set out for the company by its chemical supplier. All chemical baths are monitored twice daily using chemical titrations. The high quality control is due to the SABS approval requirements for the coating. The capacity of each tank is 3700L and there are 9 process steps in this stage:

Figure 5.1: Process flow diagram



Degreasing

The first step is degreasing in non-caustic alkaline solution (mixture of carbonates and phosphates) at 3% by volume to remove grease/oil on parts. The operating pH is 10. The solution also contains a non-ionic biodegradable wetting agent at 1.8% by volume. Chemical additions to replace drag-out and product loss are made daily or every second day, as required, depending on titration readings. To speed up the process, the temperature is maintained at 60°C by electrical immersion heaters. The tank is thermostatically controlled and insulated on sides, bottom and top. Top insulation consists of foam which forms in the degreaser and floating rubber mats on the surface of the bath. These rubber mats are pushed down by the parts on immersion and float back to the surface after withdrawal of the parts. Water is added to top up for evaporation and drag-out as required. The oil content in the bath is measured twice a year by the chemical supplier. When the oil content is >10% v.v. the bath is no longer effective.

Etching

The second stage is etching in a highly caustic sodium hydroxide solution at 0.03kg/L to remove the thin aluminium oxide layer on the surface and to create a rough surface for easy coating of chromate at a later stage. A black smut (an oxide compound) is formed on the parts. The bath is electrically heated to 50°C to speed up the etching process. Heating and insulation is in the same way as for the degreasing tank. Water and chemical additions are made as required according to titration readings taken daily. The etching solution eats away at the parts and causes some aluminium to go into solution. The aluminium content in the bath is monitored on a weekly basis. When the aluminium content reaches 10g/L, the etching solution is no longer effective.

Rinsing

To remove the remaining etching solution before dipping in acid, the metal parts are rinsed in a two step counter-current (the water flow is counter-current to the work flow) rinse system. The first rinse is a "dirty rinse" needed for the foam which is carried over from the etch bath. The feed water to the second rinse is the exit water from a later rinse tank (all 4 rinse baths operate as a counter-current system). Both these tanks have overflow weirs for dirty water to exit to sewer.

Desmutting

The performance of the chromate conversion coating is strongly affected by the presence of oxides and alkali-insoluble alloying elements (smut) on work-piece surfaces. An acidic deoxidising operation is therefore required before the conversion coating stage. The 5th tank contains nitric acid (HNO_3) for removal of the carbon smut formed on the aluminium surface during etching. The acid is bought at 60% industrial strength, and diluted with water to ~4% by volume HNO_3 (pH of ~2). The tank is protected with acid resistant glass-fibre. The contaminant build-up in the acid bath is slow. It depends mainly on the quality of the previous rinse, which will contain drag-out chemicals from the etch/degreaser baths. Other contaminants will include airborne dirt/paint. The acid bath therefore only requires dumping once/year and can sometimes be operated for 2 years without dumping. The bath is operated at ambient temperature and bath chemistry is checked twice a day. Top-up acid is added on a regular basis (approximately twice/month).

Rinsing
The parts are rinsed of remaining acid in a single-step counter-current water rinse bath. The feed water is the exit water from a later tank, the exit water leads to the rinse tank prior to the desmutting step.

Chromium Surface Conversion
The chromate conversion coating is a chemical treatment of the aluminium surface to improve its corrosion resistance (the mixed chromium/substrate metal oxide coating provides better corrosion resistance than the substrate metal oxide alone) and paint adhesion (the cellular structure of the mixed oxide film provides a base with more attachment points) (Hinton, 1991). The solution is a mixture of two proprietary chemicals. Chemical 1 is a mixture of chromic acid and phosphoric acid which produces an amorphous complex chromate film on the aluminium surface. It is maintained at 4.4% by volume in solution. Chemical 2 is a mixture of chromic acid and fluorides and is maintained at 1% by volume in solution. The fluorides facilitate the chrome coating by catalysing the conversion coating reaction. Although the solution contains chromium in the hexavalent form, chemical reduction takes place on the metal at the point of application, so that the chromium in the coating is essentially all trivalent chromium (Brummer, 1990). The detailed chemistry of the conversion coating reaction is described in Appendix E1.

An implication of forming coatings by chemical reaction is that the solution chemistry is continually changing. The chemistry has to be carefully balanced so that uniform coating properties can be maintained over the entire working life of the bath. The chromium and aluminium concentrations in the bath, active fluoride level, and temperature of the bath need to be monitored. The bath chemistry is checked twice a day and chemical additions are made daily for product and drag-out replacement as required. The bath is no longer effective when soluble contaminants build up so that they become detrimental to coating performance (usually after a 12 month period). The contaminants precipitate on the chromated film and cause paint blistering or corrosion problems when moisture penetrates the paint in the field.

Final rinse
The finals rinse is a single-stage counter-current rinse. The incoming water is fresh tap water (municipal), the exit water leads to the rinse tank prior to the chromate bath.

Passivation Rinse
The final step is a passivation 'rinse' in a 0.03% v.v. chromic acid solution to finish with a protective seal for additional rust prevention. Since the chromate coating itself contains no hexavalent chromium (Brummer, 1990), a passivating hexavalent chromium rinse is used as the final step of the treatment. Salt-spray resistance of the final product is strongly affected by this step, because it is the hexavalent chromate ions in the film structure which, in corrosive environments, trigger the repair mechanism into action (Ferro, 1994). More detail on the chemistry of chromic acid is included in Appendix E2. The bath is electrically heated to 60 °C (with immersion heaters) to speed up the drying of the part after passivation. This passivation step needs to be carefully controlled as any contamination can easily affect the quality of the final product. Since the quality of the rust-prevention is very important for SABS approval, the passivation bath needs to be maintained at a high quality, and is therefore replaced weekly on recommendation by the chemical supplier.

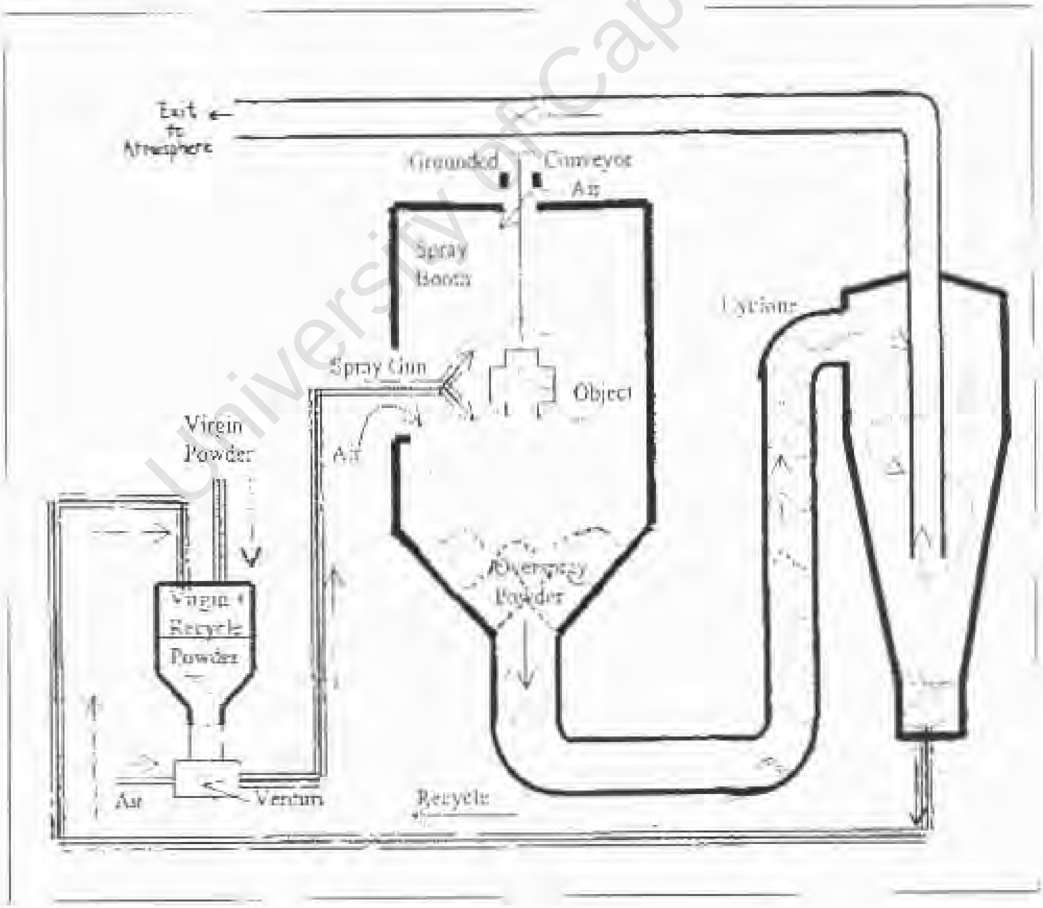
Drying

After the final step, the parts are removed from baskets and supported on racks for passive drying in ambient air prior to painting. Heat that comes off the curing ovens, on either side of the drying area, also aids the drying process to some extent. Chromate films should not be dried at elevated temperature, since they rupture (mud cracking) and lose protective value. Aluminium can tolerate temperatures to about 80°C with no adverse effects (Brummer, 1990).

5.3.2 Powder Coating

An electrostatic spray-painting method is used to apply powder films onto the dry pre-treated surface. There are 4 separate spray booths for painting to allow for easy paint colour changes. Two of them are used regularly, mainly for white powder painting. The other two are used less regularly, for colour powder painting. A diagram of the spray-booth and cyclone system is provided in Figure 5.2.

Figure 5.2: Simplified diagram of spray booth and cyclone system



The parts are suspended on wire and fed through the spray booths manually. Spray painting is also manual, performed by skilled operators using electrostatic spray guns. A mixture of air and powder is delivered from the spray hopper to an electrostatic spray gun, which places a charge on each powder particle. The charged powder is attracted to the article to be coated. Some of the over-sprayed powder settles on the walls of the spray booth or becomes airborne, but the majority is exhausted through a hole in the base of the booth which leads to a cyclone. The cyclones separate the heavier powder particles from the containment air stream and these are forced to the bottom reclaim canister. The reclaimed powder may be recovered or disposed depending on the quality. The air stream exits the top of the cyclone and contains any fine powder particles that were not separated from the stream.

The powders used are mainly epoxy-polyester hybrid powders with thermosetting resins. Each painted batch of products is tested for quality using test strips. In this way any problems are recognised and traced back to source for correction.

5.3.3 Paint Curing

To polymerise the powder applied to the substrate, the powder-painted parts are then cured by baking in an oven at 200°C for a few minutes. There are two ovens heated by burning LP (liquified-petroleum) gas. When the temperature of the metal reaches the melting point of the powder this results in melt-flowing of the powder over the part. A continuous film of liquid paint then covers the metal part. Curing agents in the powder include hardeners and crosslinkers. When the curing temperature is reached (around 200°C), the heat latent hardeners become active and the curing action begins (Ferro, 1994). The part is maintained at the cure temperature for about 10 minutes to allow the film to become 100% cured.

5.4 ENVIRONMENTAL PROFILE

General usage data and information on wastes was obtained mainly from Dhliwayo's (1998) pre-assessment report. All information was checked and adapted where necessary, and missing information was either obtained directly from company records or calculated using mass balance techniques.

5.4.1 Input Materials

Chemicals and paint

A knowledge of the raw materials used in the process helps in understanding the source of wastes emitted and the components of the wastes. The usage figures per annum and associated costs for each of the pre-treatment chemicals and the total paint are included in Table 5.1 below. Costs are included as % of total costs, as actual figures are confidential. The components of each chemical are included and any component that is hazardous it is noted *(in brackets)* in the table.

Table 5.1: Input material annual usage and costs

Input substance/ material	Components *(hazardous)*	Average annual consumption	% of Total Annual Cost
Degreasing chemical	Alkaline mixture of carbonates and phosphates	625 kg	1.2%
Degreaser additive	Non-ionic wetting agent	240L	0.2%
Etching chemical	NaOH *(Highly caustic)*	1685kg	2.2%
Desmutting chemical	HNO_3 *(strongly acidic)*	1330 kg	0.6%
Chromate conversion proprietary chemical 1	Chromic and phosphoric acid *(Cr^{6+})*	1395L	2.4%
Chromate conversion proprietary chemical 2	Chromic acid and fluorides *(Cr^{6+} and F^-)*	450 L	0.7%
Passivation chemical	Chromic acid *(Cr^{6+})*	40 L	0.1%
Paint stripping chemical	*(Caustic)*		
Powder paint	Epoxy and polyester resins	16,000 kg	90.2%
Water for rinsing and solvent for all process chemicals	municipality H_2O	6,600 kL	2.6%
Treatment chemicals: -Lime -Sodium meta-bisulphate	 CaOH $NaHSO_3$ solution	 162.5kg 50 kg	 R150 R200

The company uses a single supplier for all pre-treatment chemicals, and two powder-paint suppliers. For the pre-treatment inputs, the chromate and etching chemicals, and water are used in the highest amounts and account for the highest costs. The degreasing chemical is also used in substantial amounts. The highest overall cost (>90% of total input costs) is associated with the paint. A large range of different coloured powders are used (115 different colours in 1999) and each colour is represented by a code, used for selection by the client. Of the total usage for 1999, 51% was white powder paint. The remaining colours were each used in small amounts, with the next most used colour at around 5%.

The components of each of the proprietary chemicals were investigated to determine the rating and composition of any hazardous substances. The material-safety data sheets for the process chemicals only indicate the main chemical ingredients. It was not possible to obtain exact chemical composition as the supplier regards this as confidential information, but an idea of the components was offered. For the chromate chemical 1, and the passivation chemical, the supplier did reveal the hexavalent chromium content (the chrome content in each was found to be >90% Cr(VI) – Dhliwayo (1998)).

Table 5.2: Hazardous components of input materials

Material	Hazardous component	Hazardous nature	Concentration of hazardous material
Etching chemical	NaOH	Moderate (HR =3)	30g/L in solution
Desmutting chemical	HNO_3	Strongly acidic	0.045 g/L in solution
Chromate chemical 1	Cr(VI)	Extreme (HR=1) Carcinogenic and toxic	63.3g/L of concentrate 2.8 g/L of solution
Chromate chemical 2	Cr(VI)	HR=1	Unknown
Passivation chemical	Cr(VI)	HR=1	123.8g/L in concentrate 0.04g/L in solution
Powder paint	TGIC hardeners. Dust	Not listed in South Africa, but rated toxic in Europe. Potential fire hazard.	% unkown $10 mg/m^3$

The Hazard Rating (HR) is explained and further information regarding the hazardous nature and classifications for each of these is included in Appendix E3.

Water use:

A significant amount of water is used for the rinsing stages during pre-treatment. Rinse water usage is kept low through counter current rinsing, but there is room to reduce the consumption further. The manager would like to incorporate agitation in the baths to further improve the efficiency of the rinse. Water flows continuously at a rate of ~2.4kL/hr through the rinse system and the four rinse baths are dumped and refilled at the end of each week. Pre-treatment may sometimes run into overtime, and rinsewater usage for this amounts to 500kL/yr. Total water usage for rinsing alone is therefore 6350kL/yr. The flowrate measurement method and rinsewater usage calculations are set out in Appendix E4.

Water meter readings taken over a period of 1 week indicate an average total water usage of 31 kL/day, which means that the rinsewater usage amounts to 85% of total usage. This is in line with literature - Cushnie, (1994) estimates a rinsewater usage figure of 80% of total usage for plating shops, which usually use more process water. The use of the remaining 15% is divided between use as a solvent in process baths, for tank cleaning, and domestic requirements. All water usage calculations are set out in Appendix E4. The table below gives the breakdown of water usage for the factory

Table 5.3: Breakdown of water usage

Water Usage	Volume (kL/yr)	Cost/yr	% of total
Continuous flow rinse	5260		70%
Rinse bath dumps	590		8%
Overtime rinsing:	520		7%
Total Rinse:	**6.400**	**R15,900 (R60/day)**	**85%**
Solvent	260	R660	3%
Other (domestic, etc.)	1000	R2,500	12%
TOTAL USAGE	**7,630**	**R19,100 (R75/day)**	**100%**
Sewer charges:		R9,800	
Estimated water bills:		R29,000	
Actual water bills:		R30,200	

The calculated water consumption therefore appears to add up to the consumption according to water bills.

5.4.2 Utilities

Energy use:
Electricity is used in heating the process tanks, operating the spray guns, and operating the tank and cyclone pumps. The oven heat circulation fans, air compressors, air conditioners, and spray guns also consume a significant amount of electricity. The cyclone extraction fans consume over 75% of the total electricity usage. The bath heaters consume just under 20%, and the spray guns and air compressors just under 2% each.

Gas is used in heating the curing ovens. There are 3 gas burners supplying heat to the oven. The gas burners are outside the oven and direct the heat into flame chambers inside the oven. An electrically operated fan inside the oven, and ducts in the roof of the oven ensure the air is effectively circulated for convection heating. The gas is supplied in 48kg cylinders. 5 cylinders are used up in about 60 hrs of burning.

Table 5.4: Summary of energy usage

Utility	quantity	Cost
Electricity (KWh/yr)	206,400	R53,000
Gas usage (kg/yr)	25,000	R67,384

Compressed air:
An on-site compressor produces compressed air which is used as containment air for the powder paint in the spray guns, and to clean paint booths and cyclones by "blowing-off" the trapped powder. After compression, the air is passed through a chemical air dryer to keep it free of oil and moisture.

5.4.3 Current Waste Management Practices

5.4.3.a General Waste

Industrial (packaging) and domestic waste is collected in bins and removed by the municipal waste collector weekly for disposal. The cost of removal of the general waste is not clear as it forms part of a general service fee in the rate fees for the factory.

5.4.3.b Wastewater

The rinse system operates continuously with fresh water entering the 4th rinse tank and dirty water exiting from the first two rinse tanks via overflow weirs. Water flowrate is not controlled, the only restriction is the tap controlling the flow of fresh water into 4th tank. This tap is usually opened for the entire 9hr day-shift, but is shut off for nightshift as only painting is done at night. The dirty water is not treated but flows directly to sewer at an average pH between 8 and 9 (in the research for Chapter 4 it was found that it is common practice for metal finishers to discharge wastewater without treatment). The chemistry of the rinse baths is no longer tested regularly. Since maintained quality is always a concern, the rinse baths are emptied (to sewer) at the end of each week, and are refilled over the weekend. The acid and alkali rinses (two are maintained at pH 8-9 and the other two at pH 4-5) mix together in the rinse flow, and should in effect result in some degree of neutralisation of the water before exiting to sewer.

Water is polluted in the rinse baths where contaminants are dragged in from the previous process baths. Exiting rinsewaters to sewer contain drag-out from each of the baths, since the entire rinse-system is connected counter-currently. The contaminants build up in the rinse baths over the week to a maximum amount at the end of each week which depends on a number of factors affecting drag-out, where production rate, strength of process baths and operator controlled dripping time are major factors.

Drag-out management is not well controlled in the factory at present. In theory, the baskets are held above the baths after dipping to allow for the majority of the drag-out to drip back into the solution, but short enough so as not to let the parts dry out before the next dip. To speed up the dripping rate a bar on the basket is shaken manually by the operator. In practice, the dripping time varies depending on the operator and the production rate. The tanks are spaced close together so drag-out dripping between tanks is minimal. The majority of drips is therefore dragged-in to the following bath (i.e. the rinse bath in each case except for the degreasing solution which is dragged into the etching solution). For the final passivation bath, any drips that do go to floor after the bath and on the drying racks are left to evaporate (mainly water with very low chromic acid concentration).

The contaminants in the dirty rinsewater include suspended solids (including paint dust), aluminium, chromium, alkalis and acids. The contaminant of particular concern in the wastewater is Cr(VI) (the hazardous nature is described in Appendix E3). The limit for total Cr to sewer is 10ppm (there is no limit for aluminium). Although the limit for Cr(VI) is not specified in the new (1997) by-law, it is known that Cr(VI) (anion) cannot be removed in the sewage works (precipitation of cations) and passes through to the receiving water environment. Regulation therefore requires the use of conventional treatment (BATNEEC) to reduce the Cr (VI) to Cr (III) (cation), before it is discharge to sewer. Although Cr(VI) is not tested for, the treatment requirement implies the content should be 0.05ppm maximum. The limits and charge formula, effluent sampling method used by the local municipality as well as further information regarding Cr(VI) regulation is outlined in Appendix E5.

A brief assessment undertaken by Dhliwayo (1998), attempted to determine the Cr content in the rinse tanks. These findings were checked by taking further samples and the combined results are included in Appendix E6. Results indicated the concentration of chromium in rinse tanks 1,2 and 3 increases as more chromium is added from rinse tank 4 counter-currently. The total Cr content is in the range of 4-7 ppm according to 4 sets of measurements taken over a month, which is within the limit for total Cr. Further analysis indicted a Cr(VI) content of close to 90%, or in the range of 3-6ppm in these baths. Therefore Cr(VI) content of the continuous flow rinsewater (leaving tanks 1 and 2) is at an average of 4ppm and should in fact be treated before discharge. The Cr concentration in rinse tank 4 was found to be in the range 8-13ppm, which is discharged to sewer without treatment when the bath is drained weekly. The combined volume of water from all baths is expected to dilute the total Cr concentration to within the limit in the sewer system, however, at an average Cr(VI) content of >80%, the hexavalent chromium should be treated before discharge.

The drag-in of process chemicals not only affects the quality and hazardous nature of the rinsewater but also results in loss of raw materials to the sewer. The real cost of wastewater takes into account the cost of the loss of these chemicals. Material balance calculations based on a number of assumptions have been carried out to estimate the volume of chromate chemical, etching and desmutting chemicals lost to sewer through drag-out. The calculations are included in Appendix E6, and the results are presented in the table below.

Table 5.5: Calculated drag-out loss of chromate chemical to rinse water

Chemical	Chemical loss/year:	Equivalent solution/year:	Cost/yr:
Etching chemical	275kg/yr (16% of usage)	9,200L/yr	R2,300/yr
Desmutting acid	400L/yr (30% of usage)	6,700L/yr	R1,000/yr
Chromate chemical	450L/yr (32% of usage)	10,200L/yr	R5,000/yr
Total:		**23,100L/yr**	**R8,300/yr**

Around 10% is assumed to be lost through rinse dumps, while 90% is lost through continuous rinse flow exiting to sewer (based on volume ratio). Taking into account raw material losses and cost of water, the actual cost of wastewater losses to sewer is about R5/kL.

Sewer charges are based only on incoming water consumption and do not take any other effluent (e.g. spent process baths) into account. Samples are taken on a regular basis by the municipality to determine content of controlled substances (especially heavy metals) in the effluent. The charge formula takes the volume and concentration of certain contaminants and determines the resulting charge (Appendix E5). The company has not been charged any penalties in the past. This may be due to the fact that only the total Cr content is measured in samples. In addition, the manager does not believe that samples of the factory effluent are taken regularly.

5.4.3.c Spent Process Baths

Passivation bath:
Since the passivation step is the final rinse before painting, the passivation bath needs to be maintained at a high quality, and is therefore dumped and refilled regularly. Measurements of free-acid concentration are taken daily. The supplier data sheet recommends that if below the limit, additions can be made, but if above the limit the bath needs to be dumped and refilled. The free-acid is usually above limit within 4 days of operation, and the chemical supplier therefore recommends weekly dumping and recharging of the bath. In addition to the contamination from drag-in from the previous rinse, airborne powder paint also settles in the bath over the week and affects the quality of this final rinse.

There is no treatment of the spent passivation solution before disposal each week. Even though the concentration of the chromic acid in the bath is low the chromium is in the hexavalent form and is therefore a concern. Direct measurements taken before the bath is dumped indicate the total Cr content is around 40ppm at the end of each week (depending on production) which is significantly above the 10ppm limit for total Cr to sewer (measurement results included in Appendix E7). The supplier revealed the Cr(VI) concentration is 0.037g/L (37ppm) in working solution, which is ~90% of the total Cr content. Which means the wastewater should be treated to reduce Cr(VI) content before discharge. The bath is drained during the same period as all the rinse baths in the afternoon of the last day of each week. Though not exactly together, the combined volume in the sewer line will dilute the Cr concentration to some extent. As a rough indication of the resulting Cr content, the total mass of Cr from each bath divided by the total dumped volume (3000L x 5) yields a resulting Cr content of just over 10ppm - i.e. there is potential for the limit to be exceeded. At an average of 87% Cr(VI), there is a definite requirement to reduce the Cr(VI) prior to discharge.

Degreasing and Desmutting Baths:
The spent alkaline degreasing solution and acidic desmutting solution are not treated, but are discharged to sewer sump together, so that the two will neutralise each other in the sump before flowing out to sewer. (In the research for Chapter 4 it was found to be considered common practice for effluent to be discharged to sewer untreated). Any salt precipitation (nitrates, carbonates, phosphates) will occur in the sump/sewer-line. The oil/grease emulsified in the degreasing bath (approximately 10% v.v. or 300L of bath) is not removed and exits to sewer, as does the smut in the nitric acid. This oil is a particular concern since as it has potential to interfere with the sewage treatment works.

A relatively small amount of sludge also builds up in these baths and will probably consist of some settled airborne powder paint and any dirt/muck on the work-pieces. Before dumping, the baths are agitated to ensure the sludge is mixed with the contents before going to sewer. Dumping of the baths is performed every six months on average, but will depend on the bath analyses. If the desmutting bath does not need to be fully dumped at the same time as the degreaser, then only part of the acid will be dumped as some new acid added will improve the quality of the acid solution (partial dumping).

Etching Bath:
The etching solution is dumped when the aluminium content reaches about 10g/L, and this occurs 3 times per year on average. Before disposal of the solution, the aluminium (and other muck/dirt) in solution is allowed to settle in the bath overnight (the Al is white and colours the solution, when it settles to the bottom, the solution is clear again). The clear solution (about 30g/L NaOH, pH 12) is pumped out of the bath to sewer. The Al-rich wet sludge is manually transferred into drums (about 2 x 200L drums are filled). These drums are sealed and stored for collection by a wastehauler (together with sludge waste from the spent chromate bath). The cost of labour (sludge collection into drums) is estimated at ~R100 each time.

Chromate Bath:
The spent chromate bath is dumped once a year during the end of the year shut-down period. The solution is considered hazardous due to the Cr(VI) content, and by law requires treatment before disposal. The solution is treated conventionally by adding sodium bisulphite (reducing agent) to reduce the hazardous hexavalent chrome to less hazardous trivalent chrome. Lime is then added to precipitate the trivalent chrome as hydroxide sludge. The sludge is allowed to settle and the treated solution is discharged to sewer. The chemistry of this treatment is described in Appendix E8. After settling the precipitate the solution is pumped out to sewer until only the precipitate is left in the tank. This waste is left to stand so as to evaporate any water. The resulting semi-dry precipitate is then manually transferred into drums. These

drums are sealed and stored for collection by the wastehauler for further treatment. Approximately 10x200L drums are filled per treatment. The cost of treatment chemicals and labour for chromate bath treatment amounts to ~R500/treatment.

The cost for removal of the sludge waste by the wastehauler is high and is the major cost involved in treatment. The drums containing Al-precipitate (etch) waste and Cr precipitate waste are stored in the sealed drums and collected when the total volume is approximately 6400L (after 2 years). The wastehauler then charges approximately ~R11,000 for the load to be removed. The load will contain both Al precipitate and Cr precipitate. If the cost is assumed to be proportioned according to volume only, then the cost for disposal is as follows:

Table 5. 6: Annual volume and cost for disposal of hazardous bath sludge

Sludge	Volume/yr	% total volume	Cost/yr for disposal
Etch sludge	1,200L	40%	R2,100
Chromate sludge	2,000L	60%	R3,400
Total		**100%**	**R5,500**

The table below summarises the volumes and contents of the spent process baths which are discharged to sewer each year

Table 5. 7: Annual volume and cost of spent process baths to sewer

Sludge	Volume/yr	Cost/yr for disposal
Spent degreasing solution	6000L/yr	R3,000 (R500/kL)
Spent etching solution after sludge removal	7800L/yr	R2,000 (R250/kL)
Spent desmutting solution	3000L/yr	R260 (R90/kL)
Spent chromate solution after treatment	2000L/yr	R1,200 (R600/kL)
Spent passivation solution	126,000L/yr	R850 (R7/kL)
Total	**145kL/yr**	**R7,300/yr (R50/kL)**

5.4.3.d Paint Wastes

Oversprayed powder paint which is not contained in the spray booth is emitted to the air inside the building. On some days the airborne dust can be an irritant to eyes and chest. Some of the airborne paint settles in the process baths. Most of this dust settles to the floor and is swept up daily. The collected paint is solidified by curing in the oven and then disposed in the municipal bins.

Oversprayed powder that is contained in the booths is recovered in the cyclone. One of the cyclones was supplied by a different supplier from the other three and is much larger. The cyclones are not well maintained and efficiency therefore suffers through air-leaks etc. Direct measurements of cyclone efficiency by measuring recovered paint mass for a known mass of paint indicate an efficiency of around 87% for the larger cyclone using white paint. The working and results are presented in Appendix E9. It is expected that the maximum efficiency for both cyclone sizes and different paint-types is 90%. In any case, some unseparated small paint particles (paint dust) exit with the air-stream through the exhaust pipe at the top of the cyclone, and are emitted into the air outside the building. This dust is seen to settle on the floor, walls and cars of neighbouring buildings/area.

The recovered powder collected in the reclaim bin at the base of the cyclone, is used again to a certain extent, by mixing with virgin powder. The ratio of virgin to reclaimed powder is usually 2:1, though sometimes 1:1 is possible. The powder will continue to be used in this way until contamination or a problem with the coating is detected. White powder is not recycled too many times, especially for special customers requiring high quality. Sometimes when there is too much used powder to reuse, it is possible to sell it to another user who does not require such good quality. Paint in the reclaim bin is usually only recovered for reuse when the amount of paint warrants the downtime for collection (>3kg). Therefore, it is only recovered for longer colour runs such as for white painting or when a number of jobs for one colour can be combined (not always possible since same colour jobs come in at different times).

White painting is done during the day, and colour painting is mainly done during the nightshift. This is since colour runs are usually small and the production downtime due to frequent colour changes is better (for economic reasons) during nightshift. This has other benefits in that airborne paint in the working environment can settle on parts waiting to be painted, and coloured paint would contaminate parts that are to be painted white (colour spots show through the white coating).

Another significant source of paint loss is the powder that sticks to, and builds up on, the walls of the cyclone and paint booth. This paint is cleaned from the equipment before a colour change. Colour jobs are usually very small and there may be 2-20 colour changes in one night. Colour change time and colour contamination are significant concerns. For this reason, the cleaning process is done as quickly and a thoroughly as possible, without much concern for powder wasted or blown into the air. When there are many very small amounts of work for many different colours (<3kg paint per time), only the spray gun and exposed booth are cleaned and this takes approximately 10 minutes. All the colours collected in the cyclone will therefore be mixed together in the reclaim bin and will have to be discarded. The manager has weighed-up the cost of wasted powder and potential paint recovery versus downtime due to cyclone cleaning, and has found that the downtime is more of a concern (especially during night-shift). Cleaning of the entire cyclone chamber and bin, takes approximately 30 minutes/clean, and is only warranted for longer colour runs where >3kg powder is used.

For this cleaning method the cyclone is run without painting. Operators place a wooden board on the base of the lower discharge instead of the reclaim bin. In this way the dust is blown out to the atmosphere. In addition, compressed air is used to blow any powder sticking to the walls of the booth, while the cyclone is running. Some of the powder is blown into the working environment. The powder in the cyclone is blown out of the top air-exhaust and worsens the dust emission problems (i.e. the dust that settles in the neighbouring area).

When the powder in the reclaim bin can no longer/cannot be reused, it is collected in a box as 'dirty paint'. This is a mixture of coloured paints, and when it is full, it is placed in the oven to solidify the spent powder. In addition all dust that settles on the floor is swept up daily and collected for solidification in this way. The solid powder is disposed in the municipal bin for collection. The solid paint is not classified as hazardous in South Africa. Only the dust is a potential fire hazard.

The mass balance calculations used for determining the average annual paint loss are included in Appendix E9. The results for estimated paint losses are included in the table below.

Table 5.8: Estimated paint loss based on simple mass balance calculations

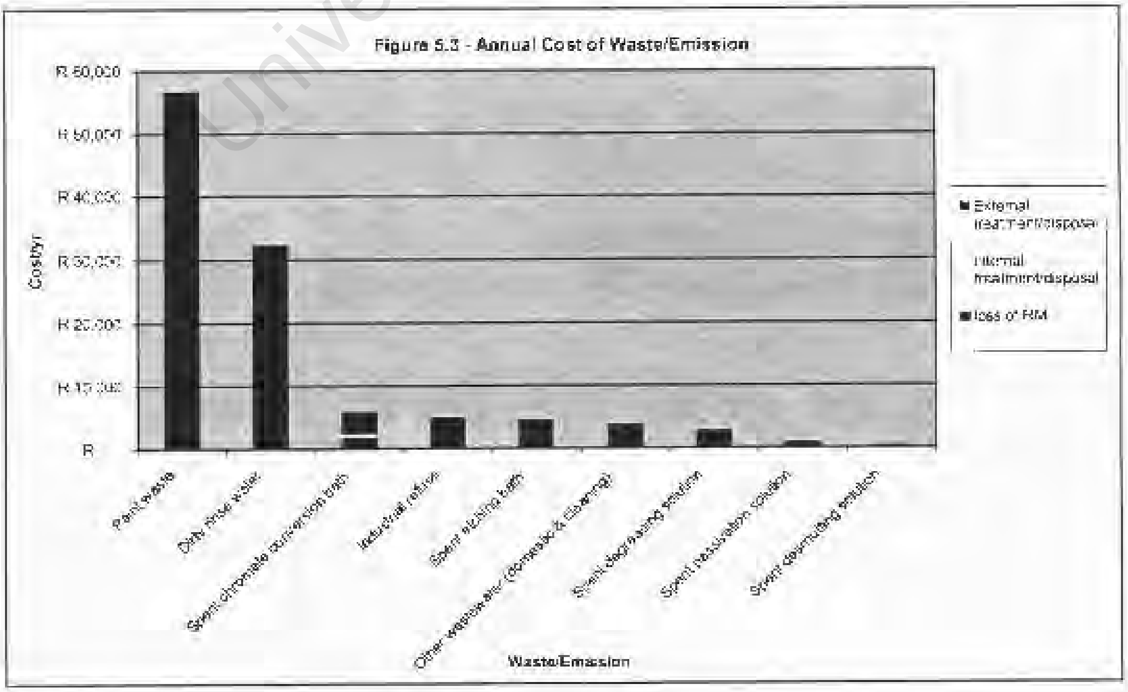
	Average annual Paint loss	Annual Cost of loss	% of total paint used
White paint	565 kg/yr	R20,300/yr	4%
Colour paint	1010 kg/yr	R36,400/yr	6%
TOTAL	**1,575 kg/yr**	**R56,700/yr**	**10%**
Loss to air	315 kg/yr	R11,400/yr	2%
Loss as solidified paint	1,260 kg/yr	R45,300/yr	8%

5.5 *COST OF WASTES AND EMISSIONS*

A summary of the cost of the wastes and emissions is included here. The 'true' cost of waste forms an important part of the waste minimisation concept, and includes raw materials lost in the waste, the utilities consumed in generating the waste, and the treatment and disposal cost of the waste, amongst others. Determining the true cost is mainly a tool for raising awareness in the company, especially with regard to the economic value of minimising wastes. Part of the reason for carrying out the waste minimisation assessment was to determine the true cost of the wastes.

The important aspects behind determining the true cost of each of the wastes have been outlined in Section 5.4 above. Working spreadsheets were used for all calculations and then linked to a summary spreadsheet to combine all costs. The summary spreadsheet is included in Appendix E10. The results are presented in a graph in Figure 5.3 below.

Figure 5.3 Annual cost breakdown for the wastes/emissions from Company 1



The paint wastes represent the highest expense and is for loss of raw material only. The resulting true cost of the dirty rinsewater is high since it includes the loss of raw materials as well as the sewer charges. These wastes are both generated continuously throughout the year. The spent chromate bath is, however, only generated once per year yet is the third highest cost owing to expensive disposal. Internal treatment costs are only noteworthy for the spent chromate conversion bath. The total costs are taken into account in the evaluation and selection of focus areas.

Table 5.9: Cost per 1000m^2 Al processed for wastes/emissions from Company 1

Waste/Emission	% of Total Waste Cost/1000m^2 Al processed
Paint waste	50%
Dirty rinse water	30%
Spent chromate bath	5%
Industrial refuse	4.5%
Spent etching bath	4%
Other wastewater	3%
Spent degreasing bath	2.5%
Spent passivation bath	0.8%
Spent desmutting bath	0.2%
Total waste cost/1000 m^2 Al processed	**R995**

Obviously the frequency of waste disposal/discharge has an important effect on the annual cost. The high cost for the chromate and etch wastes, despite disposal only once per year, arises mostly from the cost of disposal of the hazardous sludge.

5.6 PRE-ASSESSMENT RESULTS

The pre-assessment was the initial investigation into the company's operations, waste streams and emissions, and involved the collection of the above data. Literature was reviewed in order to compile background information on process operations, process technologies, and environmental impacts. On-site inspections covered all activities carried out on a regular basis in the relevant part of the company. An initial tour of the facility was required to form a good picture of how the company operates. More thorough/detailed inspections were carried out during the assessment itself.

5.6.1 Evaluation of Wastes and Emissions

The main activity of the pre-assessment was to evaluate the wastes and emissions in order to identify and select the focus areas for the assessment phase.

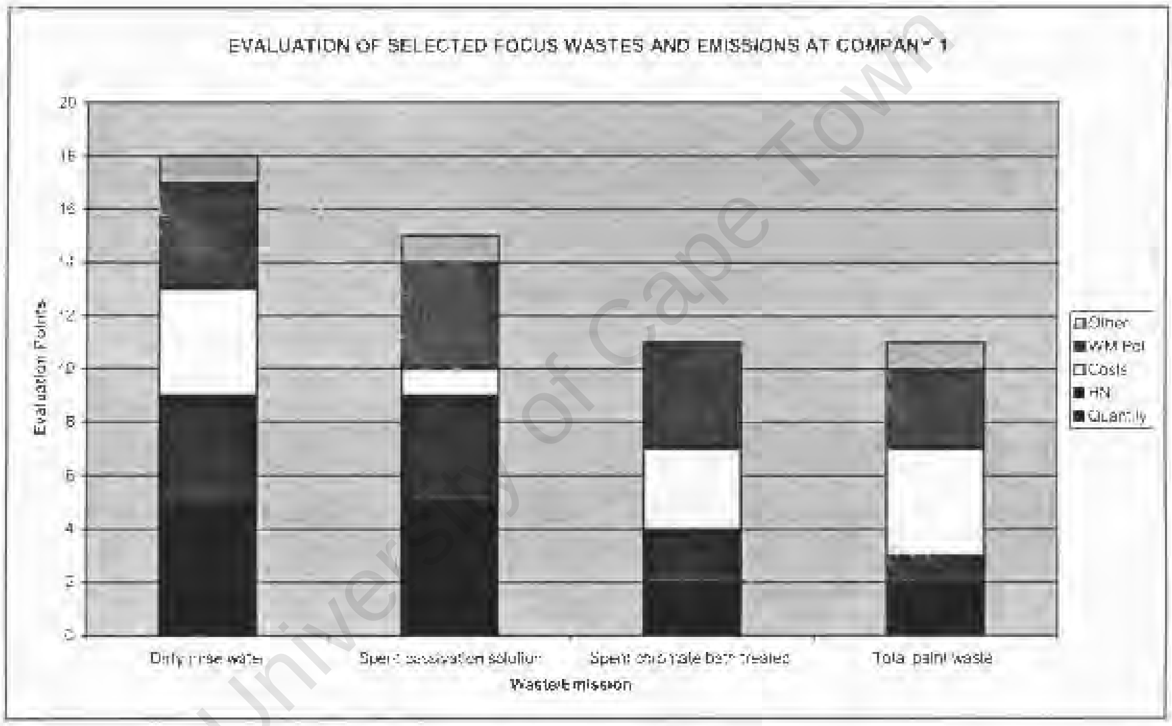
A pre-assessment of the plant had been carried out prior to the start of this study and the focus areas for the assessment had been selected as the hexavalent chrome in the wastewater and the lost powder paint (Dhliwayo, 1998). However, a more comprehensive evaluation was carried out in this study as a check as well as for consistency of methodology in both companies.

The quantity of the waste stream, hazardous nature, costs involved, and waste minimisation potential are the criteria taken into account in the evaluation. This information was compiled onto an evaluation table (the format of the table is according to the chosen methodology). The table is included in Appendix E11. Each of the wastes are assigned points for each of the criteria. The point system for the evaluation criteria is described in Appendix E12.

5.6.2 Selected Focus Areas

The same focus areas were selected, but the spent chromate bath and passivation bath wastes were also included. The graph below represents the results of the evaluation for the selected waste streams.

Figure 5.4: Selected focus areas



The graph indicates which are the contributing factors (criteria) that lead to each of the wastes being selected. The sources of these wastes and emissions were examined in more detail in the assessment. The evaluation results for all of the waste/emissions are included in Appendix E13.

5.7 ASSESSMENT OF FOCUS AREAS

The objective of the assessment was to obtain a clear understanding of the sources and causes of wastes and emissions in the focus areas, resulting in the identification of improvement options. It involved a detailed study of the focus areas to establish as many possible suitable waste minimisation options.

Activities included:

- Gathering additional data.
- Closing mass balances where possible, which required monitoring programmes to review processing conditions, and to quantify losses or emissions previously unaccounted for.
- Generating waste minimisation options.
- Screening and selecting options for further study.

The generation of waste minimisation options formed the major part of the waste minimisation assessment and in some cases required calculations and measurements to test alternatives. The activities required for generating waste minimisation options are discussed in Appendix E14.

While theoretical waste minimisation opportunities have been identified from the literature review, an attempt to assess applicability and cost-effectiveness of selected options for specific site conditions has been made using the results of the assessment. The details of the assessment procedure and findings, as well as the identified waste minimisation options for each of the focus areas, are described below.

In addition, each of the identified options is evaluated briefly as to their technical, economic and environmental feasibility.

- Whether the option fits in with how the company is run.
- Estimated technical feasibility, availability and previous success of technology.
- The environmental effect: reduction of amount and change in composition of the waste stream and any possible side-effects on the environment.
- Whether it can be justified economically for the company.
- Availability of finances.

Those options which required significant investment were analysed in more detail than simple procedural change options. The feasibility evaluation criteria and checklists are outlined in Appendix E16. The evaluation for each option is discussed for each focus area below.

5.7.1 Dirty rinsewater

5.7.1.a Problem Statement

The rinse water is discharged to sewer without prior treatment. The main concern for the dirty rinsewater is the hexavalent chromium exiting to sewer without treatment. The source of this Cr(VI) is the chromating solution which is dragged into the rinsewater during processing. Cr(VI) in the sewage works is a problem in that biological waste water treatment systems are not suitable for the hexavalent ion, and it will pass through without treatment. Cr metal may poison the bacteria, though activated sludge reportedly can tolerate up to 50ppm of chromium without undue inhibition of the bacterial activity (Kirk-Othmer, 1995). Chromic acid has been found to retard the digestion process at sewage plants at relatively low concentrations (5ppm). Further detail regarding the environmental effects of hexavalent chromium are included in Appendix E3.

The quality of the rinsewater exceeds pH specifications for the process within a week, and leads to the requirement for weekly draining each of the baths. This indicates that the drag-out of the alkali etch and acid desmutting solutions is also a problem. Another small contribution to rinsewater contamination is that small amounts of paint dust settles in the baths over the week. For quality reasons there should be no powder at all in the bath, as a small amount can spoil the conversion coating characteristics (Uittenbroek, 1999).

5.7.1.b Assessment Goal

The primary aim was to identify options to minimise the Cr(VI) content of the rinse baths at source. An additional aim was to identify options to minimise the drag-in from all process baths, with possibilities to concurrently reduce water consumption. Thereafter to investigate treatment options, and even a closed-loop rinsewater system. In addition to investigate options for preventing paint dust from settling in the pre-treatment area.

5.7.1.c Waste Minimisation Options

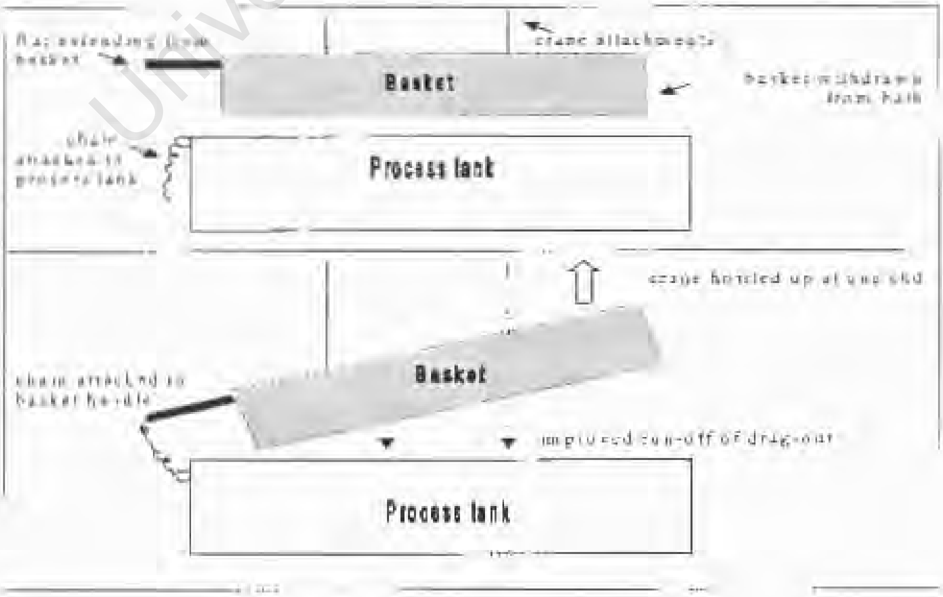
1. Option for drag-out reduction:

Drag-out is not easily controlled at present as the process is manually operated and drag-out therefore depends significantly on the operator. The current method to improve the speed of drag-out run-off is to shake the bar attached to the basket manually. The degree of returned run-off of process solution depends on the ability of the operator to manoeuvre the basket.

A brainstorm session identified a method that would allow for improved control of drag-out reduction, while at the same time increasing the speed of the run-off.

A diagram of this option is included in Figure 5.5 below.

Figure 5.5: Diagram of option for drag-out reduction through direct drag-out return



The method is as follows:

1. After the load has been withdrawn from the process bath, attach the bar extending from one end of the basket to a chain which is joined to the end of the process bath.
2. Raise the load above the bath, so that the basket is tilted and the drag-out can run-off more effectively.
3. Once the dripping is no longer visible, unhook the chain and move the load to the next bath.

There is a need to raise the awareness of the crane operators regarding the effect of drag-out and the need for drag-out reduction. The manager has indicated that the most effective means of doing this is to include specific drag-out reduction instructions in the operators job-description. This new method will be incorporated as new procedure, and will require minimal training.

This option is simple and readily technically feasible. A disadvantage is that the increased dwelling time could result in increased production time. However, this is counteracted by using additional baskets. Painting is the rate-determining step for production and pre-treatment can be adapted easily to suit. At present, painting production is sufficiently low to allow for only 3 baskets to be pre-treated at a time. It is possible, however, to have up to 9 baskets (1 for each bath) in use at a time. The factory presently has 4 baskets, and it is likely that only the 4 will be needed. If production increases significantly, the company can purchase an additional basket with available finances.

The option involves a simple change in procedure, with the initial investment costs being the installation of chains for attaching each bath to the crane, and operator training. The cost of the chains is minimal (~R250) and can be incurred immediately. The training can be carried out by the manager during working hours, and the time taken should, in effect, be minimal. General waste minimisation awareness training is a recommended waste minimisation option for all focus areas. The savings in terms of raw materials, depend on the achievable reduction in drag-out. If it is assumed that 70% reduction is possible, then the savings in loss of chemicals to rinsewater amount to R5,800/yr. Additional savings include the possibility of reduced sludge build-up through reduced drag-in of one process chemical into another process bath. Savings in water use may be achieved through reduced need for bath draining as well as reduced rinse flowrate.

The environmental effect also depends on the achievable drag-out reduction. If drag-out is reduced by 70%, then the initial drag-in of chromate into the 4th rinse bath will be reduced by 70%. The pre-assessment determined the average concentration of Cr(VI) in each rinse bath. The exiting concentration would therefore be reduced to between 1 and 1.5ppm Cr(VI), and the highest concentration in rinse bath 4 would be around 4ppm. This would have a significant improvement on the treatment requirements of the rinsewater. In addition, the concentration of acidic and alkali contaminants should be reduced by 70%, thereby possible reducing the frequency of dumping, or alternatively the rinse flowrate can be reduced. Of course, this reduction in rinse flowrate will depend on the actual resulting decrease in drag-out. Once the drag-out reduction option is in place, tests may be performed with regard to possible decrease in rinse water flowrate, while still leaving room for improved rinse efficiency. As a conservative estimate, and for the feasibility evaluation, the potential for decrease in rinsewater flowrate associated with the expected drag-out reduction, may be assumed to be 25% (R6,000/yr). The feasibility evaluation of this option is summarised in Appendix E22 (Option B1.1 - 1).

The installation of flowmeters to monitor rinsewater usage is recommended. These do not reduce water use by themselves but make the operator aware of use rates and help identify specific locations of excessive water use. The investment cost is within the company's financial ability, while the payback period depends on whether problems are identified and savings in water-use are achieved.

Whether water savings are achieved or not, the low cost of the option and the combination of benefits make the drag-out reduction option immediately feasible and it is recommended to be implemented as soon as possible. Thereafter, tests may be performed to determine the actual decrease in drag-out achieved.

The problem of the Cr(VI) content, though significantly reduced, is however still not solved. In order to reduce Cr(VI) content of the continuous flow rinse water to an acceptable limit, the drag-out of Cr(VI) would have to be reduced by 99%. This is not feasible, unless the use of hexavalent chromium is completely eliminated. This would require the substitution of the chromate chemical with a chrome-free alternative. This option is discussed in Section 5.7.2 below. The drag-out reduction option is however the first step, as it will minimise the drag-out of whatever alternative chemical is used and thereby minimise raw material losses.

Options for minimising paint contamination of rinsewater:
The dust that settles in the baths is not high, but can have a potential effect on the quality of pre-treatment. The manager does not believe that preventing the paint from entering the baths will result in lower frequency in bath drains, as the chemical quality of the baths is the primary factor. Any option to minimise paint dust settling in the pre-treatment baths would involve physical separation of the paint area from the pre-treatment area. An option would be to provide lids for the baths when not in use. However these are not an inexpensive investment at ~R15,000 (workings in Appendix E22 Option B5-4) and would not prevent the dust that settles during the dayshift. To redesign the working area and construct partitions between pre-treatment and painting would be a much higher expense at ~R40,000 (estimated by the manager) (workings in Appendix E22 Option B5-5), as it would involve moving the pre-treatment area as well as installing partitions. Savings in either case are negligible and therefore these options are not feasible for the factory at present.

However, most of the airborne paint results from inefficiencies in paint application. Options to improve the application efficiency and minimise overspray would reduce the amount of paint that settles in the baths. These options are discussed further in 5.7.4.

5.7.1.d Treatment Options

Conventional/closed-loop Treatment:
The conventional treatment option would require the installation of a series of tanks to reduce (Cr^{6+} to Cr^{3+}), blend, raise the pH and precipitate (Cr^{3+} as hydroxide), settle

and separate the resulting sludge. This treatment sludge would then require disposal as a hazardous waste. In addition to the extra working space required for the treatment section, this option would require a significant investment for the company as well as increased operating costs. Owing to the financial constraints of the company, as well as the lack of additional working space, this option is not economically feasible for the company at present, especially since the current method of discharge to sewer is effectively 'free' treatment of the Cr. The option would only become feasible if the regulations and enforcement of the regulations for Cr(VI) treatment were to become far more stringent. However, the company wishes to counteract this possibility by changing to a chrome-free conversion chemical before the new regulations are in place.

Installation of a complete closed-loop water treatment system is a possible long-term option, and will depend on the composition of the selected alternative conversion chemical. The feasibility of this option will also depend on the future increase in water costs.

5.7.2 Chromate Conversion Bath

5.7.2.a Problem Statement

The chromate conversion coatings contains hexavalent chromium which offers many advantageous properties, but is considered hazardous due to the compound's toxicity and suspected carcinogenicity (more detail regarding the hazardous nature is included in Appendix E3). The chromate conversion bath is the source of the hexavalent chrome in the dirty rinse water. In addition, the spent chromate bath requires special treatment resulting in a hazardous sludge that is expensive to dispose. A literature search revealed that this is a well-known problem for powder-coaters around the world and that much alternative chrome-free conversion coating chemicals have been developed.

5.7.2.b Assessment Goal

The assessment goal was to identify an environmentally acceptable and cost-effective, chrome-free alternative conversion treatment with the performance of chrome that could be used in Company 1. In addition, the alternative needed to be commercially available in South Africa.

5.7.2.c Assessment Results and Discussion

It was found that many alternative materials have been developed that can be used with an existing (or modified) conversion coating process, and are less toxic than chromates containing hexavalent chromium. In general, the processes using the alternative materials substitute the ion of the alternative substance for the chromate ion. Alternatives are based on components that are either similar to chromates in their behaviour or are known to offer high corrosion resistance. These include trivalent chromium, metal oxyanion analogues of chromates (e.g. permanganate), rare earth metal salts, complex transition metals, or organic systems.

A summary table of alternatives was compiled from the literature and product search. It includes a brief description of each alternative, advantages and disadvantages relative to chromates, as well as information on availability of products. Although there are more products available internationally, those included in the table are some of the more commonly used products for which information was available from suppliers. The hexavalent chromate chemical is included for comparison. The summary table is included in Appendix E14.

Analysis of Alternative Options

The product examples (included in Appendix E14) that are commercially available, have been rated to determine how each compares to the existing chromate chemical, regarding technical (process requirements and performance), economic (relative cost), and environmental (waste generation, treatment and disposal) factors. The rating for each factor is very broad as it is information available for each product varies considerably. It is as follows: -2 (much worse), -1(worse), 0(same), 1(better), to +2 (much better). The summary table is presented in Table 5.10 below:

Table 5.10 – Comparison of alternative chrome-free products

Product	Technical Rating	Economic Rating	Environmental Rating	Total Score
Chemical H (silanes)	−3 (simpler and superior to chromate)	-1 (process costs similar chromate, with lower waste disposal costs)	-2 (environmentally compliant)	6
Chemical C (organic)	−1 (fewer stages, simpler to operate with comparable results)	−2 (cheaper overall process and very low waste treatment costs)	−2 (non toxic)	5
Chemical G (organic)	+1 (assumed as for C)	−2 (assumed as for C)	−2 (assumed as for C)	5
Chemical F (Ti and fluorides)	+1 (Simpler than chromate with comparable performance).	−1.5 (cheaper overall process with fewer stages and 60% less sludge disposal)	−1 (less toxic)	3.5
Chemical D (Zr and fluorides)	-0.5 (same process requirements, nearly equal performance)	−1.5 (cheaper product and less sludge for disposal)	−1 (less toxic)	2
Chemical B (permanganate)	-0.5 (same process requirements, nearly equal performance)	+1.5 (similar to chromate but without expensive disposal costs)	−1 (less toxic)	2
Chemical I (no-rinse chromate)	-0.5 (same performance, fewer stages, but much more control)	-0.5 (much more expensive chemical, same disposal, but less rinsewater costs)	+1 (no Cr in rinsewater, but still spent bath)	+0.5

The result appears to indicate that the silane-based product would be the preferred option for Company 1. The main advantage of the silane-option is that it is the one alternative which offers superior performance to chromates. In addition, it does not appear to contain any heavy-metals or other components of concern. However, at the time of the research the product was not available in South Africa, and the manufacturers could not confirm whether it would be in the near future. The remaining products were therefore investigated further.

Organic-based alternatives appear to be the next preferred option in terms of overall performance. It was found through contact with the suppliers directly, that Chemical C is not available in South Africa, or likely to be in the near future. Chemical G is available from an international supply-house which has a representative in South Africa. However, at the time of the research, the local supplier was not able to supply

the product as it had not yet been approved for the South African representative. Information on the product from the international supply-house was not obtained. Chemical F (based on fluotitanate) has the same South African representative as Chemical G (supplier 5). The considerations are therefore as for Chemical G, but with the added factor that it has a lower overall rating than Chemical G.
Chemical D is available from the current supplier to Company 1 and could be supplied immediately. Information on the product was readily available and the supplier was able to determine the product's feasibility for use in Company 1. The findings from the detailed feasibility study for this option are included in Appendix E18.

The option was found to have comparable performance to chromates. It appears to be technically simple and has potential for use in Company 1 at similar to lower cost. The main benefit is the elimination of Cr(VI) in the wastewater, and that the resulting wastewater will not require treatment by regulation (Zr is not controlled). The spent bath will still require treatment and disposal of sludge, but at significantly reduced hazard. The manager of Company 1 was willing to change to this option even if only as a short-term option until silane-based alternatives became available locally. The product required approval from the paint supplier before it could be used, as the paint supplier backs the quality guarantee for Company 1. It was found at a late stage of the research that the paint supplier only approves of chrome-free products with 'Qualicoat' approval.

Qualicoat is a quality label for wet and powder coatings designed for aluminium used in building applications. The regulations define specifications for the coating and coated end product that have to be met in order to obtain the quality label. The process of obtaining Qualicoat approval involves approximately 2 years of testing. The testing for Chemical D by Qualicoat has begun, but still requires another year. Owing to the strict quality requirements for Company 1, the option of changing to Chemical D cannot be considered until the Qualicoat approval is obtained.

Qualicoat approved products available in South Africa:
The most-recent list of chemicals that have Qualicoat approval was obtained. There are a total of 14, and include Chemicals F, H and I from above.

Chemical I is not chrome-free, but is a rinse-free option. A data sheet for Chemical I was obtained from the local supplier and initial investigations indicate that the process control requirements are very stringent. Although there are water savings and improvements associated with elimination of both the Cr(VI) wastewater and the passivation bath, there are alternative disadvantages in that the process baths and rinse baths will requires demineralised water for make-up. In addition the paint dust which settles in the baths cannot be tolerated and will have to be completely eliminated. This would, in effect, require separation of the paint and pre-treatment areas. The product is almost 5x more expensive than the existing chromate chemical and operates at a higher concentration. The bath still contains Cr(VI) and when spent will still require special treatment and disposal as a hazardous waste. This option does not suit Company 1 and the manager is only prepared to consider this option as a last resort.

However, recently the supplier of the silane-based product (Chemical H) has merged with the current supplier (1) to Company 1, and it appears that the product will therefore be available for Company 1 from its existing supplier. Supplier 1 is in the process of investigating this product and it is expected that this product will be available within a year. In addition to the information on silane-systems in Appendix E17, further investigation regarding technical aspects of the product have been undertaken briefly. It was found that the product is being used successfully on architectural Al in one plant in Spain at present. Treatment requires simple substitution of the silane product in place of the chromate, however, the silane bath requires heating to 45°C. Further, it requires vigorous blow-off of silanes (using compressed air) after extraction, and the ideal final (passivation) rinse is with demineralised water. It appears therefore that the rinse after the conversion coating is eliminated, which is a significant environmental improvement over the existing Cr(VI) containing wastewater.

The cost of the chemical is unknown at present, but is not expected to be too high owing to the low concentration requirements. Waste generated is small amounts of mainly condensed silanes and unused fluotitanic acid. The silanes adsorb onto the sludge in conventional treatment and do not interfere with biological processes (Child, 1998).

This Chemical H will be available for local testing by Company 1 in the near future. It is likely to be at least 6 months before the feasibility for use in Company 1 is known accurately. The product does however have 'Qualicoat' approval and is therefore acceptable to the paint supplier, and the quality rating system. The requirement for a demineralised-water final rinse would be the same for any of the chrome-free alternatives and would need to be installed in any case. Changing to the new system is therefore expected to be relatively cost-effective, owing to the fewer number of process steps and the reduction in waste-disposal costs. However, this cannot be stated conclusively.

5.7.2.d Recommendation

The problem with changing to an alternative when it is the primary quality-determining pre-paint step in the process, is that the risks involved have to be thoroughly investigated and testing takes a long time. Since the company relies significantly on its SABS approval and guarantee, it cannot afford to make changes with lower performance. The options which have been available for a few years in international markets are becoming available locally now as the supply houses form alliances with other South African supply houses. It may be possible that many other alternatives will become available in the near future. It is recommended that Company 1 continue with the investigation into the 'Qualicoat' approved alternatives.

The company manager is determined to change to a chrome-free option as soon as possible, and if Chemical D achieves 'Qualicoat' approval within the year, it is a feasible and cost-effective intermediate option for the company. However, at present, it appears very likely that Company 1 may change to the silane-based option, though this depends on the results of the product testing and the feasibility evaluation for suitability at Company 1. Whether it will be cost-effective and hence feasible in the case of Company 1 depends to an important part on whether the company will be forced to treat Cr(VI) containing effluent in future. The benefit of being ahead of the competition in anticipating the need to change to an environmentally-friendly alternative while still maintaining quality cannot be ignored. It would be ideal, if the company could change to chrome-free in the new year, as this would mean the existing chromate bath, would be the last requiring disposal.

In the meantime the implementation of the drag-out reduction option will significantly reduce the Cr(VI) in the wastewater. It is most likely that the company will have changed to chrome-free option before the regulations regarding Cr and Cr(VI) become more stringent.

5.7.3 Spent Passivation Bath

5.7.3.a Problem Statement

Since the quality of the rust-prevention is very important for SABS approval, the passivation bath needs to be maintained at a high quality, and is therefore drained and refilled weekly. The bath is discharged to sewer without treatment of the spent solution. The total Cr content of the passivation bath is well above the sewer limit, and the content is ~90% Cr(VI). In addition the bath is heated and therefore at a temperature of around 50°C on discharge.

5.7.3.b Assessment Goal

Since the company is aiming to eliminate the use of chrome in the conversion treatment, they would like to eliminate the chrome in the passivation baths as well. Most of the chrome-free options recommend a final seal rinse of demineralised water, followed by heated drying. There are chrome-free chemical based final rinses available, but not with the performance of chrome. The company supplier has stated that the best alternative to chrome for final rinse is demineralised water, as it is in fact an improvement on the performance of chrome. The use of a demineralised water rinse in combination with some other changes in the paint-process, can in-fact increase the quality guarantee of the finished product by a further 10 years (15-25 years).

Demineralised water as final passivation rinse is commonly used in Europe, both with chromate and non-chromate conversion coating systems. During the industry survey in Chapter 4 it was revealed that a very new large powder coating company in South Africa uses a demineralised water final rinse successfully. The rinse requires continuous addition of demineralised water to maintain the quality which is being continuously lowered by drag-in from the prior bath. It is therefore considered impractical to heat the rinse water, and the system needs to be used in conjunction with heated drying.

The aim of the assessment was therefore to determine the requirements for and feasibility of installing a demineralised water final rinse, and the accompanying heated-drying area at Company 1.

5.7.3.c Assessment results

The mains water at Company 1 was analysed to determine hardness, and conductivity. The results are included in Appendix E19. Total hardness is at 60 ppm, which is low, as generally water <<300ppm is considered 'soft'. Conductivity is at 120μS. The bacteria content was tested by the equipment supplier and found to be sufficiently low not to require a UV cell prior to the demineralisation unit.

5.7.3.d Technical feasibility of Waste Minimisation Option

Demineralisation unit:

A quote for a potential demineralised water unit has been obtained from a local supplier. The demineralised bath cannot be static and requires implementation as a continuous re-circulating treatment. The system offered comes as a complete unit containing the cation and anion resins. The unit recommended for Company 1 can treat up to 1500L/hr. For a 3,700L bath, this will mean at least 2 turnovers of bath volume per day (2.5hrs to fill tank).

The water to be treated requires reduction in conductivity from ~120μS to <5μS. The drag-in from the previous rinse will contaminate the bath over time, thereby increasing conductivity. A conductivity meter is included as part of the equipment, and the water drip-off from parts will be tested for conductivity as they are withdrawn from the demineralisation step. When the conductivity of the drip-off reaches 20μS, the resins will require regeneration. It is estimated that up to 80,000L of water can be treated before each regeneration. 3hrs is required for automatic regeneration of the resins using 25L of 30%NaOH solution (pH 10-11) (R280), and 25L of 35% HCl (R250) (pH 1.5). The regeneration effluents will combine before discharge to sewer and effectively neutralise each other. Therefore, no treatment of this effluent is required, and it is not considered hazardous. Frequency of regeneration is unknown at present and will depend on production. Resins will require replacement after certain operating time dependent on load over time. It is estimated that this will be only after 10 years.

Drying oven:

The air-temperature drying racks will be replaced with a special drying oven. The proposed design is to install an additional tank which is heated using fans and electrical elements mounted at openings on the one side. The tank will be enclosed by a folding "lid." The required temperature is around 70°C (though this might depend on the conversion coating), and electrical cabling and control instrument connections will be required. Drying time may be reduced from 2hrs to 5 mins per load and the space for the drying area will be reduced substantially. This will free up floor space and speed up the production rate making the process more efficient. Decreased drying time will also mean less time for contaminants to build up on the coating. The working area will be cleaner, and space will be available for installing other equipment such as the demineralisation unit or a dust filtration unit.

The operation of both these units is technically simple, and both can be relatively easily installed in the factory. The potential risks are with the control and operation of the demineralisation unit. A significant amount of pre-testing may be required to determine optimum conditions. This may be done quite simply once it is known what the alternative conversion coating chemical will be.

5.7.3.e Economic Feasibility Feasibility of Waste Minimisation Option

The investment costs for the demineralisation unit and drying tank have been estimated at R38,000 and R20,000 respectively or R58,000 in total. The workings for the feasibility evaluation are included in Appendix E22 - Options B6-1 and C3-2. Estimated operating costs for the demineralisation unit amount to ~R5,500/yr above the cost of the water (water volume is expected to be the same as for passivation rinse at present). Operating costs for the drying tank are primarily for electricity and amount to ~R5,800/yr. Savings in passivation chemical and heating of the passivation bath amount to ~R2,200/yr (though if the silane chrome-free option is selected, the bath heating will be transferred to the conversion bath).

At present, costs outweigh savings, however, the change to chrome-free conversion coating which is required in combination with this has potential future savings associated with it. The chrome-free option chosen will have to have reduced overall costs in order to make the installation of the demineralisation unit and drying tank economically feasible. Potential savings connected to the chosen chrome-free option, including reduced hazardous sludge disposal charges are ~R3,400/yr, as well as potential future savings through elimination of wastewater treatment requirements, though these are difficult to determine. Other savings related to improved production time from shorter drying time, depend on the production rate. As concluded for the chrome-free option itself, whether this investment will be economically feasible for the company and hence cost-effective, depends significantly on whether the company will be forced to treat its Cr(VI) containing effluent in future. The manager believes it is prudent to change before environmental regulations become a problem. The investment cost is high, but is within the long-term financial ability of the company, and has benefits in setting the company ahead of its competitors in the future.

5.7.3.f Environmental Evaluation of Waste Minimisation Option

The regeneration of resins will result in additional effluent, but the NaOH and HCl will neutralise each other and may simply exit to sewer. There will be an increase in electricity requirements. However, the Cr(VI) to sewer from the passivation rinse (and the conversion coating wastewater) will be eliminated. The overall result would be a significant decrease in hazardous nature.

5.7.4 Paint waste

5.7.4.a Problem Statement

The airborne powder paint not only settles on neighbouring buildings and cars, but can also be an irritant in the working environment by settling in the pre-treatment baths and products waiting to be painted, thereby affecting quality. The paint waste also represents the highest waste cost for the company as paint is the most expensive input material for the process, and an estimated 10% of total usage is lost through process inefficiencies. Figures obtained from the powder manufacturer indicate that the loss should not be more than 5% (depending on the type of operation).

The loss of paint depends on a variety of factors including:

- the efficiency of the spray gun used
- the efficiency and skill of the operator
- the type of paint and part to be painted
- the part size relative to the spray booth
- the efficiency of the cyclone used
- the m^2 coated per colour run

In summary, the paint loss is therefore:

- Paint lost during spray application due to overspray which is not collected for cyclone recovery (estimated 5.5% of total loss).
- Paint lost through the exit at the top of the cyclone due to inefficiencies in the separation process (estimated 12% of total loss).
- Paint lost to air (and settles to floor) when cleaning booths (estimated 5.5% of total loss) and cyclones (estimated 7% of total loss)
- Recovered paint that is disposed when it cannot be reused, either due to low quality or colour contamination (estimated 70% of total loss).

These estimates of paint loss are used in determining the potential savings from efficiency improvements for identified waste minimisation options.

5.7.4.d Assessment of Paint Application Equipment

The primary source of all paint waste is the initial inefficiency of the paint application process (this leads to over-spray which is either lost to air, or is recovered and disposed). The paint waste therefore depends significantly on the 1st transfer efficiency which depends on the application method and equipment. Since the method of application is manual and not automatic, the factors affecting efficiency include spray gun settings, operator skill, and spray booth design.

Gun settings are not controlled at present owing to lack of confidence in the equipment and uncertainty regarding how to set it optimally for different paints and part types. Some paint colours adhere to the parts better than others and this requires adaptions in spray method to suit the type of paint. Some powders do not stick to parts very well at low spray settings and it is general practice to use a fast spray setting and quick movements of the gun to ensure paint sticks to parts. Setting of guns at a lower rate so that the spray is slower will generally result in less over-spray. There is resistance from operators to set the spray at slower speed, as it is faster and easier to spray the part at a high setting. The equipment itself is inefficient and there is a need for continuous maintenance of equipment, as well as the upgrading of ageing equipment.

The design of the painting booth is such that the whole front of the booth is open. The cyclone extraction creates an under-pressure that ensures the majority of the paint is contained in the spraybooth. However when the spray-gun is pointed at parts which extend outside of the booth, the oversprayed powder is not contained. In addition, the method of feeding the parts into the booths by hand causes the problem of overlap (also linked to operator skill) as well as the overspray which is not contained within the booth.

5.7.4.e Waste Minimisation Options for Paint Application Equipment

1. Continuous Training

The brainstorm identified the need for continuous training of paint applicators to improve knowledge regarding gun-settings and spray methods and to avoid 'bad habits' causing paint wastage. The paint equipment supplier offers free advice regarding use of paint application equipment, and this opportunity was used for a representative to train the operators. This took the form of an 'interactive training' session where paint applicators discussed difficulties and the supplier offered suggestions for improvement. The representative also observed the painting operation in order to identify obvious inefficiencies in the application method and equipment, as well as to identify possible improvement options.

A number of specific problems and improvement options were identified and these are described in Appendix E21. These have benefits for both production quality and the environment. As a result of this interactive training session, the operators and manager now have a better idea of the 'optimum' gun settings and spray method for different paint and part types and they can now be controlled with confidence. Further similar training sessions are to be arranged every few months to maintain increased awareness of the operators. The paint supplier will also contribute at the next training session.

2. Control System
In order to ensure that the guns are set-up correctly at all times, a formal control system is to be set in place. This will require the operator to check the equipment prior to each new workload and to sign-off a formal procedure check-form. This proactive control system will be a significant improvement on the current system of reactive control, where quality of products are checked, and only when a fault in painting is observed is it traced back to determine the faults in gun-settings.

The savings associated with the improved awareness and skill of the applicators from training, combined with the continuous control of equipment settings is estimated at up to 30% of the paint loss (3% of total usage). In addition, the manager believes an additional saving of R2,000/yr can be achieved through a reduction in defective products. Total savings less costs could therefore amount to R18,000/yr. The payback period for these low-cost options is therefore almost immediate (<1month). (Workings for the feasibility evaluation are included in Appendix E22, Options A1-3&5).

3. Upgrading Ageing Equipment
The spray guns are old and could be replaced for higher efficiency guns designed with the latest technology. However, a single new gun amounts to R15,000 alone and would also require modifications to the hopper. There are 5 guns, and to replace all of them would require around R75,000 capital investment. Savings in powder use by improving spray efficiency in this way can amount to about 30% of the powder loss, or R17,000/yr. This option has a payback period of 5 years for a high investment. The company may be able to afford investing in 1 new gun per year, however, there are other projects competing for the financing.

The equipment supplier has suggested instead, an upgrade of the spray guns to improve the efficiency. This involves installing an additional air-line into the existing guns to allow for easier adjustment of powder transport air, and therefore improved control of the paint cloud. 1 gun has already been modified in this way, at a cost of about R2,000. To modify the remaining guns would cost an additional R8,000. Estimated paint saving is 20% of paint loss, or R11,000/year. The total investment would therefore have a payback period of under a year. The manager intends to upgrade 1 gun every few months over the next 2 years. (The feasibility evaluation workings for options 1 and 2 are included in Appendix E22 Option B6-3.)

4. Continuous Maintenance of Equipment

The present manner of maintaining the painting equipment is reactive and equipment is only repaired after a fault occurs. The spraying equipment was found to have leaks in some places. The piping on one of the hoppers was not fitted correctly and paint dust was escaping at the attachment point. The proposed new method is to implement a continuous maintenance program as part of the control program in order to prevent potential faults/leaks before they occur. This will minimise losses due to leaks, etc. This maintenance program will be applied across all equipment and should result in estimated saving of 5% of paint loss, or R2,800/yr (Appendix E22 Option A1-4). Investment costs could include the cost of measuring instruments such as flowmeters, but can be zero.

The combined savings in paint waste through improved operator skill, improved control of gun settings and upgrading of spray equipment is estimated at 55% of paint loss or 5.5% of total paint waste. This could amount to over R30,000/yr, for simple procedural changes and low investment process efficiency improvements. This will have the greatest benefit for coloured paints as the majority of colours are not recovered for reuse and once lost through over-spray, they are wasted.

5. Improved Spray Booth Design

Identified options include extending the side-panels of the booth to increase the containment area of larger parts, or placing markers inside the booths within which parts must be set-up, to ensure parts do not extend outside the containment area. The feasibility evaluation of these options (Appendix E22 Options B5-2&3), has shown that the loss in extended production time in each case will however outweigh the small saving (R1,500/yr for overspray) in paint. Awareness raising through operator training should help to reduce this loss.

The possibility of installing a mechanical device to ensure the part is fed through the spray booth at a continuous pace, to maintain production rate while preventing spraying outside of the booth and minimising overlap, was investigated. The feasibility evaluation (Appendix E22 Option B6-3) indicates that this option is cost-effective with a payback period of ~2years for medium investment (based on the assumption that 1% of paint usage is in overlaps). It is recommended that such a device be installed 1 booth at a time over time, as finances allow.

5.7.4.f Assessment of Paint Recovery Equipment

Minimising the paint loss at source through improved transfer efficiency is the first option. However, there will still be over-spray and further paint losses may occur through inefficiencies in the recovery system. In the cyclone, the paint particles are separated from the air stream by means of a combination of centrifugal and gravitational forces. The lighter paint particles are less easily separated and hence the paint not collected and lost through inefficiency of the cyclone will be the very small (finer) particles. This paint loss is a concern as unrecovered powder from the cyclone system (>1% of total paint usage) is exhausted to the air outside the factory area where it settles on walls and cars. The pre-assessment determined the cyclone efficiency to be 87%, and according to technical literature, normal efficiencies range from 70% to 90% (PCI, 1996).

A powder coating Guide from the paint supplier states: "For a standard powder the recovery efficiency can be as high as 95%. For lines that have a high % particles <10microns in the recovered powder the recovery efficiency will be reduced (as low as 85%). Inevitable therefore, a cartridge filter is used in conjunction with a cyclone solely to prevent discharge of the fine powder to the atmosphere" (Akzo Nobel,1999). Capturing fines is more waste control than waste minimisation, and should only be looked into after waste minimisation options have been pursued first. However, the option was investigated to assess the cost if more stringent legislation were to require containment of this airborne dust.

The best option appears to be to combine the exhaust streams from each of the cyclones and lead these into a single after-filter system. A quote from a supplier estimates the installation costs to be close to R48,000 for such a system. Operating costs include energy, filter cleaning and replacement, as well as disposal of solid wastes, and are estimated at R7,000/yr. There are no tangible savings, as paint that is captured in the filters is too fine for reuse and is disposed in any case. There may be potential future savings through prevention of liability (neighbours may sue or air emission regulations may become more stringent). However, this is speculative, and at present, the option is not economically feasible for the company. The decision behind implementing such an option in the long-term depends somewhat on availability of finances, but most importantly on future regulatory requirements. Therefore possible waste minimisation options to keep losses to a minimum were investigated.

Cyclone efficiency depends on a wide variety of factors including physical characteristics of the cyclone, air quality & flow characteristics, and characteristics of the powder. The cyclones were specifically designed for their application and are therefore considered optimally designed in terms of dimensions and airflow characteristics. Options that remained to be investigated were loss in efficiency due to leaks, etc. that come about with age and lack of maintenance. Those identified in the literature (PCI, 1996) which are likely in this case are:
- infiltration of air at the powder discharge section or leaks.
- faulty design/attachment of the inner reclaim cannister

5.7.4.g Waste Minimisation Options for Paint Recovery Equipment

1. Preventative Maintenance
Powder that accumulates in the reclaim cannister is prone to re-entrainment. To avoid this situation, the receiver should always be airtight (PCI, 1996). An old reclaim cannister on one of the cyclones has been replaced to prevent air from entering the cyclone through leaks at the attachment points. This has improved the efficiency of one of the cyclones by preventing dust that is blown out due to air leaks. The continuous preventative maintenance program to be applied to the spray equipment is to be extended to the cyclone equipment as well. This should prevent further losses in this way. However, it was noted by the manager that it is difficult to assess the performance of the cyclone and the equipment supplier is to be contacted in order to determine the possibility of a mechanism for measuring cyclone performance (e.g. Pressure-drop measurements).

In any case, improvements in the initial transfer efficiency identified above will reduce the losses from the cyclone exhaust significantly – potentially by 55%.

2. Improved Cyclone Cleaning method
Another source of paint loss is the powder that sticks to and builds up on the walls of the cyclone and spray booth. The paint is cleaned from the walls of the spray booth before a colour change. The cleaning method of the booths involves physically removing the paint by scouring/beating and blowing it from the walls. The brainstorm identified the possibility of using vacuum suction to remove this paint in order to contain the paint that is cleaned. This option is not as effective as blowing the powder, and is expected to increase the cleaning time required. The powder collected will still require disposal, and the costs therefore outweigh the savings at present.

When cleaning the cyclone, it is far better for the reclaim cannister to be kept in place and not to use a board in its place. However, cleaning would take longer and may not be as efficient resulting in cross-contamination of recovered paint. This option therefore needs to be weighed up for each individual case.

5.8 EVALUATION OF WASTE MINIMISATION OPTIONS

Each identified option has been evaluated according to its technical, economic and environmental feasibility, in Section 5.7 above. The checklists used for these feasibility evaluations are included in Appendix E16. A summary table of all identified options has been compiled. The table (Table 5.11) has the same structure as the summary list of potential options for metal finishing from the literature and case study review of Chapter 2 (Appendix B2). Additional options for other waste streams were included in the list but were not analysed in any detail.

Table 5.11: Summary list of improvement options for Company 1

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
I. SOURCE REDUCTION					
A. General Waste Reduction Practices					
A1 Good Housekeeping practices					
1. Maintain improved chemical tracking & record keeping	yes	Minimal	unknown		short-term
2. Employee awareness and education regarding waste minimisation	yes	Minimal	unknown		started
3. Implement continuous control programme for ensuring equipment is properly set up at all times	yes	R 600	R 9,500	0.06	short-term
4. Implement continuous maintenance programme for ensuring leaks from all equipment (guns, hopper, connecting pipes, and cyclones) are minimised	yes	R 3,100	R 5,000	0.6	short-term

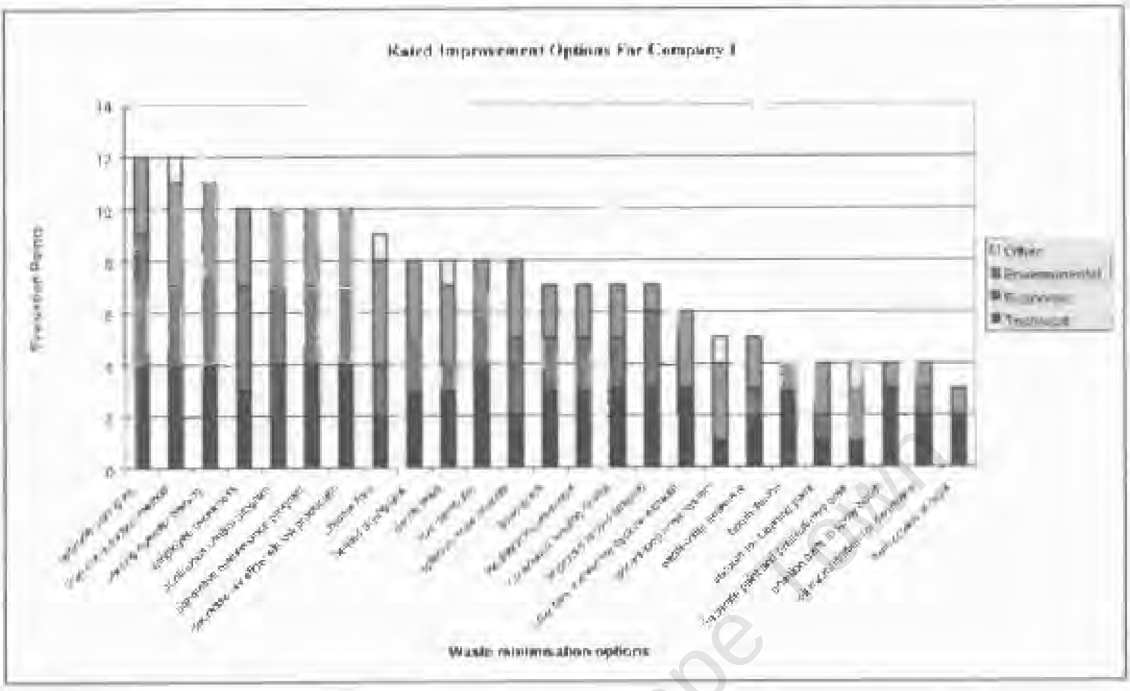
Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
5. Improve painting operator skill through a continuous interactive and motivational training programme	yes	R -	R 8,500	immediate	started
B. Improved Operations/Process Modifications					
B1. Drag-out reduction					
B1.1 Minimising drag-out					
1. Improved method to ensure longer dwelling time for parts over process baths	yes	R -	R 11,850	immediate	immediate
B2. Rinse water use reduction					
B2.3 Optimise Rinse tank design					
1. Use flow distributor to feed the rinse water evenly.	yes	Minimal	low	months	recommended
2. The incoming water may enter along the length of the rinse baths instead of on one end to increase the rinsing efficiency	no - difficult with counterflow	Low	unknown	NA	NA
B2.4 Controlling flow rate of rinse water use					
1. Adjust incoming tap to limit the volume of rinse water flowing through at the optimal flowrate.	yes - with drag-out reduction	R -	depends on drag-out reduction	immediate	recommended after drag-out reduction and tests
2. Manual control of water flow to reduce when production is low (dependent on operator adjusting flow with taps/valves).	yes	R -	depends on production	immediate	immediate
3. Install automatic rinsewater flow control device	no – technically not possible with 4 baths and only 1 inlet	NA	NA	NA	NA
4. Install flowmeters to monitor rinse flowrate and water use (raise awareness)	yes	R 2,000	depends on findings	depends on findings	recommended
B2.5 Alternative rinsing configurations					
1. Use a combination of spray rinsing and dip rinsing	no – evaporation rate not high enough	NA	NA	NA	NA
B4. Reduced energy usage					
1. Repair/improve methods of tank and surface insulation (e.g.replace existing low efficiency mats) to minimise heat losses.	yes	R 1,000	R 500	2.1	recommended

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
B5. Reduce/ eliminate the need for cleanup or improve cleanup methods					
1. Use vacuum suction instead of compressed air blow-out for cyclone and booth cleaning	not as efficient as current method	Medium	none	depends on future regulatory environmental	not at present
2. Improve booth design to minimise spraying outside of booths	no- production loss greater than savings	R 5,500	Loss in production time outweighs savings in paint	NA	NA
3. Optimise position parts are placed for spraying in spray booth to minimise spraying outside of booths	no - production loss greater than paint savings	NA	NA	NA	NA
4. Install covers over baths at night to prevent paint from settling in baths during night shift (also insulating)	no -costs outweigh savings	NA	NA	NA	NA
5. Separate paint area from pretreatment area	no - large investment for min savings	NA	NA	NA	NA
B6. Improved Process Efficiency					
1. Install heated drying tank after passivation step to decrease drying time	yes- medium term	R 20,000	costs outweigh tangible savings	company can afford it has other advantages	required with demineralised water rinse
2. Modify old paint application equipment over a period of time	yes	R 8,000	R 10,500	0.8	started
3. Install a continuous feeding device for parts in spray booths to ensure minimum overlap of paint on parts	yes	Medium	low	about 2 years	recommend installation in one booth at a time over time.
4. Improve cyclone efficiency through modifications	unknown	Unknown	unknown	unknown	should be investigated further
5. Install filters after cyclone to capture paint dust fines that are not collected	possible	R 48,000	tangible costs outweigh savings - but may have future liability	depends on future liability	long term with increased air-pollution control
B7. Extending Bath Life					
B8.2 Advanced corrective maintenance methods					
1. Microfiltration for continuous oil removal from degreaser	no - not economically feasible for company at present	NA	NA	NA	NA
C. Substitute Techniques/ Technologies					
C3. Process material/chemical substitution					
1. Substitute the chromate conversion chemical with a chrome-free alternative	yes- medium term	Depends on option	Depends on option	can be within 1-2 years	long-term when available and tested

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
2. Substitute final passivation rinse with demineralised water rinse (only in conjunction with heated drying tank).	yes- medium term	Med-high	costs outweigh tangible savings - but has other benefits	depends on future liability	long-term - requires heated drying
II. RECYCLING AND RESOURCE RECOVERY					
D. On-site Recovery and Recycling					
D3. Wastewater recycling and chemical/metal recovery					
1. Collect and treat wastewater prior to discharge to sewer	no - not economically feasible at present	Medium	Low		long-term - may become necessary
2. Treat wastewater and reuse (closed water system)	no- not economically feasible at present	High	Depends on future water costs and sewer charges		recommended in the long-term
D5. Sludge Reduction					
1. Mechanical dewatering devices to reduce chromate and etch sludge volumes (e.g. centrifuges, filter presses, vacuum filters, sludge dryers).	no	Med-high	Medium	within 5 years	can be reconsidered after change to chrome-free alternative
E. Off-site Recycling and reuse					
E1. Off-site Recycling					
1. Centralised waste treatment for wastes of similar type from different shops (e.g. recover Cr from chromate sludge?).	not at present	NA	NA	NA	NA
E2. Off-site reuse of waste material					
1. Recover valuable materials from a waste stream before disposal Recovered metals may be used as feed material for manufacturing processes, e.g. Chromium for stainless steel manufacturing;	not at present	NA	NA	NA	NA

For the next phase of the assessment, each of these options was rated based on the findings from the feasibility evaluation. The option rating system is outlined in Appendix E23. The aim of this activity was to compare all options in order to obtain a list of recommended waste minimisation options for presentation to the company's management. The implementation phase is primarily not a part of this project. However, during the project, more simple measures were implemented within the company. Those options that have already been implemented were included in the evaluation rating process in order to show where the options would have been in comparison with the recommended options. The table of options with associated ratings is included in Appendix E24. The graph of the results is included in Figure 5.7 below.

Figure 5.7: Summary of rated options for Company 1



5.9 *RECOMMENDED WASTE MINIMISATION MEASURES*

5.9.1 Good housekeeping

- The drag-out reduction method is recommended for immediate implementation.
- The continuous maintenance and control programs for process equipment is recommended to be implemented as soon as a system can be set in place. The quality system in Company 1 at present appears to be a fundamental and entrenched aspect of the company's operations. It remains for this same approach to be applied within areas of environmental performance.
- General awareness regarding water-use and installation of flowmeters to measure the rinsewater consumption is recommended. Once drag-out reduction is in place, potential for water reduction can be considered. Water flow should be reduced during non- or low-production periods.

Overall savings for these options is estimated at R35,000/yr, for an estimated total investment cost of approximately R5,000.

5.9.2 In-house technical modifications

- The substitute of the chromate bath for an approved chrome-free chemical is recommended. The silane-based product should be investigated in detail as it appears to be the best option for Company 1, since it gives superior performance to chrome and is environmentally compliant. The option will require installation of a demineralised water final rinse and a drying oven, but these will have other benefits for the company.

5.9.3 *Possible hardware options*

- The installation of the demineralised water rinse and drying oven combined is required with the chrome-free option. The option is recommended as, although the initial investment cost is substantial, it is believed that in the long-term, this option will be cost-effective for the company.
- In the future it may be possible to extend the demineralised water treatment installation to treat the dirty rinse water for reuse in a closed-loop system. System needs to be robust and flexible and requirements will change with chrome-free chemical. The cost-effectiveness of this option will depend on the future increases in water prices/sewer charges.
- The improved paint application efficiency should reduce the paint that is wasted through cyclone inefficiency. The installation of an after-filter system for capturing dust-fines is not cost-effective at present, but may be required in the long-term as air-pollution control laws become more stringent.

5.10 CONCLUSIONS

The assessment carried out at case study company 1 has identified significant potential for cost-effective waste minimisation. There are a total of 33 options identified of which 18 were found to be feasible. Of the unfeasible options, some of these were not technically feasible for site-specific reasons, others were likely to interfere with production, and the remainder were found not economically feasible due to financial constraints of the company.

Two feasible options have already been implemented/ begun implementation and these include:

1. Paint operator training for improved efficiency (to be repeated regularly).
2. Upgrading paint spray-guns to improve control of settings and hence efficiency.

These have the potential to save an estimated R20,000/yr for a total investment of only R10,000. Of the remaining feasible options it is recommended that those with higher overall ratings be implemented first.

Simple and cost-effective procedural and good-housekeeping measures which may be implemented immediately are expected to result in significant savings in terms of reduced raw material losses through drag-out, as well as up to reduction in paint usage. The target for drag-out reduction is 70%, while that for paint usage reduction is 5% of total usage. These cost-effective options minimise the focus wastes at source and therefore reduce the need for additional options.

Options requiring significant investment (chrome-free with demineralised water rinse and drying tank) are not cost-effective if the operating costs are simply weighed against the tangible savings at present. However, if the company were made to treat its effluents and carry the costs (especially the regularly dumped passivation bath at 35 ppm Cr(VI)), then these investments would look a lot more attractive. Another consideration is that increased demand for alternative chrome-free products in South Africa may result in more alternatives being made available locally, which may in turn bring down the price and improve the economic feasibility for Company 1. It is mainly the anticipated future more-stringent environmental regulations (coupled with concern from the factory manager) that may result in these additional potential waste minimisation options being a cost-effective choice for Company 1.

Chapter 6: Case Study 2 – A Hot Dip Galvanizing Facility

Waste minimisation is a journey not a destination' U.S. EPA, 1989

6.1 INTRODUCTION

The second case study company for which a detailed waste minimisation assessment was carried out, is a medium-sized general hot dip galvanizing factory. The process is typical of general hot dip galvanizing facilities, and generates a significant amount of waste. The waste of main concern to the company management is the large volume of ammonium-chloride fumes generated during hot-dipping and which are emitted within and around the factory area. These fumes have raised concern from neighbouring facilities. In addition, significant process-chemical and zinc metal spills/spatter falls to the work-area floor and generates wastewater contaminated with heavy metals during clean-up. In addition, the process uses a large volume of water for rinsing operations.

During the planning and organisation phase of the assessment, the main goal identified by the company, and which was the reason for their joining the project, was to identify ways to minimise the degree of fuming from the galvanizing operation. The Company's Operations Manager formed the main part of the assessment team, and the Manager added necessary input as time allowed.

The waste minimisation assessment methodology used in this case study is the same as for Company 1 and is outlined in Chapter 2, Section 2.4. All phases of the waste minimisation assessment were carried out as part of this project over a period of 18 months. This chapter describes the activities of the waste minimisation assessment, and presents the results as a list of feasible waste minimisation options which may be/have already been implemented by the company.

6.2 COMPANY PROFILE

The company is a medium scale factory with a total of 42 employees. It is a relatively young company commissioned in 1994. Its core-business is the hot-dip galvanizing of pre-fabricated steel products for the local market. The company coats a wide variety of products. The majority of the products arise from the security industry (e.g. fencing, gates) and from the construction industry (e.g. structural steel). The parts are pre-treated, galvanized and quenched.

The company is in a very competitive market, with a few established large companies, as well as numerous smaller operations. It is a member of the South African Hot Dip Galvanizers Association (HDGASA) and has a close working relationship with individuals in that association who provide technical advice when required. Its products have SABS (South African Bureau of Standards) quality approval.

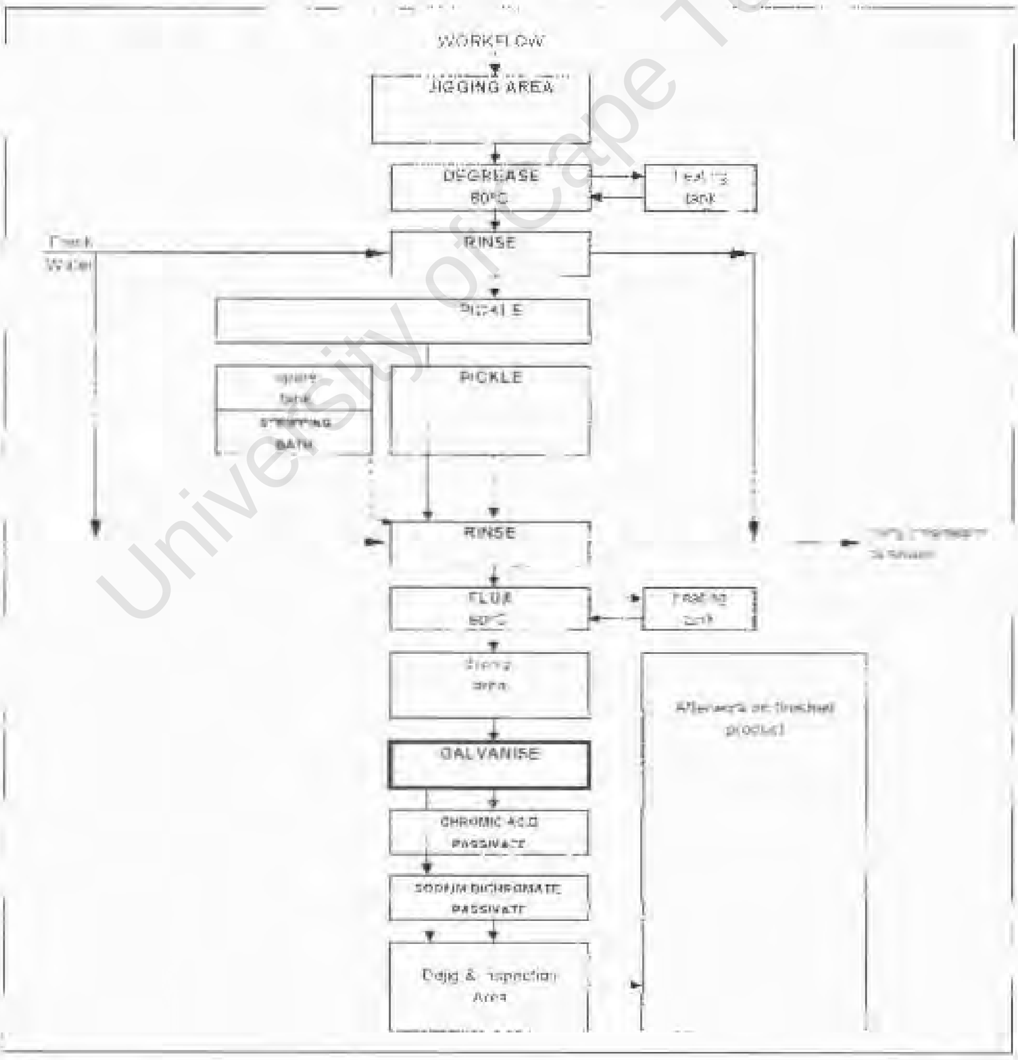
6.3 PROCESS DESCRIPTION

The factory operates a typical general galvanizing system with processing in the following order:

1. Pre-treatment
2. Galvanizing
3. Post-treatment

A process diagram has been drawn up and is included in Figure 6.1. The pre-treatment tanks are 7m in length and 1.5m wide. The two acid tanks are bigger with the one twice as long and the other twice as wide as the other baths. This gives 4 spaces for jigs in the acid which is needed since the pickling step takes the longest and is the rate determining step for the process. There is also a stripping acid tank. All tanks are above the floor surface at a height (depth) of 2.7m. The zinc bath is 7m by 1.5m and is large enough for the majority of products, though double-dipping is necessary for some parts.

Figure 6.1 Process flow diagram for Company 2



6.3.1 Pre-treatment

Jigging
Before pre-treatment, the parts are inspected and then loaded onto the jigs. Wire is used to connect the work pieces to the jig. There are 3 different diameters (thick, medium, thin) of wire used, depending on the strength required. All products are suspended vertically as far as possible or at an angle of close to 45° to ensure good run off of bath materials from the work piece. The jigs are lifted by the overhead cranes.

Degreasing
A hot caustic solution is the degreasing chemical used to remove the protective grease on the surface of the steel. The proprietary chemical from the supplier contains a mixture of NaOH, sodium metasilicate, sodium tripolyphosphate, and a non-ionic wetting agent. The bath is maintained at 60°C using electricity in a separate heating tank through which the bath contents are circulated continuously. Owing to evaporation, overflow, and drag-out, the liquid level has to be checked daily and topped up with water on a regular basis. Bath chemistry is checked every 3rd day on average and chemical additions are made when necessary.

Rinsing
The rinse bath removes the alkali from the work pieces by rinsing in water before pickling. If the work is not rinsed, the alkali will neutralise and waste acid. The rinse operates as a single stage continuous flow system with incoming water from municipality, and exiting water runs to drain. The pH is checked regularly by the Operations manager (every third day on average with the other baths). When the pH rises close to 10 it is drained (frequency depends on work load, varying from 2 weeks to 6 weeks between drainage, but is every 4 weeks on average or about 11 times in a year). Flow is manually regulated by valves, which are opened fully during operation and shut off at the end of the shift.

Pickling
The purpose of the pickling is to remove all adhering mill scale, annealing oxide and rust from the steel surfaces of the work by immersion in an acid solution. Hydrochloric acid is used at 16.5% by volume concentration at ambient temperature. An inhibitor is added to the acid to prevent over-pickling and reduce fuming. Pickling efficiency is determined by the concentration of the acid and the Fe content. The bath chemistry is checked regularly by the Operations manager and fresh acid is added when necessary (after ~6 months) to increase the concentration. Spent acid (12% by volume) is used in the stripping tank.

Stripping
Stripping is necessary to remove galvanizing from parts that have to be re-galvanized. The lower concentration spent pickling acid is sufficient to strip the zinc and so fresh acid is not needed. If the stripping acid concentration is too high, it will cause foaming of the acid, which may overflow from the tank as the galvanizing is being stripped. When the acid is too weak for stripping, the acid will be discarded in the outside storage tank to await removal.

Rinsing
The purpose of this rinse is to remove acid, iron (Fe) particles, and Fe salts from the work before fluxing, by rinsing in water. The acid salts ($FeCl_2$) cause excess dross formation in the zinc galvanizing bath, and acid carryover reduces the pH of the flux, which needs to be maintained in a set range. The rinse previously was a double rinse consisting of a static rinse tank followed by a flowing rinse tank, with water cascading constantly from the 2nd tank into the first. In theory, the double rinse uses no more water than a single rinse, and is far more effective. However, the static rinse tank has been broken since June 1997 and is no longer used. There is therefore only the single flowing rinse that operates in the same way as the degreaser rinse. The rinse operates as a continuous flow system with incoming fresh water from the municipality and exiting water to sewer. The product is completely immersed in the cold water rinse and when thoroughly rinsed is proceeded to the flux tank.

Fluxing
The primary purpose of fluxing is to promote the alloying of the molten Zn with the base metal, ensuring a good continuous coating. The flux wash deposits a film on the surface, preventing oxidation that would otherwise occur by exposure in the air during the interval between pickling and galvanizing. In the melted state the flux has a cleansing action which removes any remaining oxides or Fe salts. The flux wash prevents introduction of excessive amounts of iron chloride to the molten zinc, resulting in smoother coatings and greatly improved adherence (information obtained from the suppliers Technical data sheet).

The operating temperature of the flux is maintained at 60°C using electricity in separate heating tank through which the bath contents are circulated continuously. The heating allows for more effective fluxing action and dissolution of sufficient flux crystals to the desired concentration. It also heats the work pieces so that less time is required for thorough drying. The fluxing chemical is a triple salt mixture of zinc chloride and ammonium chloride in a set ratio, and includes a non-ionic wetting agent. NH_4Cl on its own is not as effective and can lead to excessive fuming. The bath chemistry is checked regularly and the flux solution is controlled by additions of flux chemicals on a regular basis, since water is added to make up for drag-out and evaporation.

Drying
The layer of flux is dried on the work piece prior to dipping into molten Zn. The drying deck provides space for drying the work after fluxing. The work must be thoroughly dry before it is placed in the Zn bath, as moisture on the work will cause excessive spatter.

6.3.2 Galvanizing

The pretreated parts are dipped into molten zinc, producing a coating of Fe/Zn alloys with pure Zn on the surface. The coating is formed by reaction between the molten zinc and the iron and is therefore complete and alloyed with the base metal. (GA, 1981). The galvanizing bath is designed to maintain the molten zinc at 450 °C. Heating is achieved using electricity. Elements are mounted on a series of supporting panels around the tank, insulated by fibre-frax material and connected to thyristor drives in the control room.

The grade of zinc used has a minimum of 98.5% pure Zn with 1.35% by mass Pb and total contaminants should not exceed 1.5%. For bath protection, the molten Zn level is maintained as closely as possible at 50 mm below the bath top flange. This will prevent ash (zinc oxide) from packing onto bath walls. For this reason, the bath is topped up on a daily basis. The maximum quantity of Zn fed into the bath at any given time is not greater than 3 tons, and is usually 1 or 2 tons. Small quantities (<0.007%) of Aluminium are added to reduce the rate of oxidation of the molten Zn and so cut Zn losses. Regular make-up additions of Al are necessary to compensate for loss by oxidation and in the coating. The Al is added as a 20/80 zinc-aluminium alloy to facilitate quick dissolution in the Zn.

During immersion of the parts, a certain amount of "boiling off" occurs depending on the product. In general, sufficient coating is obtained if the work is left in the bath until "boiling off" stops, and then withdrawn without delay. The rate of withdrawal determines the thickness of the unalloyed zinc layer left on the work.

Dusting
As the parts are withdrawn from the molten zinc, operators throw ammonium chloride dusting salts by hand over certain areas of the parts to aid run-off of zinc, especially on complex sections.

6.3.3 Post-treatment

Combined Quench & Passivation
The hot galvanized parts are dipped in one of two quench & passivation baths containing very dilute (0.1% by volume) solution of chromic acid and sodium dichromate respectively. The first is a corrosion protection for parts that are to be painted (duplex systems), the second is a final product seal for rust prevention (parts not to be painted). Both help prevent white rust formation and also act as a quench to quickly solidify the zinc. The quenching operation not only solidifies the zinc coating, but also washes off residues that may have deposited on the coating surface during withdrawal from the galvanizing bath. Rapid quenching avoids the formation of brittle coatings and unattractive dull grey appearances. The passivating chemical provides temporary protection during the period that the natural protective film is being developed. This passivation for white-rust prevention is especially necessary in the humid climate in the Western Cape where the factory is located. The need for quenching with and without the passivation chemical is described in more detail in Appendix F1.

Owing to the very low concentration of chemicals in the bath, the chemistry of the baths is not checked regularly. Solution concentration is approximately controlled by additions of chemicals when necessary (only approximately 3 times a year), since water is added to make up for drag-out and evaporation.

Drying, Inspection and Cleaning
After quenching, the excess solution is allowed to drain off the work pieces and the jigs are placed on the off-loading platform. The pieces are then allowed to dry and cool before they are cut loose from the hanging wires and removed from the jigs. All items are inspected and then taken to the cleaning area, where zinc droplets are filed

off and touch ups are done using zinc-rich primer. Completed items are stored in front of the factory building, in an outside area such that enough drainage and venting is maintained to prevent any chemical corrosion.

6.4 ENVIRONMENTAL PROFILE

General usage data and information on wastes was not readily available for the company, and once the information had been tracked down it had to be adapted for waste minimisation use. Most of the information was on how the waste leaves the factory, rather than how it is generated. Therefore, in most cases the quantity and content of wastes and emissions for the factory are based on estimates or determined through material balances where possible.

6.4.1 Input Materials

Chemicals and Zinc

As discussed in the assessment for Company 1, knowledge of the raw materials used in the process helps in understanding the source of wastes emitted and the components of the wastes. The usage figures per annum and associated costs for each of the pre-treatment chemicals and the zinc metal were obtained from company records, but in some cases mass balances were necessary to fill in missing information.

The company uses 3 different chemical suppliers for the pre- and post-treatment chemicals, and a single specific zinc metal supplier. The annual usage figures are included in Table 6.1 below. Costs are included as % of total costs, as actual figures are confidential. The component of each chemical is included, in the table and any component that is hazardous is noted *(in brackets)* in the table.

Table 6.1: Input material annual usage and costs

Input substance/ material	**Components *(hazardous)***	**Average annual consumption**	**% of Total Annual Cost**
Zinc	*(Zn)*	370 tons	92%
Degreasing chemical	NaOH *(Highly caustic)*	5600 kg	2%
Pickling Acid	HCl *(acidic)*	43000L	2%
Fluxing chemical	$NH_4Cl.ZnCl_2$ *(moderate hazard)*	8500kg	2.5%
Flux dust	NH_4Cl *(moderate hazard)*	6600kg	0.6%
Passivation chemical 1	Chromic acid *(Cr^{6+})*	67L	0.04%
Passivation chemical 2	Sodium dichromate *(Cr^{6+})*	67L	0,02%
Water for rinsing and as solvent for all process chemicals	Municipality H_2O	9,500kL	0.3%
Wire	Steel	2200kg	0.3%

The highest input cost by far (>90%) is for the zinc. Noteworthy is that the cost is based on the US$ price (despite the fact that the Zn is sourced locally), and hence is subject to exchange rate effects. All the pre-treatment chemicals together account for only 7% of the input material costs. The acid is the chemical used in greatest volume, followed by degreaser and flux chemical. These therefore account for the highest costs for pre-treatment chemicals. The water costs amount to only 0.3% of the total input material costs.

The components of each of the proprietary chemicals were investigated to determine the rating and composition of any hazardous substances. Unfortunately, due to confidentiality reasons, the chemical supplier was not able to reveal exact composition of the proprietary chemicals, but an idea of the components was offered, from which the following information was compiled.

Table 6.2: Hazardous components of input materials

Material	Hazardous component	Hazardous nature	Concentration of hazardous material
Degreasing chemical	NaOH	Moderate (HR=3)	0.07kg/L in solution
Pickling acid	HCl	Moderate (HR=3)	0.165 L/L in solution
Flux chemical	NH_4Cl $ZnCl_2$	Low (HR=4) Moderate (HR=3)	0.067kg/L in solution 0.053kg/L in solution
Chromic acid	H_2CrO_4 Cr(VI) form	Extreme (HR=1) Carcinogenic and toxic	0.001L/L
Sodium dichromate	$Na_2Cr_2O_7$ Cr(VI) form	High (HR=2)	0.001L/L
Zinc metal	Zn	High (HR=2)	0.98kg/kg

The Hazard Rating (HR) is explained and further information regarding the hazardous nature and classifications for each of these is included in Appendix F2.

Water use:

A significant amount of water is used for the rinsing stages in the pre-treatment process. The flowrate is not controlled, and the taps are opened to maximum, run continuously throughout the operating day, and are only switched off at the end of the shift. The single stage continuous-flow rinsing system used is generally considered (in the literature reviewed in Chapter 2) as one of the least efficient of the various possible rinsing options. Water flows continuously at a rate of ~1.6kL/hr through each of the 2 rinse baths. In addition, the acid rinse bath is drained (usually by half) once a week since the quality diminishes within a few days (the pH drops rapidly, and the iron carry-over from the acid is high). The degreaser rinse is only drained approximately once a month on average. Water is also used as a solvent in process baths. It is therefore needed for usage, drag-out and evaporation replacement on a continuous basis, and for bath recharges as required. The additional water is used for evaporation replacement, floorwash, tank cleaning, domestic and general usage.

The flowrate measurement method and rinsewater usage calculations are set out in Appendix F3. The table below gives the breakdown of water usage for the factory.

Table 6.3: Breakdown of water usage

Water Usage	Volume (kL/yr)	Cost/yr	% of total
Continuous flow rinse	6,900		76%
Rinse bath dumps	800		9%
Total Rinse:	7,700	R19,500 (R80/day)	85%
Solvent	340	R850	4%
Evaporation	380	R950	4%
Floorwashing	300	R750	3%
Other (domestic, etc.)	340	R850	4%
TOTAL USAGE	9,100	R23,000 (R95/day)	100%
Sewer charges:		R12,000	
Estimated water bills.		R35,000	
Actual water bills.		R12,000	35%

The factory water meter has not worked since start-up and at present, the company is only charged for 35% of actual usage. If actual usage calculations are assumed to be representative, then the company is being undercharged by about R23,000/yr. The company has reported the breakage, but there has been no action from the municipality.

Electricity:

Electricity is the only energy source used. The majority (90%) is used for maintaining the molten zinc at 450°C 24hrs/day, 365 days/year. Heating of the galvanizing bath is achieved using elements that are mounted on a series of supporting panels on the Zn kettle. The elements are insulated and connected to thyristor drives in the control room which automatically "feed" the elements as the demand varies. Several thermocouples monitor and maintain kettle operation. Alarm systems indicate when a problem exists (temperature too low or too high, or maximum kVA demand reached).

Electricity is also used in heating the flux and degreaser tanks (5%), operating the overhead cranes (3%), and the remaining 2% for lighting, drilling and office computers. For the degreasing and flux baths, separate heating tanks are used to thermostatically control the solution temperature, while a circulation pump maintains constant flow of the solution to ensure even temperature distribution.

The company is charged for kWh units as well as total demand in kVA. The company implemented a device to prevent demand from rising above peak value (peak shaving) mid 1998. The cost at ~R2,500 was saved within the first month. Total cost for electricity has therefore decreased over the past 3 years despite the increase in electricity prices:

Table 6.4: Electricity use

Utility	1997		1998		Jan-Nov 1999	
	quantity	cost	Quantity	cost	quantity	cost
Electricity 6000kVA & KWh/yr		R402,500	1,760,000	R370,000		R365,000

Galvanizing furnaces have a relatively high energy requirement because of the metal temperatures involved. The energy cost in galvanizing is typically around 10% of the total cost of the coating application, and is around 11% for this company. The high energy consumption indirectly causes air pollution via the power stations. The company has paid significant attention to energy savings and is believed to be operating at high efficiency in terms of electricity usage.

6.4.2 Current Waste Management Practices

6.4.2.a General waste

Wire is used for attaching work to jigs. Pieces not covered in zinc are re-used as much as possible. Any wire that cannot be reused is sold as scrap (steel wire coated with zinc), although there is not much demand for it at present. The total amount of wasted wire is approximately 2tons/year and the cost of the waste represents loss of raw material minus sale value.

Drums are provided by the municipality for collection of paper, packaging and other industrial refuse. There are ten 200L drums, of which 6 are filled per week on average. These are collected by the municipality on a weekly basis at a cost of R275/month.

Table 6.5: General waste

General Waste	quantity	Cost (R)
	Annual Average (based on 1998 figures)	
Used wire (kg/yr)	2,200	R8,400
Industrial (kL/yr)	53	R3,000

6.4.2.b Wastewater

Wastewater to sewer:

The majority of wastewater to the sewer is the dirty rinsewater, contaminated when drag-out from the degreasing and pickling baths is carried into the rinse baths. To keep drag-out low, when the work is withdrawn from the bath, the slowest crane lift speed is used, the work is then held briefly above the tank to allow run off of the majority of the solution. However the time allowed for dripping is not long as it is controlled mainly by the crane requirements and the need for speedy production. There is no set time allocated for allowing dragout to run back into the tank. The amount of drag-out also depends on the type of work, the crane operator and the solution temperature and concentration.

The resulting drag-in from the acid and degreaser to the rinse baths results in NaOH and HCl in the wastewater, which goes to the sewer. The wastewater is not treated, but it is assumed that some degree of neutralisation takes place where the streams combine going to sewer (pipes join up before the exit). From the research in Chapter 4, such wastewater management appears to be common practice for the majority of metal finishing operations in South Africa. When the tanks are dumped, however, they are not usually emptied together. When the pH of the acid rinse reaches near 5.5, the bath is drained (once per week on average). Sometimes the pH may reach 5 before it is checked; in which case the low pH water is drained to sewer in large volume (15kL/time on average, and may sometimes be the entire 30kL bath). In fact, analysis of the pH measurements recorded in the company log-files has shown that the average pH for 1999 is 4.4 which is well below the local government's discharge limit of 5.5.

Draining frequency in 1999 was actually once per week on average. The company have sometimes experienced warnings from the local council regarding the low pH of their rinse water.

Another reason for dumping the acid rinse bath frequently is to maintain the iron carry-over from the acid pickle to the flux as low as possible (<1g/L). This is for coating quality reasons, but requires excessive use of water. There is a certain amount of iron in the wastewater, as well as some zinc (carried over from the stripping acid). The presence of heavy metals is taken into account in the sewer charges (the charge formula is described in Appendix E5). The charges depend on whether the heavy metal content is found to be above the limit in samples taken. As yet there have been no additional costs for this experienced by the company. Rough measurements indicate the Fe and Zn content to be around 12 ppm and 10 ppm respectively, which is sufficiently below the specified limits of 50 ppm and 30 ppm respectively. The measurement method and results are described in Appendix F4.

The drag-out not only affects the quality of the rinsewater but also results in loss of raw materials to the sewer. Material balance calculations involving a number of assumptions have been carried out to determine the volume of acid and degreaser chemicals lost to sewer through drag-out. The calculations are included in Appendix F4, and the results are presented in the table below.

Table 6.6: Calculated drag-out loss of degreaser and pickling acid to rinse water

Chemical	Chemical loss/year:	Equivalent solution/year:	Cost/year:
Degreasing chemical:	1100kg (30% of usage)	15,700L	R10,700
Pickling Acid:	3700L (37% of usage)	7,400L	R5,000
Total:		23,100L	R15,700

Taking into account raw material losses and cost of water, the actual cost of wastewater losses to sewer is about R4/kL (would be R6/kL if calculated actual water use were charged for).

The only other wastewater that goes to the sewer is the domestic water. All other wastewater, of which the majority is the floorwash water runs through the trench system to a so-called French drain on the factory site, which is discussed below.

Wastewater to the French drain:
The function of the so-called French-drain is to destruct organic wastes such as oil/grease by bacterial action. It was initially installed for the oil skimmings from the surface of the degreasing bath, which overflow through pipes from a lip around the tank, into a trench system that feeds into the French drain. However, other spills and drips from all process tanks also lead to this trench system, and are also washed to the French drain during weekly floorwashing.

The oily grease that builds-up over time on the degreasing bath surface is regularly skimmed off. This is usually performed every second day, prior to the start of the shift. Over the week, this oily sludge and the process chemicals build up on the floor around the baths and in the trench system and lie mostly stagnant until the floorwash water washes these to drain.

Any drips that do not run to the trench system and to the drain on their own are washed there during the floor wash procedure. The accumulated volume of oily degreasing solution skimmed over the year was roughly calculated at approximately 14,000L/yr. The grease becomes sludge-like in the trench system as it cools down from the degreasing temperature.

Any drag-out that is not transferred to a following tank drips to the floor and these chemical solutions flow to the trench system and into the French drain. The degreaser bath and degreaser rinse tanks are situated close together, so drag-out drip to the floor are minimal and the majority is carried over to the rinse water. However, between the acid baths and the acid rinse tanks there is a large space left when the broken second rinse tank was removed, and as a result, acid solution drips onto this floorspace. There are no rinse baths after the flux and passivation baths and the drag-out from these baths falls mostly to the floor. The fluxed parts are hung in the drying area for a period of time during which drips fall to the floor of the drying area. For the passivation baths, the parts are moved to the dejigging area after final dipping and a certain amount of initial drag-out, as well as drips while parts are drying, fall to the floor. Observation has shown that the volume of drag-out from the passivation baths is high, and sometimes even excessive in that large pools of solution will fall to the floor. In fact it appears that the drag-out that falls to floor is usually substantial unless the parts themselves do not pick up much drag-out.

The chemical amounts that drip to the floor have been calculated based on assumptions and mass balances. These are set out in Appendix F4, and the results are presented in the Table 6.7 below.

Table 6.7: Calculated volume of drag-out from process baths that drips to floor and is washed to the trench system

Chemical	Chemical loss /year:	Cost/year:
Pickling acid:	3700L (37% of usage)	R5,000
Flux:	2000kg (40% of usage)	R17,800
Chromic acid:	16L (75% of usage)	R600
Sodium dichromate:	16L (75% of usage)	R130
Total:		**R23,500**

The floor is washed once/week using fresh water from a hose at a flowrate of approximately 1800L/hr (combined flowrate of rinse tanks – since same tap source), and usually takes about two hours. The accumulated volume was calculated at 300kL/yr in Appendix F3.

Wash water flowing to the French drain combines all the chemical spills, and may include some Zn (metal), and any chemicals from baths. The zinc metal spatter that is caught in the trench system and cannot be recovered amounts to approximately 10kg/week (estimate from Operations Manager). The total loss therefore is approximately 400kg of Zn metal/yr or R3,000/yr. This zinc may go into solution as a result of the acid content of the wastewater (chromic acid and HCl content). Although amounts are small, the accumulation over the 5 years of operation so far amounts to 2.5tons of Zn metal to the French drain. Analysis of the water and soil in the French drain would be required to determine the actual extent of the contamination. If there is significant pollution, it may be necessary to look into an alternative and remediation may be necessary.

The total cost of waste to the French drain, not taking into account any potential liability, amounts to R26,500/annum (mainly due to loss of raw materials).

6.4.2.c Spent Process Baths

The degreasing, flux and passivation solutions are not discarded and are maintained at the correct concentration by regular additions of the chemicals and solvent water. The degreasing and flux solutions are agitated once daily (due to time considerations) using compressed air, in order to maintain good mixing of the solution and reduce the sludge build up. Sludge removal is performed when contaminant build-up is too high. This is normally carried during the annual shutdown period once at the end of each year. In addition to the muck/dirt that settles in the baths, the sludges contain solution chemicals. The degreasing sludge that accumulates also contains oil & grease. Flux sludge contains precipitated iron salts carried over from the acid via the acid rinse. The passivation baths sludge contains hexavalent chromium and some zinc metal which spatters into the bath. An attempt is made to recover the solid zinc that settles in these baths, and this is returned to the galvanizing bath for re-melting. The acidic nature of the final baths does however mean that a certain amount of the zinc metal is dissolved into solution and both solid and dissolved zinc will end up in the sludge.

During sludge removal, the liquid contents of the tanks are pumped to an emptied rinse tank. The sludge which remains in the tank (approximately 1/10th of the tank volume) is removed manually (using drums) to the outside storage tank, where it is disposed in the spent acid. The empty tanks are flushed and cleaned using hoses and clean water. During this period, any maintenance required in the tank is performed. The process solution is then pumped back to the tank and additions are made to top up the tank.

Once the Fe level in the acid solution reaches about 10%, or the acid becomes too weak for stripping, it has to be discarded. The spent acid and acid sludge is usually discarded at the end of each year during the shut down period. A Gauteng based organisation collects the spent acid, tankers it away, regenerates it (using a roasting process) to a concentration of about 16% and resells it to the users. The spent acid is removed for free provided the regenerated acid is bought back by the company at the equivalent cost of new acid. In this way, the cost of treating waste is not incurred by the company.

6.4.2.d Air Emissions

The pickling acid is a gas (hydrogen chlorine) which is dissolved in water. It is volatile, and therefore fuming can occur in the vicinity of the tank particularly if the concentration is high and the temperature is raised. The hydrochloric acid (HCl) is not artificially heated but will normally be at a temperature of about 25 °C, due to the chemical reaction that takes place between iron and acid during pickling (Barnett, 1998). Information on the hazardous nature of these fumes and methods required to control/reduce them is included in Appendix F2. Inhibitors are added to minimise fuming from the pickling acid and the company follows all other required practices, however, some hydrogen chlorine fume is always generated from the HCl baths, especially when the humidity in the atmosphere is high. A certain amount of corrosion of steel structures above the bath has taken place as a result of the fumes.

The majority of the corrosion of steel structures in the working area is however due to the fumes above the galvanizing bath which arise from volatilisation of the flux chemicals during immersion in hot zinc. The smoke contains hydrogen chloride, ammonium chloride and small amounts of zinc. There is also a possibility that the emissions from the zinc kettle will include lead added for production purposes (typically 1%) or derived from the lead content of the zinc bars (up to 1.5%). These fumes cause corrosion of the building structure and overhead cranes in particular. The fumes are caused by the ammonium chloride salts in the flux solution, which are by no means toxic in the strictest sense of the term (Barnett, 1998). These salts are hygroscopic and therefore attract any moisture present in the atmosphere. Thus the intensity of the fuming with regard to ammonium chloride content can be misleading particularly when the relative humidity level is high. The degree of fuming above the galvanizing bath arising from the fluxing chemicals on their own, is mostly confined to the precincts of the galvanizing bath and unlikely to be observed outside the plant area.

However, more significant emissions of fumes into the atmosphere are associated with the process referred to as "dusting". This entails the throwing of ammonium chloride salts onto the components as they emerge from the molten Zn, to aid the run-off of Zn. The problem is that when dusting takes place, the quantity of salts used is probably far in excess of what is required, but to control this is extremely difficult. Ammonium chloride fumes are not hazardous to health unless inhaled in large quantities (the U.S. EPA MAC for ammonium chloride smoke is 10ppm). These fumes are, however, corrosive to steel. Zinc ammonium chloride (as used in the flux bath) causes less fuming than ammonium chloride, but in its commercial form it reacts more slowly and is thus less suitable for incidental uses in which rapid fluxing is essential i.e. dusting (Barnett, 1998).

There is no fume control or extraction in the working area at present. The volume of fumes cannot be accurately estimated, and the true cost of the fume wastes should also take the replacement cost of corroded equipment into account. As a rough estimate, the cost was only assumed to be the cost of dusting salts, which amounts to R18,000 per annum. The costs associated with the corrosion of surrounding steel structures over time could be significant and should be added to this.

6.4.2.e Solid waste

The ash and dross that form in the galvanizing bath are removed on a regular basis. Ash is formed on the surface of the bath when the molten Zn reacts with oxygen to form ZnO (ash). Regular skimming is necessary during galvanizing to avoid ash collection on galvanized surfaces. The skimming is carried out by means of a flowing action, using scrapers (excessive agitation and creation of ripples accelerates the formation of more ash and increases Zn metal entrainment). Skimming takes place immediately before immersion and immediately after withdrawal. The skimmed ash is removed from the sides of the tank and placed in a metal drum. This collected ash is melted down to recover the entrained metal zinc. The melting is performed in the molten Zn bath. The remaining ash residue is sold to the zinc supplier at about 1/3 of the price of new zinc and thus the metal content is given away at 1/3 of its actual value to the galvanizer. Ash generation amounts to about 100 tons/yr. and costs around R420,000/yr.

The iron that is carried over in the flux results in a thicker zinc coating during hot-dipping (unwanted wasted zinc) and also results in dross formation in the zinc bath. The major cause of dross formation is the galvanizing process itself. The coating is formed by the metallurgical reaction between iron and molten zinc whereby a series of hard iron/zinc alloys are developed on the surface of the steel. While the metallurgical reaction is taking place, some of the Fe/Zn alloy escapes from the steel surface and is initially suspended in the surrounding molten zinc. This alloy formed is denser than Zn, and it precipitates to the bath floor where it is eventually removed as dross. Another source of dross is the bath itself. The steel used for constructing galvanizing baths is only moderately reactive with molten zinc. This results in a thick and relatively impervious alloy layer being formed on the bath walls. Despite this, some reaction between the iron and zinc does continue. Depending on the zinc temperature and other factors, dissolution of the galvanizing bath plate can vary from one to two millimetres per year where a well designed heating system is employed.

The accumulated dross has to be removed regularly (approximately once/month), since heat transfer through the dross is poor and therefore local overheating of the bath wall can result if too much dross is piled against it. Some dross particles are entrained in the coating surface and can result in a rough finish. Dross amounts to approximately 1.5-2tons/month depending on production and condition of steel. The amount of dross in 1999 was lower since production was down by 20% from 1998. The sales price of dross is approximately only 75% of the cost of zinc, and the zinc content of the dross is > 90%. For company 2, the cost of dross waste due to loss of zinc less sales value is R1,200/ton of dross formed. Dross generation can amount to 20tons/year or more, which represents a loss of some R25,000/yr.

The overall loss per kg dross is not as high as for ash but the associated costs such as additional energy requirements as a result of the dross build up, and labour costs to remove the dross are more significant. Another important aspect is the lower quality for coating also associated with iron in the galvanizing bath which can lead to parts having to be regalvanized. The number of 'redos' at present is approximately 1% of total steel galvanized (estimated 1/3rd of 3% total redos are due to Fe in molten zinc), which implies that there is 1% more waste for the same production. Dross contains up to 90-96% zinc most of which is in Fe/Zn alloy form. The most viable process is to recover the zinc as zinc oxide or zinc dust. Since about 75% of the zinc price is paid for dross by recycling companies, it is not viable for most galvanizers to acquire their own Zn recovery equipment.

The ash and dross that are removed from the Zn bath, do contain valuable Zn, and may be considered residual products. Together they may account for anything from 20 – 50% of the total Zn consumed according to the nature of the work, and the care with which the baths are operated. Dross contains up to 96% Zn for only 4% Fe. Ash is a mixture of ZnO and varying quantities of entrained Zn. The free metallic Zn constitutes at least 80% of the total weight of the ash (GA, 1981). A considerable amount of Zn can also be entrained during the removal of the ash from the bath if this is not done carefully.

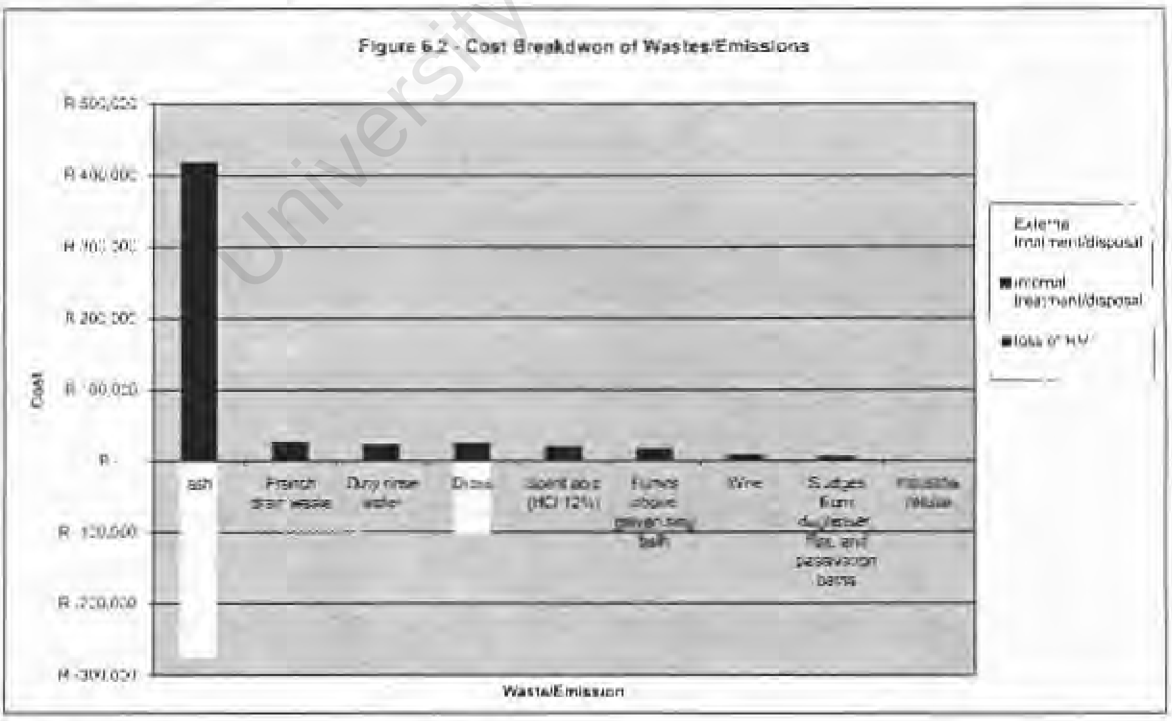
Some zinc is also wasted through spatter on the walls and floors which occurs during "boiling" of the Zn on immersion of products into the Zn bath. As parts are lowered into the galvanizing bath, a certain amount of explosion occurs as a result of the wet flux or moisture trapped inside hollow sections. The explosion results in spatter of molten zinc around the area of the bath. Some lands on walls and floor around the kettle. This spatter is, however, contained within the walls of the factory and is not lost. Attempts are made to clean up the spatter more effectively at the end of each week and particularly during the shut down period at the end of the year. It is estimated that approximately 7% of total Zn usage is lost through unrecovered spatter which amounts to R185,000/yr. This is a general industry estimate, which the Operations Manager considers representative.

6.5 COST OF WASTES AND EMISSIONS

A summary of the cost of the wastes and emissions is included here. The 'true' costs of the wastes/emissions have been calculated for the same reasons and in the same way as for company 1's waste minimisation assessment. The calculations to determine the true cost of the wastes from Company 2 were relatively simple for all waste streams except for the dirty rinse water, and French drain wastes where it was difficult to determine drag-out from the process-baths with any accuracy.

Working spreadsheets were used for all calculations and then linked to a summary spreadsheet to combine all costs. The summary spreadsheet is included in Appendix F5. The results are presented in a graph in Figure 6.2 below.

Figure 6.2: Annual cost breakdown for the wastes/emissions from Company 2



The ash wastes represent the highest expense and is due to the high Zn content, and the fact that the sales price of ash is only 1/3rd of the price of zinc. The remaining wastes are relatively low in cost and it is obvious that loss of raw materials is the most significant cost in all the wastes apart from the industrial refuse (packaging, etc.). The cost of the spent acid is only for raw material losses, since the acid is regenerated for free and bought back at the equivalent new acid price. Internal treatment costs are for labour only and are practically negligible. The greatest labour requirement for wastes is for the dross removal. The total costs were taken into account in the evaluation and selection of focus areas during the waste minimisation assessment.

Table 6.8: Percentage of total waste cost per ton of production for each waste/emission from Company 2

Waste/Emission	% of Total waste cost/ton production
Ash	76%
Dirty rinsewater	5%
French drain waste	5%
Dross	4%
Spent acid	3.5%
Fumes	3%
Wire	2%
Sludges	1%
Industrial	0.5%
Total cost of wastes/ton production	**R170**

6.6 PRE-ASSESSMENT

The pre-assessment was an initial overview of the company's operations and waste streams and emissions and involved the collection of data from which the above overview was compiled. Literature was reviewed in order to compile background information on process operations, process technologies, and environmental impacts. On-site inspections covered all activities carried out on a regular basis in the relevant part of the company. An initial tour of the facility was required to form a good picture of how the company operates. More thorough/detailed inspections were carried out during the detailed assessment.

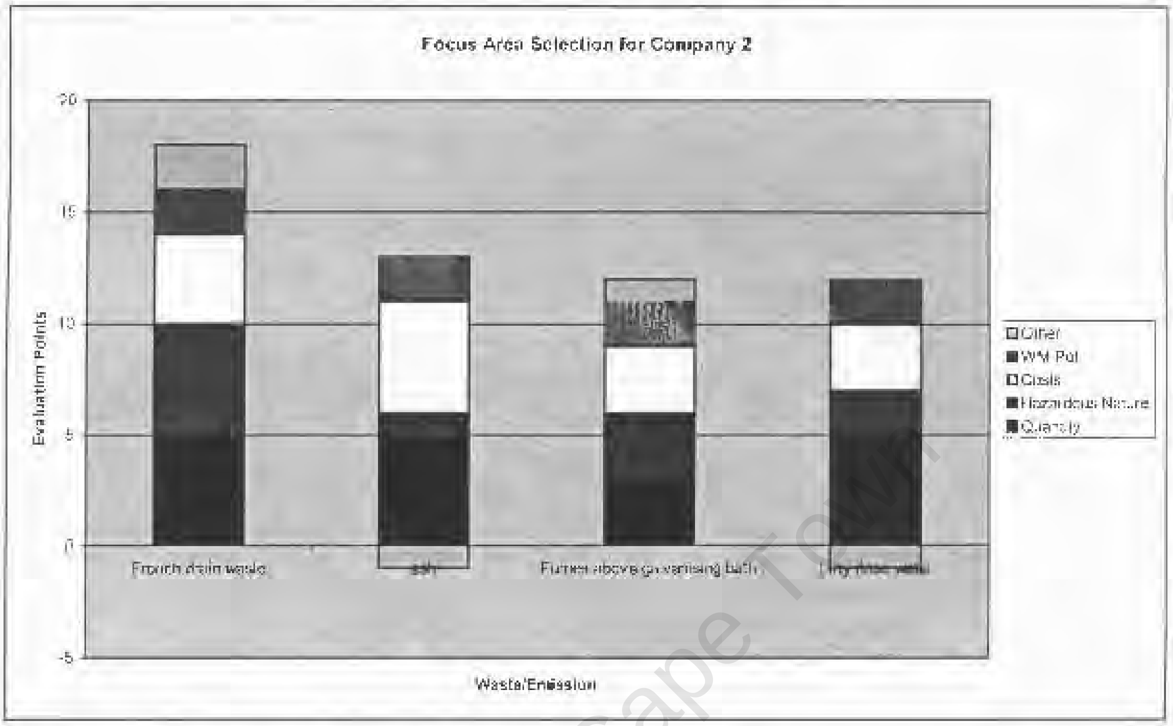
6.6.1 Evaluation of Wastes and Emissions

As discussed for Company 1, the main activity of the pre-assessment was to evaluate the wastes and emissions in order to identify and select the focus areas for the assessment phase. The comprehensive evaluation of each of the wastes to select focus areas was carried out using the same methodology as for Company 1. The quantity of the waste stream, hazardous nature, costs involved, and waste minimisation potential are the criteria taken into account in the evaluation. This information was compiled onto an evaluation table (the format of the table is according to the chosen methodology). The Evaluation Table is included in Appendix F6. Each of the wastes is assigned points for each of the criteria. The point system for the evaluation criteria is described in Appendix E12.

6.6.2 *Selected Focus Areas*

The graph below represents the results of the evaluation for the selected waste streams.

Figure 6.3: Selected focus areas for Company 2



The graph clearly indicates which are the contributing factors (criteria) that lead to each of the wastes being selected. The sources of these wastes and emissions were examined in more detail in the assessment. The results for all of the waste/emissions are included in Appendix F7.

6.7 *WASTE MINIMISATION ASSESSMENT*

The objective of the assessment was to obtain a clear understanding of the sources and causes of wastes and emissions in the focus areas, resulting in the identification of improvement options. It involved a detailed study of the focus areas to establish the largest possible number of suitable waste minimisation options.

Activities included:

- Gathering additional data.
- Closing mass balances where possible, which required monitoring programmes to review processing conditions and to quantify losses or emissions previously unaccounted for.
- Generating waste minimisation options.
- Screening and selecting options for further study.

The generation of waste minimisation options formed the major part of the waste minimisation assessment and in some cases required calculations and measurements to test various possible waste minimisation options. The activities required for generating waste minimisation options are discussed in Appendix F8. The details of the assessment procedure and findings, as well as the identified waste minimisation options for each of the focus areas, are described below.

In addition, each of the identified options is evaluated briefly as to their technical, economic and environmental feasibility.

- Whether the option fits in with how the company is run.
- Estimated technical feasibility.
- The environmental effect: reduction of amount and change in composition of the waste stream and any possible side-effects on the environment.
- Whether it can be justified economically for the company.
- Availability of finances.

Those options which required significant investment were analysed in more detail than simple procedural change options. The feasibility evaluation criteria and checklists are outlined in Appendix E16. The evaluation for each option is discussed for each focus area below.

6.7.1 French Drain

6.7.1.a Problem Statement

The wastes leading to the French Drain were identified as the primary focus area for waste minimisation at Company 2. Not only do the waste contents represent a significant loss of raw materials, but the majority of the waste is hazardous waste. The problem is the chemical spills/drips to floor are excessive and therefore require floorwashing that leads to additional contaminated wastewater. This is not treated or properly disposed, as it is washed to the French drain on the factory site, where it accumulates in the area. The assessment of this focus area therefore involved the determination of the extent of the environmental effect of the drain, followed by an analysis of the sources of all waste to it with the aim of identifying ways to eliminate or reduce these wastes. The options identified needed to be cost-effective since currently, managing this waste is effectively 'free' for the company (if the potential future liability is not taken into account).

6.7.1.b Environmental Impact of the French Drain

Size, depth and nature of drain:

The size and depth of the French drain were measured by the Operations manager and were determined to be 6m x 6m x 4m (length x breadth x depth). The wet area around the drain was in fact found to extend even further so that the depth and width of wet area are 7m and 9m respectively. The French drain operates simply as a pipe running into the ground which allows all liquids to sink into the ground and solids to settle in the soil. It is expected that the drain destructs the organic waste – grease/oil – in the wastewater, but the extent to which this actually occurs is unkown. In any case, over the 4 years that Company 2 has been in operation, process chemicals and zinc have been accumulating in the soil. It is also likely that the liquids (containing heavy metals and chemicals in solution) may come into contact with groundwater in the area, causing contamination.

The geological and hydrogeological conditions in the vicinity of the site are of importance since they influence the vulnerability of the groundwater to contamination and potential contaminant migration. A number of experts were contacted for information regarding the depth of water table in the factory area. Kriel (1999) supplied information on geological and hydrogeological conditions for the site were published maps and other geological and geotechnical information based on previous work in the area. The findings are discussed in Appendix F10. The conclusion is that the surface soils on site are sandy and relatively permeable and potential contaminants can thus enter the shallow aquifer below the factory site very easily. The legal implications are discussed in Appendix F11.

6.7.1.c Assessment Goal

The priority for the assessment was to identify all sources of waste to the French drain and to determine the exact nature of the waste by analysing wastewater and sludge flowing to the drain,

a. to see if the waste itself could be minimised or eliminated, and

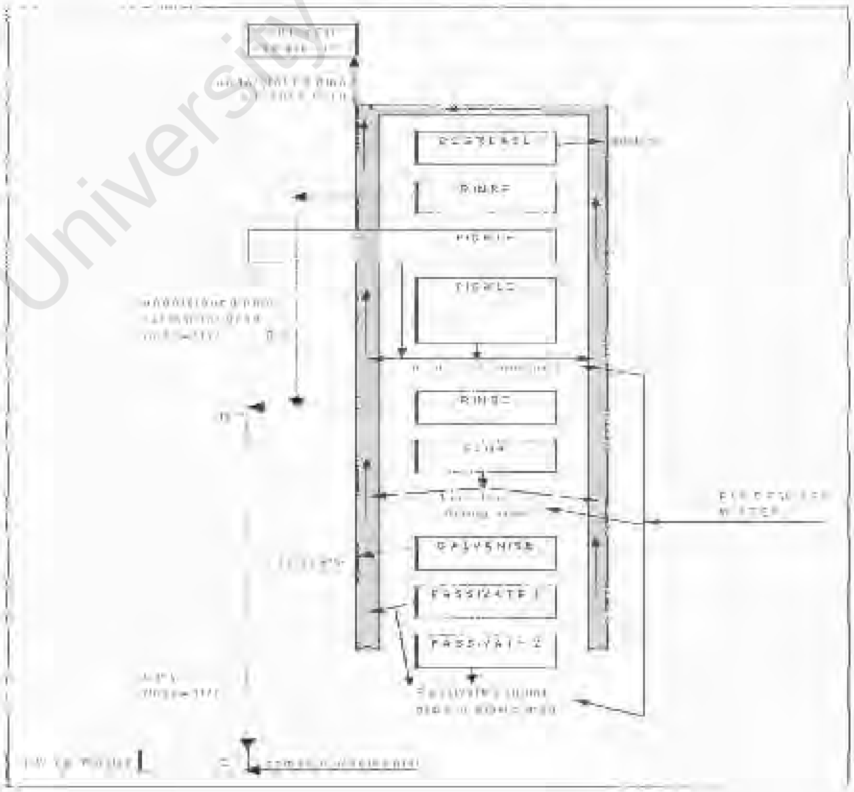
b. to see if there are alternative options for managing this waste e.g. segregation, treatment, and/or alternative disposal.

6.7.1.d Assessment Results and Discussion

Overview of French drain wastes:

A diagram of the trench system around the process baths leading to the French drain is presented in Figure 6.4.

Figure 6.4: Diagram of the trench system around the process baths leading to the French drain



All sources of wastes to the trench system and hence leading to the French drain are included in Figure 6.4. and analysed in more detail below.

The extent of drag-out in each case is not easily measurable as it varies considerably with type of product, production rate, as well as with crane operator. There is a wide range of different products coated and production is hardly ever consistent. Small and simple products result in very little liquid clinging to the surface and therefore drag-out is low. However complex or large products attract large amounts of drag-out and cause a significant amount of dripping to the floor. Near the end of bath-life, the content of the drag-out may be significantly different from that of a fresh bath (such as higher heavy metal content or lower solution concentration of acid).

All attempts to measure the drag-out volume were met with obstacles which either hindered measurement directly by the dangerous nature of the process chemicals and size of the jigs, or indirectly, by not being representative of the whole and therefore affecting the extrapolation of results. This seemed unnecessarily complicated to obtain data that would be sufficient as a rough estimate. It was decided that the pre-assessment calculations based on assumptions and material balances were sufficient to give an indication of the extent of the problem. A summary of the pre-assessment findings regarding all sources of waste to the French drain is included in Table 6.9 below.

Table 6.9: Volume contribution of all waste sources to the Trench system

Chemical	Hazardous component content	Chemical amount/year:	Equivalent solution/year:	% contribution to total volume:
Pickling acid:	16.5% L/L HCL	3700L/yr	7,400L/yr	2%
Flux:	12% kg/L $NH_4Cl.ZnCl_2$	2000kg/yr	16,700L/yr	5%
Chromic acid:	0.1% H_2CrO_4	16L/yr	16,000L/yr	4.5%
Sodium dichromate:	0.1% $NaCr_2O_7$	16L/yr	16,000L/yr	4.5%
Degreaser oil skim:	80% oil/grease 1.5% NaOH	200kg/yr	14,000L/yr	4%
Zn metal spatter	98% Zn metal	400kg/yr		1350ppm
Floorwash water			300,000L/yr	80%
Total:			**370,100L/yr**	**100%**

From the pre-assessment analysis, it was concluded that the components of concern running to the French drain were the heavy metals Zn, Fe and Cr, as well as the oil/grease from the degreaser. The pH of the wastewater is also of concern as it affects the amount of zinc and iron that are in solution (acidity causes Zn and Fe metal to dissolve). Zn sources include both metallic zinc and Zn^{2+} as zinc chloride in the fluxing chemical. The heavy metal content of each of the contributing baths was measured to determine the relative contribution of each source, as well as the sum total. The measurements and calculations are included in Appendix F12. The results are presented in Table 6.10

Table 6.10 Contribution of each waste source to heavy metal content of French drain

Source	% contribution to Zn content	% contribution to Fe content	% contribution to Cr content
Acid 1	2%	26%	8.5%
Acid 2	5%	73%	10%
Flux	51%	1%	0.5%
Chromic acid	2%	Negligible	28%
Sodium dichromate	2%	Negligible	53%
Zn spatter	38%		

The flux bath contains a high concentration of zinc (27%mol/mol) in solution as zinc chloride forms a significant part of the bath make-up. The bath also contains a certain amount of iron carried over from the acid bath via the acid rinse. The zinc content of the passivation baths is very high (builds up over time from zinc spatter which lands in these baths). This solid zinc is collected as much as possible and returned to the galvanizing bath. However, the acidic nature of the baths causes a certain amount of zinc to go into solution. The drag-out from the passivation baths will therefore be a source of both zinc and chrome.

The metal zinc from uncollected spatter that is washed with the floorwash has a significant effect on the Zn content of the wastewater in the trench system. The amount of spatter which is actually lost with the liquid in the trench systems around the tanks is difficult to determine with accuracy. For the purpose of the above workings, an estimate from the Operations Manager was used.

Direct measurement of heavy metal content of French drain wastes

The volume and content of wastewater flowing to the French drain varies considerably over time. In order to obtain an indication of the heavy metal content of the wastewater, direct samples were taken as an initial investigation.

The French drain was blocked and there was a considerable amount of wastewater overflow above the drain. Direct samples were therefore taken from this source (labelled FD on Figure 6.4). Samples were also taken at the final exit point of the trench system, before the underground pipe entrance which leads into the French drain (labelled point A in Figure 6.4). The table below summarises the results which are based on an average of samples taken. The sampling method and complete results are included in Appendix F13.

Table 6.11 Results of measurement of heavy metal content of wastewater to Trench system and French drain

Point	Zn (ppm)	Fe (ppm)	Cr (ppm)
FD (French drain)	413	156	0.2
A (Trench system)	580	100	0.15

It is likely that the wastewater above the French drain may be diluted with rainwater. In any case, these samples were taken to serve as an initial indication of the magnitude of the heavy metal content. The results indicate that both the Zn and Fe content are three- to tenfold higher than the limits of 30ppm and 50ppm respectively for discharge to sewer. The Cr content is however low and well below the 10ppm limit.

The oil content originating from degreaser overflow was not measured, owing to the difficulty in collecting a clean (without dirt/muck) representative sample. However, through visual inspection there appeared to be a relatively high amount of oil/grease as it is always present and a thin oil slick layer floated on the surface of the wastewater in the overflow of the blocked drain.

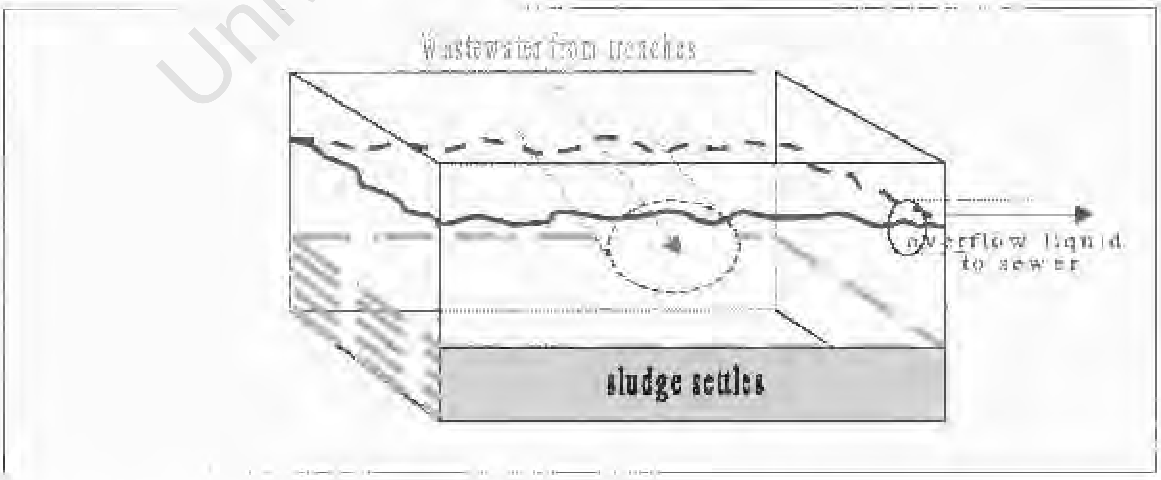
As a result of these initial findings it was recommended to the company management that a more detailed investigation would yield more accurate results, and could be undertaken if time allowed. However, the management considered the initial results a significant enough reason to consider minimising the waste, and did not require any further detailed investigation before taking action. The management were particularly concerned as to the environmental and legal implications of the French drain, and were determined to stop its use as soon as an alternative was identified. In addition, the French drain had been blocked for a period of a few weeks and was not operating correctly in any case.

The management believed that by combining the trench system wastewater with the dirty rinse water, the heavy metals would be sufficiently diluted to within the sewer limits. This was not recommended, but in the management's viewpoint, the first priority was to eliminate the French drain, thereafter methods of reducing the zinc and iron content could be investigated.

6.7.1.e New System Implemented

The pipe to the French drain was redirected to flow to the sewer via a trapment and inspection point. In this area the trench wastes were collected so that the solids/sludge is captured and only the liquid flows off the surface (via a surface pipe) to the sewer. A diagram of this trapment point is included in Figure 6.5.

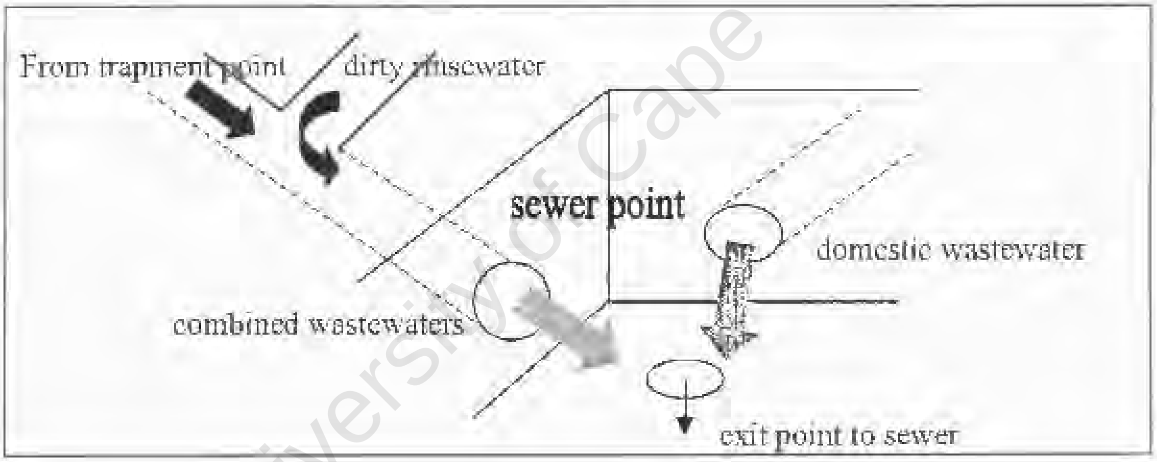
Figure 6.5: Diagram of the trapment and inspection point for wastewater from the trench system



For the new system, the sources of all waste to the sewer were therefore, as for the French drain but with the dirty rinse water included. In addition, the overflow from the degreaser bath was eliminated, since the process of skimming of oil from the degreaser was stopped completely (the degreaser concentration was increased to ensure that the quality of degreasing was maintained). The degreaser bath is no longer allowed to overflow during water fill-ups for evaporation (in this way the oil/grease which falls to the floor was completely eliminated). The overflow to floor from the flux bath (which sometimes occurs during water top-ups for evaporation replacement) has also been eliminated. If any overflow does occur it is collected in drums which are placed under the pipes which flow from the catchment lip around the tank. The content of these drums is returned to the bath on a regular basis.

The sludge that builds up each week in the trapment point is collected and disposed on Monday mornings prior to the start of the day shift. The sludge is disposed in the outside storage tank (with the spent acid and other sludges which are removed at no cost with the spent acid for regeneration). The pipe carrying the liquid from the trapment point to the sewer, joins with the dirty rinsewater and the domestic water from the bathrooms at the final sewer point. A diagram of how the pipes run into this point is included in Figure 6.6.

Figure 6.6: Diagram of pipes exiting to sewer at final analysis point



6.7.1.f A New Focus Area - New Problem Statement

The environmental benefit of no longer having chemicals and heavy metals run into the French drain is considerable. The wastewater will in effect now be treated in the municipal WWT plant, and the sludge will be treated with the spent acid (even though this is not good practice to do so without the knowledge of the acid regeneration company). However, this new system was not considered an ideal solution and was considered only a temporary solution until an alternative could be found. It is an improved option, in that the waste management has moved up in the waste minimisation hierarchy from simple disposal to treatment (of sorts), but the source of the waste has not been minimised, the final disposal point has merely been changed.

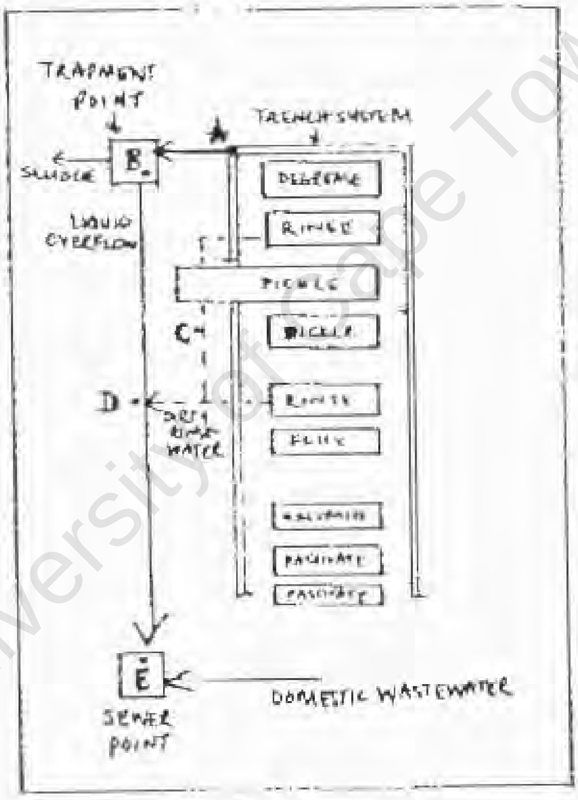
6.7.1.g Further Assessment Results and Discussion

This is rather a unique case for a waste minimisation assessment, as usually (according to the methodology) the environmental effects of implementing an option for a focus area are investigated thoroughly prior to implementing the option. Another interesting aspect, is that the dirty rinsewater is already a focus area on its own. The fact that the other wastewater is now mixed with the dirty rinsewater means that these two wastes are effectively combined into one focus area.

The next priority, therefore, was to determine if the contaminant content of the wastewater running to the sewer (floorwash water now diluted with rinsewater and domestic water) was within the limits specified by the local council (refer to Appendix E5 for limits and charge formula).

Analysis of Sewer System:
A diagram of the new system identifying the combined wastewater to the sewer was drawn up and is presented in Figure 6.7.

Figure 6.7: Diagram of new wastewater system running to sewer



Point A is where the trench systems joins up to drain to an underground pipe which flows to the trapment point B. C is a point in the wastewater flow system running from the degreaser rinse before it joins up with the acid rinsewater. The rinsewater and wastewater flowing off the surface of the trapment point (see Figure 6.5) join up under ground and exit to sewer together at point D, which is also where the domestic wastewater exits through a separate pipe (Figure 6.6). Point E is where the municipality takes samples of the wastewater for their own analyses.

The volume of dirty rinsewater was determined in the pre-assessment. If this is combined with the volume of wastewater to the French drain, it is found that the resulting wastewater volume will be 95% dirty rinsewater and 5% trench-system wastewater. The Zn and Fe content of the dirty rinsewater were determined in Appendix F4. The table below summarises the results of combining the to wastewater streams.

Table 6.12: Summary of combined wastewater to sewer

Waste source	Volume	% of total volume	Zn (ppm)	Fe (ppm)
Trench wastewater	370kL/yr	5%	500	100
Dirty rinsewater	7,800kL/yr	95%	10	12
TOTAL	8170kL/yr			
Rough estimate of resulting content			35	16
Sewer Limits			*30*	*50*

This rough initial analysis is based only on yearly averages, and does not indicate the day to day effects when rinsewater volume does not include bath dumps, and trench system waste does not include floorwashwater. The results do however indicates that while the Fe content may be within the sewer limits, the Zn content is unlikely to be. Samples were therefore taken diretly from the sewer point (point E in Figure 6.7) to measure the actual content. The sampling method and results are presented in Appendix F14. A summary of the results is presented below.

Table 6.13: Results of sample analysis for heavy metal content and pH of combined wastewaters to sewer

	Zn (ppm)	Fe (ppm)	Cr (ppm)	pH
Sewer Limit	*30*	*50*	*10*	*5.5-10*
Average of samples:	**49**	**12**	**0.05**	**7.3**
Range:	4.7 – 113	0.19 - 56.7	0 - 0.08	4 - 11
Std. Deviation:	35.7	19.0	0.03	2
No. of samples	11	11	11	10

It appears from the wide range in results that the heavy metal content in the wastewater is never constant and can be well over the limit as well as below it. There is a large amount of variation and discrepancy in the results from these sample points. The reason for fluctuations can only be speculated, but may be due to the method of sampling, which was not controlled, as well as the possibility of chemical spills and wide variations in production for example. These results are an average based on a series of samples taken over only a few weeks as the new system was only in place for a short period of time.

More samples taken over a longer period of time will give a better indication of the actual effects and fluctuations, but the results are at least assumed to be a representative indication of the magnitude of the content of the substances of concern in the wastewater. The above results are an indication that the Zn content is above the sewer limit, and although the Fe content generally falls below the limit, there is a possibility that it can exceed the limit at any point, as the source is not controlled.

Based on these initial findings (with discrepancies and large fluctuations) it was suggested to the company management that a detailed study should be performed to obtain more accurate results and be sure of the extent of the problem. Owing to time constraints for the team members in the remaining period for the waste minimisation assessment, such a study would have to be carried out separately. However, the company management noted that they were aware that the trench system caused problems and would consider implementing options to reduce all sources of waste to the system, even without quantifying the overall effect through detailed analysis. What is obvious is that the contribution of Zn from the trench system is the major problem area, since the Zn and content of the dirty rinsewater is not nearly as high as the content in the final exit point.

It was therefore decided to investigate possible options to reduce all sources of waste to trench system, with a particular focus on those options that would have additional beneficial effects for the process, e.g. quality improvements for product. The rinsewater was examined as a separate, specific focus area in Section 6.7.2

6.7.1.h Waste Minimisation Options

1 Oil skim reduction:

The surface of the degreaser is no longer skimmed of oil, and as a result, the degreaser concentration was increased, to ensure that the efficiency of the degreasing operation is maintained. The increase in degreaser concentration has some associated negative environmental effects with the increased raw material consumption, as well as the increase in drag-in of degreaser chemical into the rinsewater. The effect on rinsewater is investigated further in Section 6.7.2.

The company were, however, not happy with the reduced quality of the degreasing, owing to the thick black oily sludge layer (4cm) which was building up on the surface of the bath since skimming was stopped. In order to correct this, the company investigated changing to an alternative degreasing chemical. An emulsifying degreaser was suggested as the best option by the Hot Dip Galvanizers Association South Africa, and a supplier was recommended. The new chemical is an emulsifying degreaser with a higher proportion of solvents which provides good quality at lower concentration, and does not require regular skimming of oil. In fact it converts the saponifiable oil into soap, and the remaining oil is emulsified in suspension. It is specified to operate at lower concentration, and is less expensive (R2.60 less per kg). The company has now changed to this alternative degreasing chemical by adding as required to the existing process solution, until the content is effectively the new chemical only. Once the bath is completely recharged with the new chemical, the concentration can effectively be decreased by 2% to the specified concentration of 5%. This will help reduce rinsewater contamination through drag-out.

To date there has been a significant decrease in the oily-layer on the surface of the bath, which has now effectively been eliminated. More detailed information regarding the new degreasing chemical is included in Appendix F15.

Previously, the oil and grease from skimming, coagulated into sludge when it cooled in the trenches, and had to be washed to the French drain, where it is expected that the oil was destructed through bacterial action on the organic waste. However, it is unclear to what extent this has occurred, and since the oil is contaminated with heavy metals and other process chemicals, the elimination of this waste is considered an environmental improvement. The sludge that builds-up in the new bath is only expected to consist of dirt, muck and inerts which will require removal only after 2 years. The degreasing solution does not require disposal after sludge removal. The application of microfiltration to remove the emulsified oil is a treatment option to extend bath life identified in the literature, but is not necessary or economically feasible with this new degreasing chemical.

Another option for alternative chemicals for degreasing was seen in practice in the plant visit in Denmark on the European Study Tour. This involves the use of a bacteriological degreasing system, which has many benefits apart from elimination of oil-skim. Some of the benefits include reduced operating temperature, extended bath life through continuous oil removal, and most importantly, elimination of the need for degreaser rinse. The option is discussed in more detail in Appendix F24. It has been evaluated as to its feasibility (Appendix F22 – Option C2- 3) and it was found that the technology is in its infancy and may not be commercially available in South Africa for a few years.

2. Options for drag-out reduction

The insufficient dripping times above the baths resulting in drag-out to floor and rinse baths can not simply be ascribed to the operator. A significant reason for insufficient dripping time is the need for the crane to move to its next pickup as quickly as possible after it has lowered the jig in place. There are only 2 cranes operating and timing requirements result in operators needing to use the cranes as optimally as possible in order to keep up a sufficiently high production rate. Crane-timing analysis has been performed in detail by the Operations manager to ensure smooth flow and optimum production rate. It is a complex process, and difficult to find the optimum sequence. Drag-out reduction is taken into account in that the withdrawal speed is at a minimum, but drainage time is limited at present. Drag-out reduction options should not complicate the crane timing analysis further, but rather attmpt to find a simple solution.

Possible drag-out reduction options were identified during the brainstorm session for the company. The details of the Brainstorm session are described in Appendix F9. The following potential options were identified in the session.

Since the products vary, crane operators have to be aware of the effects of drag-out so they can adapt dripping times depending on the type of product being treated. In less busy times, adjustments in the length of drip time should be made (operator skill). Training is recommended to raise awareness amongst the crane operators as to the benefits of reducing drag-out wherever possible through slow withdrawal speeds and maximum allowable dripping time over the baths. This can be done through training or briefing by the Operations manager. The problem of drag-out was discussed during the brainstorm session at which all the employees were present. The manager believes that simply participating in the brainstorm session has lead to increased awareness, and operators appear to be making an effort to keep drag-out to a minimum where possible.

It is possible to place a rack/bar above the baths so that the jig can be hung there while the crane is needed elsewhere. The timing of the crane needed to remove the parts from this rack will have to be determined. Unfortunately, this will not be possible for parts that need to be double-dipped.

A method of reducing drag-out with minimal effect on production time would be to increase the run-off of the drag-out as the part is being withdrawn. This could be achieved by causing the lifting crane to vibrate as the load is being withdrawn. Owing to the weight of the load, a mechanical and possible automatic vibrating mechanism would be best. The crane manufacturer has investigated this option and has found that the mechanism is not available locally, but can be sourced from Germany. The mechanism is an of-centre motion device that automatically vibrates and shakes off the excess drag-out as crane raises the load from the process bath. The feasibility of importing this mechanism is being investigated.

An alternative option identified by the assessment team would be to create the same effect manually. Once the load is withdrawn fully, the dwelling time for drag-out return can be reduced by agitating or jolting the load above the bath. The Operations Manager suggested stop-starting the crane mechanism to create this effect. It is likely that with the raised awareness at drag-out reduction combined with either the crane-mechanism or jolting method, drag-out may be reduced by as much as 70% of the total drag-out from each bath. The total possible savings for this reduction in drag-out losses overall (both drips to floor and carry-over to other baths) would be around R27,000/yr in raw materials alone. The reduction in drips to the floor will reduce the need for floor clean-up significantly. Other benefits of reducing drag-out in this way include:

- Reduced contamination of process baths from drag-in, with the possibility of reduced sludge build-up.
- Reduced contamination of rinsewater, with possible associated decrease in water usage.
- Reduced carry-over of iron from acid bath (via rinse) to flux bath, which will result in improved flux quality, decrease in dross formation, as well as reduced zinc pick-up.

The cost of the crane mechanism is not known at present, but with the combined savings, it is likely to have a reasonable payback period for the investment, in which case the option is recommended in the long term. However, the manual jolting option has been implemented in the meanwhile and the Operations Manager does not believe it has a significant effect on production time. The latter option involves zero investment; savings are significant and most likely to far outweigh loss in production time. The details of the feasibility analysis for these options are included in Appendix F22, Options B1.1. and B1.2 –1.

An option identified in the literature (reviewed in Chapter 2) to prevent spills to floor and hence reduce/eliminate the need for floorwashing is to install trays to collect the drips that fall to floor in the drying areas and which allow the solution to be returned to the baths. This would also mean chemical recovery leading to a lower chemical usage. The feasibility of these options has also been investigated and workings are included in Appendix F22 - Options B1.2 -3 & 4. The payback period for installation of a drip tray in the flux drying area will depend on the drag-out reduction from the option above, but even with 70% less drag-out, the tray will have a payback period of around 3.5years, which is reasonable for the relatively low investment of R17,000. A drip tray in the final drying area after the passivation baths was not found to be technically feasible, owing to the fact that the solution from the 2 different chemical passivation baths falls to the same area.

Dripping between the acid bath and the rinse can be collected in the spare rinse tank which is not being used at present. The acid can be returned to the acid bath or stripping bath (if quality is insufficient) as required. This investment cost involves moving the bath into place and installation of piping and a pump. The savings depend on the degree of drag-out reduction from the manual jolting option, however, the low investment costs make this option economically feasible in any case. The feasibility analysis is included in Appendix F22 (Option B1.3 – 1). This option is not possible if the spare tank is repaired and the double rinse is re-installed (Option B2.5 - 1), but this will have the same effect in preventing the acid drips to floor in any case.

3. Options for floorwash reduction

Before floorwashing, the floor is swept to collect dry sweepings and recover zinc for return to the zinc bath. The need for the water wash is to clean the drag-out drips, overflow and other chemical spills.

The actual amount charged for water usage is low (only 35% of actual usage) so there is little *cost incentive* for the company at present to reduce water flowrate. Floorwashing represents even less of a cost saving in terms of water use since it uses only a small proportion of the total water usage in any case. If the company were interested in reducing this water usage, purely for environmental reasons, then the method would have to have negligible cost. In any case, the current floorwash method is not very efficient, since a large hose with low water pressure at continuous flow is used. An alternative option would be to use less amount of water at higher pressure. An option for this, identified in the brainstorm session is to use less water for floor wash by using a trigger mechanism on the wash hose. This would allow water to run out the hose only when the trigger is pressed. Wasted water when moving the hose from one area to the next would also be avoided. The disadvantage is that this will increase the concentration of contaminants in the wash water unless these (drips and spills) are also decreased by implementing the drag-out reduction options. The feasibility evaluation of this option is included in Appendix F22 – Option B5 – 1. The investment costs are low and the payback period is within a year, and this can be implemented immediately unless the floorwashing is eliminated altogether.

The optimum option identified by the assessment team is to completely eliminate the wet floorwash if the chemical drips that require cleaning are eliminated. The reduction of drag-out and implementation of drip-trays/tanks would effectively eliminate the spills to floor. In this way, dry sweeping alone would suffice and the collected dry-sweepings could be melted for recovery of zinc metal. The pipe leading from the trench system to the sewer can be closed up and this would eliminate the clean-up waste-water problem altogether. It requires a combination of drag-out reduction methods in order for it to be possible. The feasibility analysis presented in Appendix F22 – Option B5-2 has shown a potential saving of R25,000/yr, and payback period of about 8months for an investment of <R20,000. The environmental improvement is significant with a complete reduction in chemical spills and elimination of the problem clean-up wastewater. In addition the working area is improved. The need for the French drain is effectively completely eliminated. This

option is in the process of being implemented. The remaining trench system will be of benefit to contain accidental spills if they occur.

4. Options for Spatter Reduction

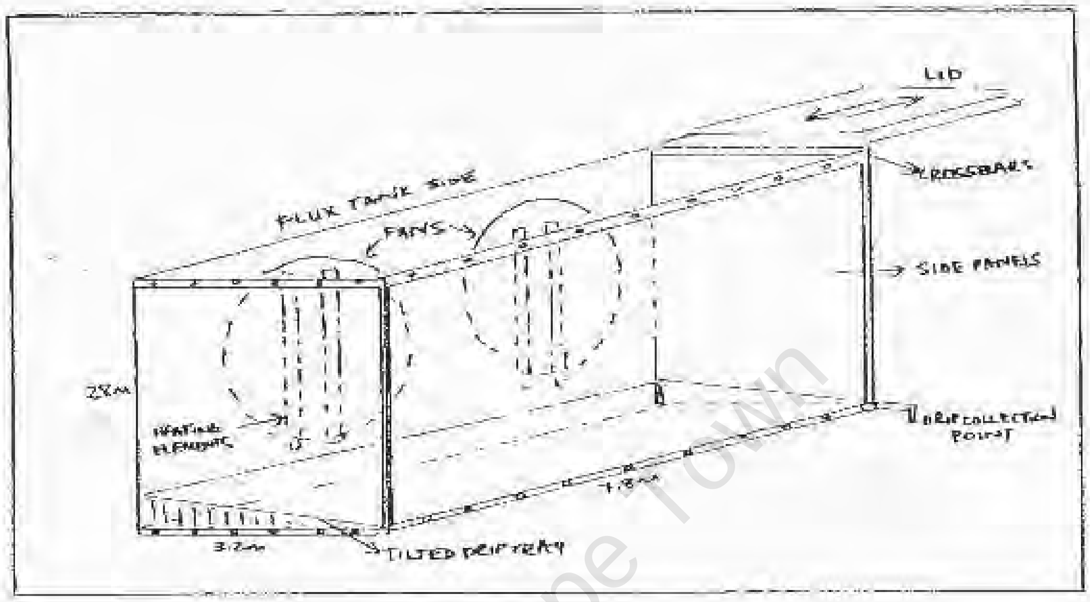
To reduce the Zn metal spatter that is caught up in the trench system and which has a significant effect on the Zn content of the wastewater, a cover could be placed over the trenches in the area of the galvanizing bath to prevent spatter from entering the trench system, and allow it to be more easily collected by keeping it dry. However, since the drips and floorwash are in the process of being eliminated, the zinc spatter which falls to trenches and floor can be easily swept-up and collected, and the spatter can still fall to the floor.

Another option is to contain the spatter before it falls to the floor by installing an anti-splash hood over the galvanizing bath. This option was found to be common practice in Europe and was observed in operation in both plant visits on the European study tour discussed in Chapter 3. An additional benefit is containment of fumes which is required by regulation in Europe. According to the Hot Dip Galvanizers Association South Africa, hoods have been installed in two of the larger galvanizing companies in South Africa. The investment for such a hood is considerable (R100,000), and the equipment is not easily available locally. Those companies in South Africa who have installed hoods have sourced design from Europe. It is technically difficult to install such a hood system where the workflow is perpindicular to the baths, as in Company 2. Brochures collected from suppliers in Europe have been investigated by the company manager, and the manager does not believe that the option suits the company's operation at present. This option can save up to R160,000/yr from containing zinc spatter, and can be reconsidered in the long-term (workings are presented in Appendix F22 – Option B5 –3). The fumes that are contained require scrubbing which is an additonal cost, and is more pollution control than waste minimisation. The savings from implementing other options in the company may make the financing of this option feasible in the future if it becomes a requirement by law as in Europe.

A better option than controlling the spatter would be to minimise the spatter at source by reducing the total amount of spatter generated. Spatter generation is worsened by insufficient drying of the flux. However, overdrying the flux affects the quality of the coating. The use of a flux-drying oven to ensure that the flux is sufficiently dried on parts as well as pre-heating the parts for immersion in molten Zn reduces spatter and is generally considered good practice in hot dip galvanizing operations (GA, 1981). If heated drying is installed it would have a number of benefits, including reduced spatter. An added benefit would be concurrent reduction in the amount of fuming (fuming is worse when the parts are still wet with flux). Improved quality of coating and subsequent reduced zinc usage are extra benefits. Finally, the resulting reduction in boiling-off which causes spatter, will decrease the amount of ash formed. The option of installing a heated flux-drying area would therefore have benefits for more than one focus area. The Company has previously considered such an option, but had not investigated it in any detail. However, with the awareness of savings associated with waste reduction (not just quality improvement), this option has now been investigated in more detail.

The free consulting section of the electricity supply company (Industrelek of Eskom) has come up with a simple and innovative design for a heated drying area. The diagram in Figure 6.8 illustrates the proposed design.

Figure 6.8 The design of the proposed heated flux drying area for Company 2



The design therefore includes a tilted drip-tray (Option B1.2 –3 above) at the base to contain any spills and allow for collection and return to the flux bath. The parts are easily available and sourced locally, and the equipment can be installed by the company staff. The feasibility evaluation of this option has been carried out and is included in Appendix F22 – Option B6 – 2. The total investment cost is estimated at R60,000. Combining all possible savings, based on rough estimates in possible reduction (supplied by Operations manager), the company can save around R350,000/yr, which means the payback period is within a couple of months. The company will be implementing this option in the short-term.

5. French Drain remediation:
Remediation requirements for the French drain still remain to be investigated. This does not form part of this project but it is recommended that the company receive help with this by allowing other university students to do the investigation as part of a separate project.

6.7.2 *Dirty Rinsewater*

6.7.2.a Problem Statement
The dirty rinsewater was identified as an important focus area for waste minimisation at Company 2, due to both the high consumption of water for this purpose (8600kL/yr), as well as the contaminant content. The hazardous contaminants include

NaOH, HCl, zinc and iron that are dragged-in from the preceeding process baths. The pre-assessment found the heavy metal content to be within spec, however, the pH of the rinsewater is of concern. Although acid and alkali neutralisation takes place when the two rinses exit together, the dumping of the baths when they fall below quality is not usually at the same time. The rinsing system after the pickling baths is particularly inefficient since there is only a single rinse bath for two double-size pickling tanks. This inefficiency is observed in the rapid decrease in rinse-quality so that the bath requires complete dump and refill weekly, adding to the high water consumption. The wastewater is not properly treated before being discharged to sewer and the pH of the acid rinse is regularly below specified limits. The drag-out not only affects the quality of the rinsewater but also results in loss of raw materials to the sewer of around R16,000/yr (according to pre-assessment calculations).

Prior to this project the management were unaware of actual rinsewater usage and water use is not a major concern as it represents <1% of total input costs for the company. The water meter has been broken since the start-up of the company. The cost of water is inexpensive in general, but based on pre-assessment estimates, this company are charged for up to 70% less than the actual usage.

6.7.2.b Assessment Goal

The assessment of this focus area therefore involved an analysis of the effects of process solution drag-in and the rinsing efficiency with the aim of identifying ways to both reduce drag-out and water consumption. The required quality of rinse water is central to the reduction of rinse water use. Reduced flow rate may lower the water quality, resulting in loss of quality or appearance, or causing contamination of the next tank. Any methods of reducing the water consumption without decreasing drag-in will lead to increased contaminant concentration of the dirty rinsewater. Since the charging system for water to sewer depends on concentration and not on total load, the aim is to first reduce the hazardous nature of the rinsewater and then implement a corresponding decrease in water consumption. If the water consumption is decreased on its own, with the current charge system, this may have negative cost implications. An important aspect here is that if heavy metal content of wastewater to sewer is above limit, effluent charges using the *actual* water usage volume would give a much higher effluent charge than the current volume which is charged for (see Appendix E5 for charge formula). This is important to remember if the water meter is fixed and nothing is done to reduce the water consumption or heavy metal content.

The options identified need to be cost-effective since currently, managing this waste is inexpensive for the company. At present there is little, *economic* incentive for the company to reduce water usage. However, the water price is expected to increase in the near future and it is possible that at some stage the water meter will be repaired. In this case it would be important for the company to be aware of actual water usage and how it can be reduced.

6.7.2.c Assessment Results and Discussion

Analysis of Rinsing System:

An initial investigation of the rinse system revealed that the rinse baths incoming hose was on the same side as the outgoing pipe. This meant that a closed circuit effect was being set up with fresh rinse water running out before it could mix with the dirty rinse water. The fresh water was being wasted and rinsing was ineffective resulting in over-consumption and frequent dumping of rinsewater. The company implemented this waste minimisation option immediately by changing the water inlet to the diagonally opposite side of the baths. This effectively increases mixing and improves the efficiency of rinsing with the same water flowrate.

From the pre-assessment workings it was estimated that the drag-in of acid to the rinse bath from both pickling tanks is 15L/day on average (workings in Appendix 6.4). As discussed in Section 6.7.1, it is difficult to directly measure representative drag-out values, mainly due to the varying production at the factory. Instead, these were calculated based on assumptions and mass balances. As a check on the estimate for drag-out volume, the following equation was used:

$$Q = \frac{D}{M}\left(\frac{C_d}{C_n}\right)^{\frac{1}{n}}$$ ....Equation 6.1 (Cushnie, 1994)

Where
Q = rinse flowrate (e.g. L/day)
D = Drag-out (e.g. L/day)
M = time during which drag-out is measured (e.g. days)
C_d = concentration of contaminant in drag-out
C_n = concentration of contaminant in the counter-current rinse tank
n= Number of counter-current rinse tanks

The smaller the time period (M) over which the drag-out is measured the better the accuracy of the equation. However, for the purposes of this calculation, the period of a week was used, as the result served only as a rough check on the magnitude of the estimated drag-out value.

For the acid baths, there is only 1 rinse tank, so the equation can be re-arranged as follows:

$$C_n = \frac{D.C_d}{Q.M}$$ ....Equation 6.2

The concentration of the acid in the rinse bath can be converted from pH to mol/L using the following conversion:

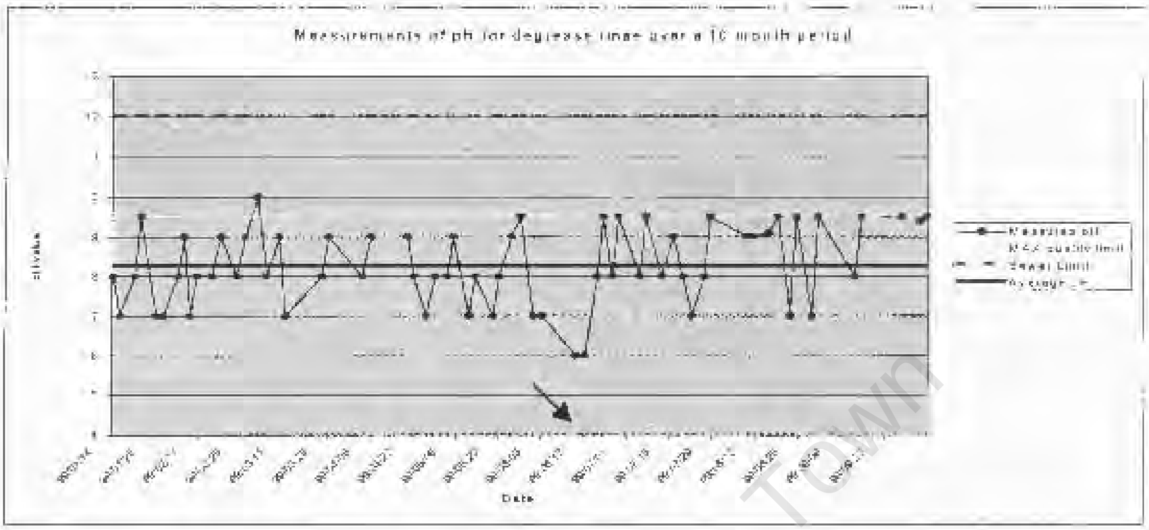
$$C_A = 10^{-pH}$$ ....Equation 6.3

Where C_A = concentration of HCl (mol/L) = $[H^+]$ = concentration of H^+ (mol/L)

The calculations using the above equations are presented in Appendix F16. The result showed that with an estimated average drag-in of 15L/day into the rinse bath, the pH after 1 week should effectively be pH 5. The pH does in fact reach near 5 by the end of each week, and so the assumption is assumed to be representative.

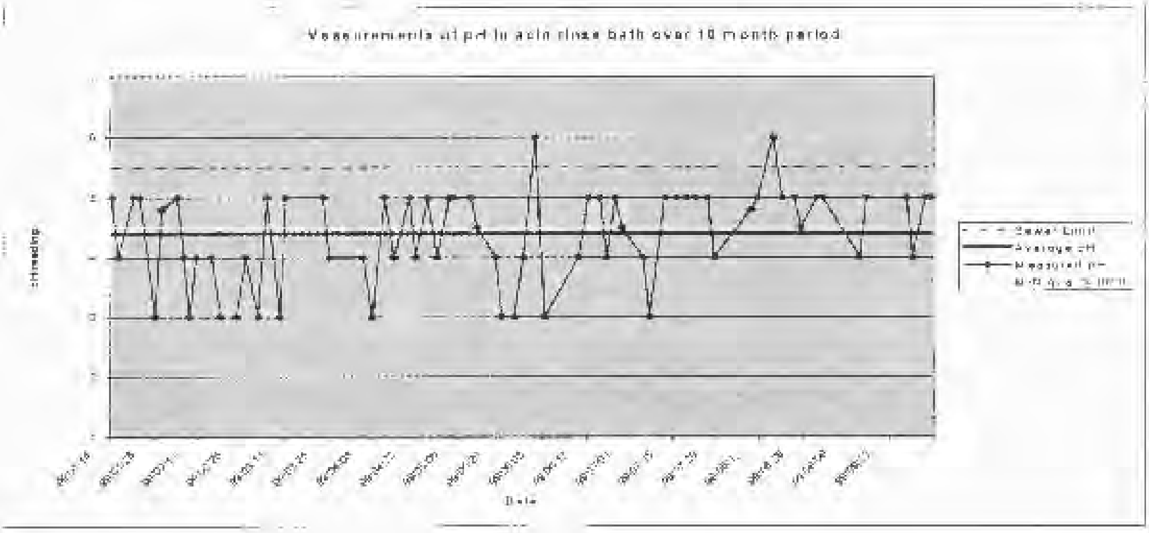
Graphs of pH vs. time for the degreaser and acid rinse were compiled from the company log data for 1999. The data is included in Appendix F17 and the graphs are presented below.

Figure 6.9: Graph of pH vs. time for the degreaser rinse bath



The pH of the alkali rinse seldom rises above, but often reaches the maximum quality limit of 9.5 (chemical supplier's specifications). It falls well below the maximum allowable pH limit to sewer of pH 12, but is sufficiently high to effectively neutralise the low pH acid rinse water when they combine (average pH of mix is 6.2 equal mix). The arrow indicates when the degreaser concentration was increased (after eliminating oil skimming). The effect on the rinse is observable in the increased number of times the quality limit is now reached. The sharp drops in the graph indicate where the bath has been substantially drained. The increased degreaser concentration has effectively resulted in increased contamination of the rinsewater, with resulting decrease in rinse efficiency and increased water consumption. The decrease expected in the future, once the bath is completely replaced with the alternative, is expected to help relieve this problem.

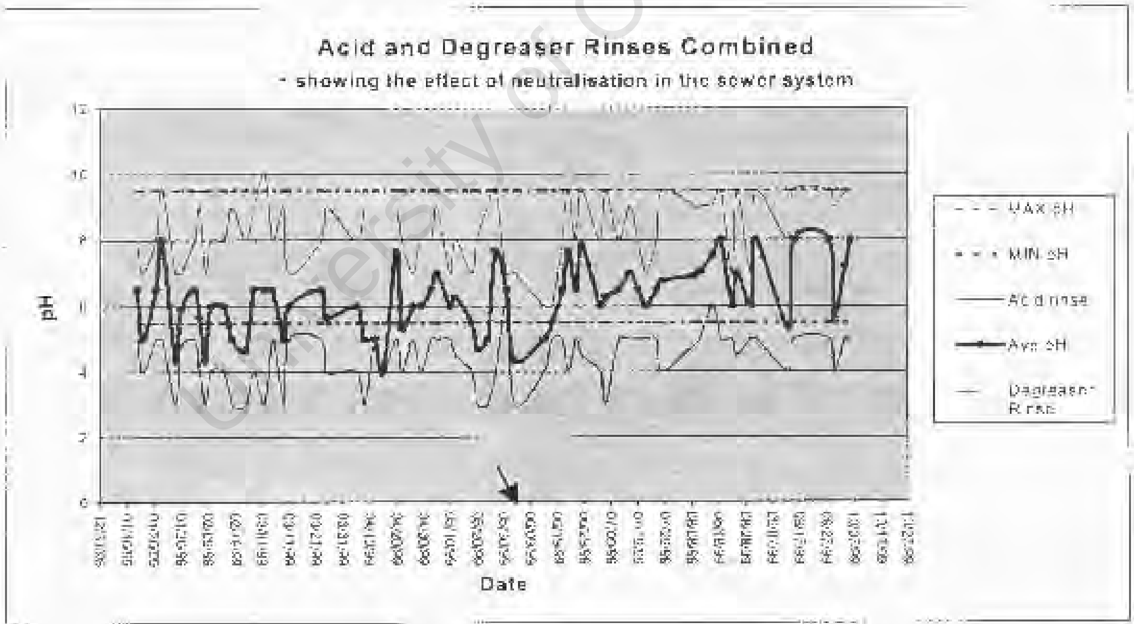
Figure 6.10: Graph of pH vs. time for the acid rinse bath



The minimum allowable pH for wastewater to sewer (stipulated by the CMC) is pH 5.5, which is higher than the minimum specified pH for the rinsing to be effective (Operating Manual specifications). This is not a problem as long as the degreaser rinse is combined with the acid rinse before exiting to sewer, in which case the resulting pH to rinsewater is close to neutral (6.2 on average). The limit for sewer discharge may however be a problem when the bath is drained. The sharp rises in the pH values indicate the times when the bath has been drained and refilled. The average pH of the acid rinse water falls well below the minimum specification for rinse quality. This data illustrates the inefficiency of the acid rinse system at present.

A rough indication of the effect on pH for the combined rinses is presented in the graph below. If it is assumed that for the majority of the time the flowrate of degreaser and acid rinsewater are approximately equal (measurements indicate this), then it may be assumed that when the rinsewaters combine, that the pH of the mixed water is the average of the acid and degreaser rinse pH. The graph of acid and degreaser rinse together with the expected (averaged) pH of the mixed rinse is presented in Figure 6.12. The effect of draining the bath is taken into account by including the pH of the drained bath twice in the calculation of the average. This method of determining the combined average pH is explained in Appendix F17. The results are not assumed to be correct, but serve only as a representation of the expected effects of draining the baths on the overall pH.

Figure 6.11: Graph of effective pH vs. time for the rinses combined



The graph above shows that before the degreaser concentration was increased, the rinsewater to sewer was frequently below limit. The arrow indicates where the degreaser concentration was increased. Although the overall loss of chemicals is higher due to the increase in drag-in of degreaser chemical, it does have the 'benefit' of effectively neutralising the low pH acid rinse water. However, the result is an overall increase in water consumption, due to rinsing inefficiency and more frequent baths drains. Draining of the degreaser rinse is now effectively 3x more frequent than before, thereby effectively increasing the rinsewater consumption by 6% or 500kL/yr.

The overall finding is that both the degreasing and pickling rinses are inefficient. The drag-in of process chemicals is substantial for both baths and resulting contamination requires increased water use to maintain rinsing quality. Based on these additional findings, the management were particularly interested in identifying options to improve the rinsing efficiencies of both rinse baths. From the literature review in Chapter 2, options for drag-out reduction, improved rinsing efficiency, as well as alternative rinse configurations were identified. Additional options were identified in the company brainstorm session (described in Appendix F9). The potential waste minimisation options for the dirty rinsewater are described below.

6.7.2.d Waste Minimisation Options

1. Options for drag-out and water-use reduction:

The option for reducing drag-out overall through mechanical jolting (or crane vibration at a later stage) identified in the brainstorm session and analysed in Section 6.7.1 above is in the process of being implemented at the company. The estimated possible reduction in drag-out was assumed to be 70% overall reduction for each bath. The effect this will have on the rinsewater quality is expected to be highly beneficial. The resulting decrease in contaminant build-up will have a positive effect on the rinsing efficiency and the water consumption. Equation 6.2 above shows that the concentration of contaminant in the rinse (C_r) is directly proportional to the drag-out volume and concentration. Therefore, if the drag-out volume is decreased by 70%, the resulting concentration of contaminant in the rinse bath will be reduced by 70%. The actual decrease in drag-out will have to be determined after implementation. Nevertheless, the rinse quality is expected to increase, resulting in reduced requirements for bath draining as well as a decrease in the number of times that the limits are reached.

As a corollary to this observation, it should also be possible to reduce the rinse flowrate by 70% for the same rinse performance. However, improved rinsing efficiency is required, in which case the flowrate should not be reduced by as much, but rather by only 50% for example. Of course, this reduction in rinse flowrate will depend on the actual resulting decrease in drag-out. Once the drag-out reduction option is in place, tests may be performed with regard to possible decrease in rinse water flowrate, while still leaving room for improved rinse efficiency. As a conservative estimate, and for the feasibility evaluation, the potential for decrease in rinsewater flowrate associated with the expected drag-out reduction, is assumed to be 40%. The combined drag-out reduction of 70% and water flowrate reduction of 40% would have an overall effect of 30% decrease in rinse contaminant concentration. The 40% reduction in rinsewater usage should result in savings of R11,500/yr. However, the company is undercharged for water at present, and the savings in water use may not be observed. The savings will be necessary if the water meter is repaired.

To reduce flow by a set amount is however difficult with the variation in production at the company. During low production periods the Operations Manager can reduce the flowrate, and has in fact implemented this option on the degreaser rinse in the past. However, it is difficult to determine the optimum decrease, and trial and error has associated risks. A solution to this may be to implement automatic rinsewater flow, by installing a conductivity control device or equivalent. For the degreaser rinse bath. the oil carry-over can interfere with the sensors, and there are other associated maintenance problems resulting in relatively high operating costs. The feasibility of this option is briefly examined in Appendix F22. Option B2.4 –3. The investment costs outweigh the savings at present, and the feasibility of the option depends on the future water price or sewer charge increases.

Another drag-out reduction option identified in the literature review of Chapter 2. is to change process solution chemistry to minimise drag-out. The increased concentration of the degreaser at present results in higher drag-out concentration, which has reduced the rinsing efficiency substantially. The new degreasing chemical is being added over time as required, and once the complete bath is substituted with the new, it will be possible to reduce the concentration to around 5% without affecting quality.

According to the Hot Dip Galvanizers Association South Africa, some companies have switched to the use of acid degreasers that avoid the need for a rinse after degreasing and prior to pickling. Hydrochloric acid is used at around 8%. Phosphoric acid based degreasers are now also available. Waste disposed with phosphoric acid material is less of a problem than HCl degreasers (Barnett, 1999). This option has not been analysed in detail, as it does not suit the company at present, but the company management are willing to consider this option in the long-term.

The volume of drag-out from the degreaser and acid baths are not known exactly and were only estimated in pre-assessment calculations. The savings in chemicals and water consumption, which could be made through drag-out reduction can therefore only be roughly quantified based on assumptions in reductions. However, the company management are prepared to implement possible drag-out reduction methods, even without exact knowledge of savings. As discussed in section 6.7.1 there are a number of additional benefits to reducing drag-out which combined would be of particular benefit to the quality of the coating.

2. Options for reduced water consumption:
Regardless of the drag-out and type of rinse tank arrangement, water use reduction can be achieved by co-ordinating actual water use and water use requirements. When perfectly matched, the rinse water use for a given work load is optimised.

The installation of flowmeters to monitor rinsewater usage is recommended. These do not reduce water use by themselves but make the operator aware of use rates and help identify specific locations of excessive water use. The investment cost is within the company's financial ability, while the payback period depends on whether problems are identified (refer to Appendix F22, Option B2.4-4).

An option observed in a plant site visit in Denmark is the possibility of using the same rinse bath for rinsing after the degreaser and after the acid. This would effectively be maintained at neutral pH through the neutralising action of the acid and alkali reaction. However, the Hot Dip Galvanizers Association South Africa, indicated that this is not possible for the type of degreasing chemical and HCl as it would result in excessive foaming and salt pick-up on the parts which would affect coating quality significantly. For the same reason, the option of using counter-current rinsing for the combined rinses is not a possibility.

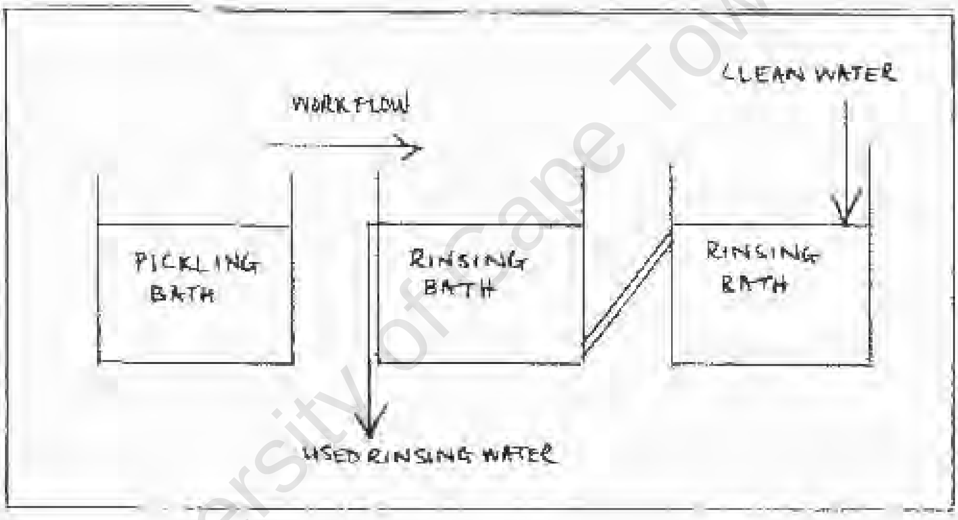
Another water use reduction option identified in the literature would be to use the degreasing rinse water as evaporation replacement in the degreaser bath as opposed to fresh water. This would however, save only a very small amount of water (60kL/annum or <1% of total usage), and approximately 5kg/yr or R50/yr in degreaser chemicals (calculations are set out in Appendix F22, Option B1.3 –2)

3. Options for improved rinsing efficiency

An option to increase rinsing efficiency would be to allow the incoming rinse water to enter down the entire length of the bath as opposed to on one side only. This would improve the rinsing efficiency by causing increased agitation. This may be implemented in combination with both drag-out and rinsewater reduction options.

Another option identified in the brainstorm session is the re-installation of the double-rinse system for the pickling rinse. A diagram of this system is included in Figure 6.12 below.

Figure 6.12 – Diagram of double counter-flow rinse system after pickling



The cost of fixing the broken tank and reinstalling the double system is weighed against the improved rinsing efficiency and reduced water consumption. This option will be particularly effective in conjunction with decrease in drag-out (D). Equation 6.1 above can be used to determine the optimum rinse flowrate. The literature review of Chapter 2 has shown that water use can be decreased by 50% with the installation of each additional counterflow rinse tank. The feasibility of this option has been evaluated, based on the assumption of 50% reduction in rinse flow, and 70% reduction in drag-out. Workings are included in Appendix F22, Option B2.5-1. The negative effect includes increased production time for double rinsing each load. With estimated investment costs at around R20,000, payback period is over 5 years with current low water costs. Once again, the feasibility of this option will improve with increased water costs, whether actual water use is charged for (payback period reduced by half), or whether charges increase.

Another option to improve rinsing efficiency would be to combine spray and dip rinsing of the parts. The feasibility of this option would depend on the design of a spray rinsing system, as it would have to allow for double-dip parts, and it would have to be highly flexible to allow for differing sizes and complexities of parts. Spray rinsing is most effective for flat-surfaced parts and is less effective with recessed and hidden surfaces. Owing to the wide variation in type and complexities of products, this option is regarded as technically not feasible.

6.7.3 Ash

6.7.3.a Problem Statement

The cost of this waste to the company is the highest of all wastes at R418,000/yr, and is the primary reason why this waste was selected as a focus area. It represents a waste of 33% of total zinc consumption/annum. The quantity of ash generated at around 100 tons/yr is also a significant factor. In terms of environmental effects, the Zn loss in the ash results in a higher zinc consumption as well as the need for increased electricity consumption to remelt more zinc. Both of these options affect the environment indirectly. In addition the recovery of zinc from the ash off-site has an associated energy use.

6.7.3.b Assessment Goal

The aim of the assessment was to investigate the ash-formation process and analyse the ash collection method, in order to identify options to minimise the overall amount of ash (zinc-oxide) generated as well as the amount of metal zinc entrained in the ash.

6.7.3.c Assessment Results and Discussion

Ash analysis:
Samples of the ash were taken and measured for zinc content. The sampling and analysis methods are discussed in Appendix F18. The ash was found to contain 95% Zn, where 70% is zinc metal and 30% is in ZnO form.

In order to check this finding a zinc balance was carried out. The workings are included in Appendix F19. The results indicate that the total zinc input, less the usage is approximately equivalent to the sum of losses through ash, dross and spatter. The calculations depend on the estimated Zn pick-up on product, which in this case was assumed to be 8.5% of the mass of steel galvanized, as well as the loss of spatter which was assumed to be 7% of total zinc usage. These values were offered by the Operations Manager as the best estimate. The zinc in the ash was determined to be 26% of the total zinc usage. Since ash is only sold at $1/3^{rd}$ of the Zinc price and it contains 95% zinc, this is a particular concern for the company.

Analysis of ash collection method:
The ash collection method was analysed in more detail during the assessment. The ash collected during the day is kept on the side of the bath. At the end of a day's shift, the ash collected during the day is thrown onto the zinc bath and left overnight. In the morning the ash is worked through to re-melt the zinc metal until reddish zinc ash remains. This is then skimmed from the surface and kept in drums for collection. This ash skimming is not very efficient and there is still a considerable amount of zinc

metal entrained in the ash. The loss in monetary terms is high, especially considering that zinc is the highest input cost for the process. In addition, valuable production time is lost at the end of the day and in the morning when the collected ash is thrown on and worked through.

An internet search for information from international hot dip galvanizing associations lead to the website for the European General Galvanizers Association (www.EGGA.org). Included in the general galvanizing advice was information on common faults with ash collection and a simple method of how to reduce the amount of ash generated. The inefficiency of the current method to collect ash at Company 2 is that the ash is removed from the bath after each skim and only worked through to recover the zinc from the total load at the end of the day. The improved method is to work through each load of ash as it is skimmed and only remove the ash from the bath once, after it has been worked through. This reduces the amount of ash generated (more is generated in the skimming process), but mostly reduces the amount of Zn metal entrained as the ash is removed only once from the bath.

6.7.3.d Waste minimisation Options

1. New Ash collection Method:

The improved collection method has been implemented. It required the installation of a weir on one side of the zinc kettle 150mm wide and 150mm deep, at very low cost. All the ash collected during the day, instead of being removed to the edge of the bath, is moved to this weir. In this way the ash is continuously worked through throughout the day and is removed when the reddish zinc oxide is left. The operators have time to do this while dips are waiting to be done, so there is no loss in production time or additional labour costs. The result is expected to be a considerable reduction in the amount of zinc metal entrained in the ash.

Analysis of ash after improved collection method:

Since implementation of this option the amount of ash collected has reduced substantially from >1 barrel per day to ½ barrel per day.

BEFORE	Ash weight per drum = 420kg
	1.5 drums collected per day = 630kg
AFTER	Ash weight per drum = 394 kg
	0.5 drums collected per day = 197 kg
DIFFERENCE	433kg

The reduced mass/drum of the new ash indicates a significant reduction in metal content of the zinc. In addition observation also indicates that the new ash is more red and more easily breakable (crumbles), which indicates there is far less zinc metal holding the ash together. Reduction in grey metal content is noteable.

Samples of the new zinc ash were taken for analysis to determine zinc content as before. The results of the sample analysis are included in Appendix F20. The new ash has a measured total zinc content of 87%, of which 34% is zinc metal and 66% is zinc-oxide. Although the accuracy of the measurement method is not high, the degree of reduction is significant enough for this not to be an important consideration.

The results of the sample analysis indicate that the entrained zinc metal content has reduced by 36%. Total zinc content in the ash has therefore decreased by 8%. Zinc oxide sold after recovery of metal zinc yields an equivalent price per ton to that for untreated ash. This is because the ash is essentially not sold for zinc recovery, but as a residual product. There is a big demand for zinc oxide as a trace element in fertilizer for the agricultural industry. Therefore the company will receive the same price for the ash despite the reduction in Zn metal entrained. Analysis of savings as a result of the change has been carried out and the calculations are included in Appendix F21. The calculations indicate that the change represents an estimated saving of ~R250,000/yr for the company. This value depends on the estimates and assumptions. As it also depends on production, the saving per ton of steel galvanized is: R 75/ton or 17kg of Zn per ton of steel galvanized.

The saving in zinc consumption is not the only saving, there is also the additional saving in working time with the elimination of the need to throw the ash back into the zinc at the end of the day and work through the ash in the morning.

Analysis of zinc consumption for the month before the change versus the month after the change indicates that the zinc consumption was approximately the same for significantly increased production. The manager is satisfied that there is a significant overall decrease in zinc consumption as a result of the change. Although the waste is not a particular environmental concern, the increased zinc and energy usage as a result of the waste are a concern. An additional benefit of this option is that it was one of the first to be implemented in the company and served as an interest-grabber for the company by showing the significant savings that can result by reducing waste with little or no cost to the company. The management were therefore encouraged by this and interested in pursuing other possible improvements options for their process. In addition, the savings have the potential to lead to increased financial ability of the company to invest in other options.

2. Additional Options:
The proposed installation of the heated flux drying area is expecced to result in a further reduction of ash formation. The pre-heating and dry flux will result in the reduction of "boiling" when parts are immersed in the zinc bath, thereby reducing oxidation of the surface zinc (ash formation). When the zinc splashes out, oxidation occurs in two ways: turbulence on the zinc surfaces in the bath causes oxidation, and molten zinc particles propelled through the atmosphere also tend to become partially oxidised. The metal zinc is swept up and returned to the bath, but again, the remelting of small particles results in the formation of more ash (Barnett, 1999). The Operations Manager estimates a further reduction of ash of approximately 7%, which can save a further R12,000/yr or 3tons of zinc/yr. The workings are inclued in the feasibility analysis for the flux drying oven in Appendix F22 - Option B6.2.

6.7.4 Fumes

6.7.4.a Problem Statement

The degree of fuming above the galvanizing bath as a result of flux volatalisation and ammonium chloride dusting, was the initial reason for the company joining this project. Neighbouring facilities have queried the excessive fuming which is seen to emit from the factory. Fume emissions from the galvanizing operation can from time to time dangerously obscure vision on the adjacent roadways. In addition, the fumes are hygroscopic in nature and attract moisture which causes corrosion of steel structures above the baths, most importantly the overhead cranes. The workers also complain that the fumes sometimes irritate their chests and they have requested milk to drink during or before shifts as it is believed to help relieve the irritation. Ammonium chloride fumes are not considered hazardous to health unless inhaled in large quantities.

6.7.4.b Assessment Goal

To identify ways to reduce the total amount of fuming above the galvanizing bath.

6.7.4.c Assessment Results and Discussion

As the pre-fluxed parts are dipped in the molten Zn, the flux volatalises resulting in a certain degree of fuming. This fuming is made worse if the flux is not sufficiently dried on the parts. Observation of the process revealed that the parts are often carried over to the Zn bath while still dripping with flux. This was somewhat caused by the excessive drag-out from the flux bath due to insufficient draining above the process bath. Further, insufficient drying of the parts arises from the concern by operators not to overdry the parts as it badly affects the quality of the galvanizing. For the operators, there is a preference for increased fuming over the responsibility associated with bad quality product.

Dusting with ammonium chloride salts results in more significant fuming than flux burn-off alone. Zinc ammonium chloride (as used in the flux bath) causes less fuming than ammonium chloride, but in its commercial form it reacts more slowly and is thus less suitable for incidental uses in which rapid fluxing is essential i.e. dusting (W. Barnett, 1998). Ammonium chloride salts (dust) are therefore thrown onto the components as they emerge from the molten zinc to aid the run-off of the zinc. The Hot Dip Galvanizers Association South Africa (HDGASA), were contacted for information regarding the need for the dusting process. In their view, the "dusting" practice, using whatever method, is not a pre-requisite for a good galvanized coating and is considered unnecessary, provided components are adequately cleaned, surface treatment has been effectively carried out prior to zinc dipping, and the zinc surface on the bath is adequately skimmed prior to withdrawal (Barnett, 1998). It is for these reasons that the use of ammonium chloride salts as a dusting medium, on withdrawal of components from the zinc, is forbidden in some countries (this was confirmed on the European Study Tour reviewed in Chapter 3).

According to the company manager, dusting was originally employed mainly for complex parts to aid the run off of zinc. However, over the years, dusting of most parts has become commonplace as it makes the work of skimming ash easier and ensures good run-off of the zinc which results in good quality coating. The problem is that when dusting takes place, the quantity of salts used is probably far in excess of what is required, but to control this is extremely difficult. The amount of dust used is uncontrolled, and there is significant potential to reduce fumes, merely by controlling the method of application.

6.7.4.d Waste Minimisation Options

1. Alternative methods of applying dust:
Alternative methods of applying dust were investigated. The Hot Dip Galvanizers Association indicated that one South African company uses a spray method of dusting. For this, the dust is made into solution and placed in a spray gun (similar to agricultural spray guns for spraying pesticides). The dusting can therefore be directed more carefully onto the parts, controlling the usage. The operations manager therefore investigated possible purchase of such equipment and performed some tests to determine the effects of spraying dust in solution. They were not completely satisfied with the result and there was not much improvement in the degree of fuming.

However, at the time of these investigations, the cranes above the baths had reached the stage where they were badly corroded and needed to be replaced. The company had to purchase new cranes to replace the corroded ones. The existing cranes had only been in operation for four years (since the process was installed). The cost of these new cranes was substantial (>R500,000) and lead to the management rethinking the need to reduce the amount of fuming.

2. New dusting procedure
It was therefore decided to change the dusting procedure to allow dusting only of very complex parts. The operators were instructed to use dust only where absolutely necessary, and to control the amount used to a minimum. In conjunction with this, the concentration of the flux bath was increased from 8% to 12% to ensure maintained quality of the galvanizing.

The resulting decrease in dust usage is from 12x50kg bags per month to only 1x50kg bag per month. This represents a saving of 6000kg/yr of ammonium chloride salts, or R16,000/yr. The resulting saving is offset by the increased flux concentration of 4% – an additional 325kg/yr, or R3000[1]/yr. Overall savings are therefore R13,000/yr for a no cost change in procedure. In addition, there is an intangible saving associated with reduced corrosion of overhead steel structures, which may be considerable if the high cost of new crane equipment is taken into account. The working for this is included in Appendix F22 – Option B6-1. This does not include the further savings through reduced corrosion of overhead cranes and other steel structures. Overall dust reduction is 92%, which has resulted in a noticeable improvement in the degree of fuming.

The Operations Manager has further changed the method of applying the dust when it is required on bad double-dip marks in particular. Now it is no longer thrown over these areas in an uncontrolled manner, but applied by dabbing the salt over the area using rags. The effect of this is likely to further reduce the dust consumption. As yet this effect has not been measurable.

3. Additional Option which will benefit Other Focus Areas:
An option identified that will have benefits for a number of focus wastes and others is the installation of equipment to maintain clean flux solution. Maintaining quality of the flux is the critical step in the pre-treatment process. In addition to the effect from optimal drying of the flux, maintaining a 'clean' flux solution further helps reduce the degree of fuming. The main contaminant in the flux bath is the Fe that is carried over

from the pickling acid via the rinse. If the Fe content in the flux bath is kept to a minimum, the concentration of the flux bath can be reduced without affecting the quality of fluxing. This leads to less fumes during galvanizing. Drag-out reduction options are the first step by reducing the initial Fe carry-over from the pickling acid to the flux bath via the rinse.

A regeneration unit can be installed that keeps the iron concentration of the flux bath at a minimum. This begins a chain-reaction of cost savings and this option was therefore investigated further owing to a number of other waste minimisation advantages associated with it, namely:

- Reduced gross zinc consumption
- Reduced dross production
- Reduced zinc ash production
- No waste disposal costs
- Far higher quality galvanizing

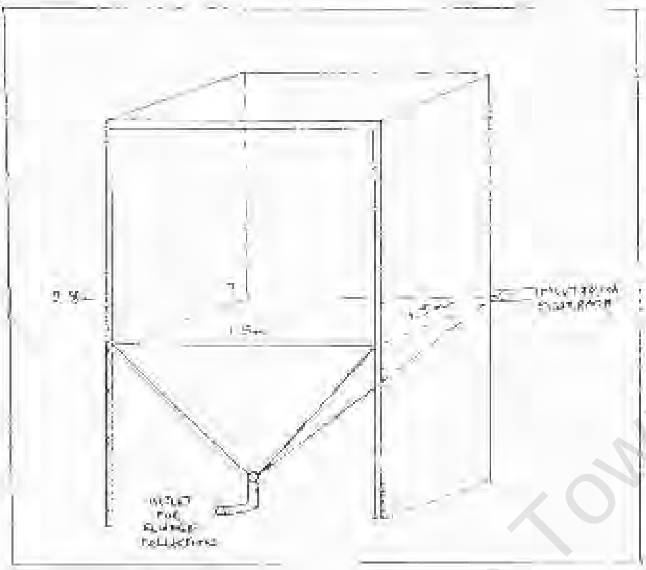
These benefits and requirements of flux purification equipment are discussed in more detail in Appendix F25. The option of continuous flux filtration was described in 2 different case studies found in the literature, and was also seen in practice in one of the plants visited on the European study tour.

An internet search revealed that Australia has produced a system for continual purification of the flux bath that involves electrolytic oxidation of iron and reduction of zinc. The supplier was contacted for more information and it was found that the unit is too bulky for use in Company 2. Automatic purification equipment is probably only viable in a large plant (Barnett, 1999). There are some purification units developed in Holland that are also being tested, but are not commercially available at present, particularly not locally. Examples of such units are described in Appendix F25. The chairman of the Hot Dip Galvanizers Association South Africa gave the name of a local company that is capable of designing a simple robust alternative, and has done so previously for two other local companies. Unfortunately the company was no longer listed and could not be contacted.

A brochure supplied by the Dutch hot dip galvanizers association (SDV) revealed that commercially available purification installations can keep the iron concentration at a low level of around 1-2g/L. However, the Fe content in the flux bath solution at Company 2 is measured daily by the Operations manager and does not exceed 1g/L (refer to Appendix F26). The Fe content is kept low at present through the use of substantial quantities of rinsewater after pickling. Closer analysis of the flux bath reveals that there is a significant amount of precipitated iron-chloride salts which settle in the tank and the majority of the Fe is therefore in this solid sludge that settles in the bath.

The assessment team decided to investigate possibilities for removing this sludge. A brainstorm session lead to an alternative option for continuously removing the high iron-content sludge. Since the flux is heated by continuously circulating through a heating tank, it was decided to install a tapered base to the heating tank which would capture the sludge as it circulated and could be continuously removed. The heating tank requires repair/replacement in any case, as the rubber lining is dissolving and causing an oily build-up in the solution. Figure 6.13 below depicts the proposed design.

Figure 6.13: Proposed flux heating tank design for sludge removal



The feasibility of this option has been roughly evaluated and workings are included in Appendix F22 – Option B8.1-2. The investment cost for the option is < R20 000 and was found to have a payback period of between 6 months and a year depending on the actual achievable reductions in ash, dross and Zn pick-up. The potential decrease in fuming cannot be determined. The company is intending to implement the option in the short-term. It is expected that the sludge will require removal from the tank on a weekly basis at first, but once the majority has been removed, the collection frequency may reduce to 1x/month, depending on production. The total sludge volume should not exceed 3000L/yr as that is the volume of sludge removed at the end of year at present. There is a possibility that the collected sludge could be sold for iron recovery. In the meantime it will be disposed in the spent acid. The acid regeneration process involves the removal of iron chloride in any case to produce an iron by-product.

3. Further Options

Although the fuming has been substantially reduced thanks to minimising dust usage, there is still considerable fuming as a result of the flux solution volatilising. The installation of the heated flux drying area will have a positive effect on this. The management had been considering this for the improved galvanizing quality associated with optimum drying as well as the savings in zinc through reduced spatter. The further improvement of reduced fuming added to the feasibility of this option. The feasibility evaluation is included in Appendix F22 – Option B6 -2. As discussed in Section 6.7.1, the option is to be implemented in the short term and it is believed that it will reduce the degree of fuming from flux volatilisation substantially. In addition the flux dusting can be eliminated completely.

Further reduction in fuming is not considered necessary at present, but may be necessary in the future if air pollution laws become as stringent as they are in Europe and the USA (reviewed in Chapter 3). In Europe it is now compulsory to control the concentration and amount of fuming above the galvanizing kettle. For this, fume extraction is installed with a hood over the bath which can be extended upwards to form a fume collection device above the tank and hoist/crane unit. The hood system has other advantages in that it also prevents explosive splashings (spatter) from leaving the bath itself - this not only saves zinc metal in its pure state for immediate reuse but it also increases the safety of the work-place. Once fumes are collected, they may be filtered or scrubbed with water (it may be possible to return the washings to the flux bath at least in part). Some companies incorporate the acid fumes from the pickle tank into this scrubbing system also. The feasibility of the hood option has been evaluated in section 6.7.1 for its waste minimisation benefits in spatter reduction. The evaluation is included in Appendix F22 – Option B5-3.

Other methods of fume extraction are considered more pollution control than prevention, and were therefore not evaluated as options. However, information on the various options is included in Appendix F23. It is useful for the company to be aware of these, as fume extraction may become compulsory for South African companies as it is now in some overseas countries. In any case, reduction of fumes at source will lead to savings in energy requirements of the fume extraction/ventilation unit that may be required in the end.

6.8 EVALUATION OF IDENTIFIED OPTIONS

Each identified option has been evaluated according to its technical, economic and environmental feasibility, in Section 6.7 above. The checklists used for these feasibility evaluations are included in Appendix E16. A summary table of all identified options has been compiled. The table has the same structure as the summary list of potential options for metal finishing from the literature and case study review (Appendix B2). Additional options for other waste streams were included in the list but were not analysed in any detail.

Table 6.14: Summary list of improvement options for Company 2

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
I. SOURCE REDUCTION					
A. General Waste Reduction Practices					
A1. Good Housekeeping practices					
1. Maintain improved chemical tracking & record keeping	yes	Minimal	unknown		short term
2. Employee awareness and education	yes	Minimal	unknown		started
B. Improved Operations/Process Modifications					
B1 Drag-out reduction					
B1.1 Minimising drag-out					
1. Vibration mechanism on crane to speed up run-off (less drag-out in shorter dwelling time)	yes	Medium	R 27,000	<1year	long-term

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
B1.2 Direct drag-out return					
1. Jolt jig above bath after withdrawal for quicker and greater run-off of drag-out	yes	R -	R 27,000	immediate	implemented
2. Install rack over process bath to hang jig while crane moves elsewhere (must not interfere with double dipping)	no - interferes with double-dipping	NA	NA	NA	NA
3. Tilted drip tray to capture drag-out from flux bath to return to bath.	yes	R 16,500	R 15,500	1.06	short term
4. Tilted drip tray to capture drag-out from passivation baths to return to bath	not technically feasible - two baths and only one drying area	NA	NA	NA	NA
B1.3 Drag-out recovery and return					
1. Place spare tank after acid bath to capture drips to floor and recover acid for stripping bath	yes	R 750	R500 - R4000 depending on overall drag-out reduction.	0- 2 years depending on overall drag-out reduction	recommended - unless double-rinse is re-installed
2. Use degreaser rinse water instead of freshwater for evaporation replacement for degreaser bath (save water and chemicals)	no	R 1,100	costs outweigh savings	NA	NA
B2. Rinse water use reduction					
B2.1 Avoid the need to rinse					
Considered with bacteriological degreasing and flux purification.					
B2.3 Optimise Rinse tank design					
1. Locate water inlet & discharge points at opposite positions in the tank to avoid short-circuiting.	yes	R -	unknown	immediate	implemented
2. Use flow distributor to feed the rinse water evenly	yes	Minimal	low	months	Recommended
3. The incoming water may enter along the length of the rinse bath instead of on one end to increase the rinsing efficiency.	yes	Low	unknown	months	recommended
B2.4 Controlling flow rate of rinse water use					
1. Adjust incoming tap to limit the volume of rinse water flowing through by maintaining a constant flow at the optimal flowrate.	yes - with drag-out reduction	R -	depends on drag-out reduction, and on future water charges	immediate	recommended after drag-out reduction and tests

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
2. Manual control of water flow to reduce when production is low (dependent on operator adjusting flow with taps)	yes	R –	depends on production	immediate	implemented
3. Install automatic rinsewater flow control device	yes	Medium	costs outweigh savings at present	depends on future water and sewer charges	long term
4. Install flowmeters to monitor rinse flowrate and water use (raise awareness)	yes	R -	depends on findings	depends on findings	recommended
B2.5 Alternative rinsing configurations					
1. Re-install double counterflow rinse for acid rinse (can reduce rinsewater use here by up to 50%)	yes	R 22,000	R 3,400	5	long-term depending on future cost of water
2. Use the same rinse water for both the acid and degreaser rinsing with neutralisation reaction.	no - soap formation interferes with flux	NA	NA	NA	NA
3. Use a combination of spray rinsing and dip rinsing	not technically feasible - complex parts and varying production	NA	NA	NA	NA
B5. Reduce/ eliminate the need for cleanup or improve cleanup methods					
1. Use less water for floorwash by installing a trigger mechanism on the hose used	yes	low	Very low	<1year	not necessary with closed trench system
2. Close up trench system. Use dry-sweeping instead of wet washing for floor cleaning if chemical drips are eliminated/prevented	yes	R 17,000	R 25,000	0.7	implemented
3. Install anti-splash cover/hood over zinc bath	yes but considerable investment	very high	R 163,500	2 years	long term - especially if future air emission requirements
4. Place a cover over trenches where spatter may fall to prevent Zn from flowing to wastewater	yes	low	medium	<1year	unnecessary with closed-trench system
B6. Improved Process Efficiency					
1. Eliminate unnecessary NH4Cl dusting to reduce amount of fuming above galvanising bath.	yes	R -	R 13,000	immediate	implemented

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
2. Ensure optimum drying of flux (heated drying) to avoid unnecessary fuming from wet flux volatilisation and to minimise spatter.	yes	R 57,000	R 290,000	0.2	short-term
3. Improve Ash collection method to minimise Zn metal entrainment	yes	minimal	R 200,000	immediate	implemented
B7. Extending Bath Life					
B8. Corrective Bath Maintenance					
B8.1 Common corrective maintenance methods					
1. Fe removal from flux using filtration	yes	high	med	<1.5 years	supplier not available - designed settling alternative
2. Fe removal from flux using settling	yes	R 18,500	R 27,000	0.7	short-term
B8.2 Advanced corrective maintenance methods					
1. Microfiltration applied to the degreasing bath for the removal of emulsified oil and grease. Also applicable to the recovery of degreasing solution drag-out from rinse water.	new degreasing chemical has extended bath life - not economically feasible at present	NA	NA	NA	NA
2. Fe recovery from flux bath using commercially available electrolytic flux recovery system.	not technically feasible for Company 2 - too bulky	NA	NA	NA	NA
C. Substitute Techniques/ Technologies					
C2. Cleaning matrerial/chemical substitution					
1. Alternative (emulsifying) degreasing chemical which allows for elimination of surface skimming	yes	R2.60 less per kg chemical + eliminated associated oil skimming costs	R10,000-R20,000/yr for chemical. Plus future savings from elimination of oil waste	immediate	implemented
2. Use acidic degreasing which may allow for elimination of rinse before pickling.	yes, but does not suit the company at present.	more expensive than existing chemical, waste acid/sludge disposal may be an expense.	savings associated with rinse elimination depend on future water charges	depends on future water charges	should be investigated in long-term
3. Bacteriological degreasingto replace aqueous degreaser	no - technology not available locally	high	high	NA	NA

Waste Minimisation Option	Feasibility	Investment costs	Annual Savings	Payback Period (yrs)	Recommended implementation
C3. Process material/chemical substitution					
1. Chrome-free alternatives to Passivation Chemical – may use phosphate-based chemical, or possibility of using silanes in the near future when commercially available.	not as effective as chromate - silanes maybe in future				could be investigated in the long term
2. Use light pickle instead of freshwater for acid rinse only if use flux purification	no - requires advanced flux purification	NA	NA	NA	NA
3. Activated pickling (low Acid, high Fe salts pickle) only in conjunction with flux purification	no - unknown technology locally	NA	NA	NA	NA
II. RECYCLING AND RESOURCE RECOVERY					
D. On-site Recovery and Recycling					
D1. Waste segregation					
1. Segregate sludges from spent acid	not economically feasible	high	negative	NA	Should be considered if required
D3. Wastewater recycling and chemical/metal recovery					
1. Collect and treat wastewater prior to discharge to sewer	not economically feasible at present	high	low		consider if increased water and sewer charges
2. Collect, treat and reuse treated wastewater	not economically feasible at present	very high	low		consider if increased water and sewer charges
3. Recover Zn on used wire through melting on-site.	not economically feasible at present	high	low		
E. Off-site Recycling and reuse					
E1. Off-site Recycling					
1. Recovery of Zn from spent wire off-site.	not economically feasible at present	high	low		
E2. Off-site reuse of waste material					
1. Use waste from one process as raw material for another process (e.g. FeCl2 from flux sludge?).	unknown				Possible future investigation

Each of these options has been rated based on the findings from the feasibility evaluation. The option rating system is as for Company 1 outlined in Appendix E23. The aim of this activity was to compare all options in order to obtain a list of recommended waste minimisation options for presentation to the company's management. Those options that have already been implemented were included in the evaluation rating process in order to show where the options would have been in

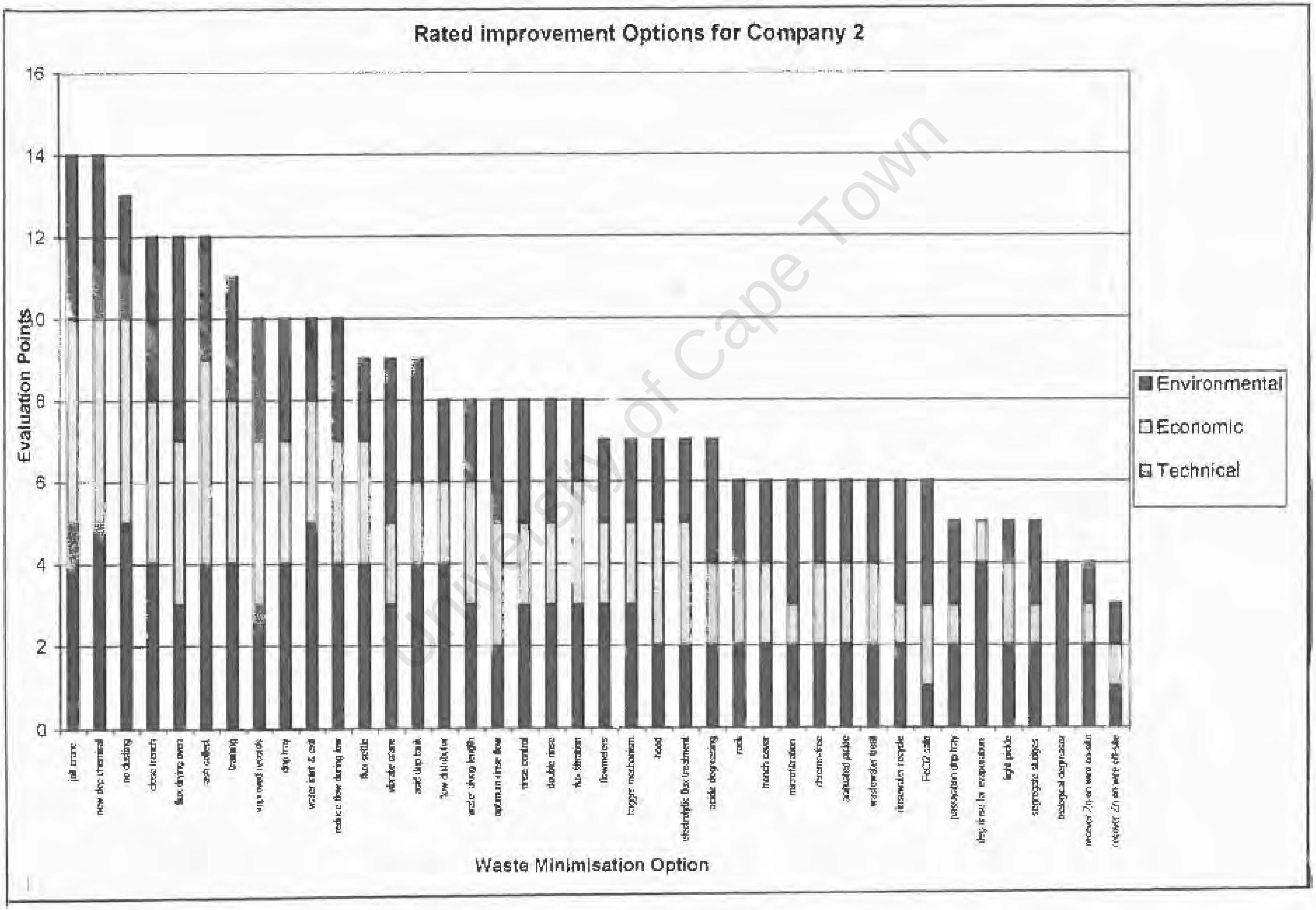


Figure 6.14 – Summary of rated options for Company 2

6.9 RECOMMENDED OPTIONS

Of the 1st eleven options with the highest rating, 7 have already been implemented. The implementation of drag-out reduction reduces the need for some of the additional options, while improving the feasibility of others. Additional recommended options are:

6.9.1 Good housekeeping

The option of 'improved record-keeping' rates in the top 10 and is recommended. During the assessment it was difficult to obtain and analyse available data. This data has now been transferred from separate files into electronic form on spreadsheets. This allows for simple analysis of the data and can be continued as new data is filed. Using the spreadsheet already set up the log data can be entered into the computer directly from the log sheet each week. The operations manager can then use this in his own time to analyse bath chemistry, etc. For example, once a month analysis can be performed to observe changes. If flowmeters are installed on the water lines, this method can be used to monitor water use.

6.9.2 In-house technical modifications

Although the installation of the spare rinse tank to capture acid drips has a higher rating than the re-installation of the double rinse, the implemented drag-out reduction means that the drip-tank is almost unnecessary and the reduced rinse flowrate associated with the double-rinse becomes more technically feasible. The need to improve rinsing efficiency, and the likelihood of possible future water-price increase are additional reasons for installing this option. It is therefore recommended for the company to reinstall the double rinse at reduced flowrate once tests have been performed on the actual effect of the reduced drag-out.

Installation of flow distribution and restriction devices for the incoming rinsewater are also recommended. Flowmeters for raising awareness regarding water usage will also help in determining the optimum rinse flowrate after drag-out reduction.

6.9.3 Hardware options

Two options are to be implemented in the short term:

- The heated flux-drying option is to be combined with the drip tray and installed within the year.
- The new flux heating tank to maintain 'clean' flux through sludge removal is to be installed when the tank is replaced within the year.

These will result in improvements in a number of waste streams. For these, the total investment is R76,000 and estimated savings may be as high as R500,000/yr.

It is recommended that the company continuously review the options over time as conditions change. The savings from the options that are implemented might allow for increased availability of finances and hence the possibility to implement more expensive options that are not economically feasible at present.

In addition to these options, the company has recently received a copy of the 1999 edition of 'General Galvanizing Practice' from the UK Galvanizers Association which has a significant amount of information on environmental improvements and waste minimisation options for galvanizers. The Operations manager has already shown interest in further options identified in the handbook.

6.10 CONCLUSION

All phases of the waste minimisation assessment have been carried out at Company 2. A total of 42 waste minimisation options were identified for the company of which 24 were found to be feasible. Of the unfeasible options, 5 of these were not technically feasible for site-specific reasons, 2 were Cleaner Technology options (biological degreasing and activated pickling) identified as potential in other countries, but the technology was found to be not available locally. One was likely to interfere with production, and the remainder were found not economically feasible due to costs outweighing savings. The potential for these options depend on the future availability of finances or technology, and future changes in environmental regulations, in particular future increases in water and sewer charges.

Of the feasible options, 8 ($1/3^{rd}$) have already been implemented with no or negligible investment costs. These options involve improved house-keeping and simple procedural changes and have resulted in significant reduction in wastes from the company. Estimated economic savings which could be calculated for some of these options are as follows:

Table 6.15: Estimated Economic Savings from Implemented Options

Option	Estimated annual saving
Drag-out reduction through crane jolting	R27,000
Close-up trench system and eliminate floorwashing	R25,000
Minimise ammonium chloride 'dusting'	R13,000
Improved ash collection method	R250,000
New degreaser chemical	R10,000
TOTAL	**R325,000/annum**

The major saving is as a result of reduction in zinc losses. These options are all highly cost-effective. Not only do they serve as 'interest-grabbers' for further waste minimisation in the company, but the associated savings improve the ability of the company to invest in more expensive waste minimisation options. All of the implemented options result in an overall improvement in the environmental effect of the resulting waste. A considerable environmental improvement is the elimination of the illegal and hazardous French drain wastes. The drag-out reduction option has benefits for all of the focus areas.

It is therefore clear that potential for cost-effective waste minimisation has been identified. The interest shown by the Operations Manager through his continual search for options and willingness to implement changes, served as a major driver to identifying waste minimisation potential. External assistance from the electricity supplier, the HDGASA, as well as international associations facilitated the assessment and identification of potential options. Many of the potential options were identified from international experience (e.g. drag-out reduction, flux purification), however, the concrete solutions are mostly innovative applications and adaptions of these ideas by the company to suit their technical and financial capacity.

Chapter 7: Concluding Discussion

"In the final analysis, what is critical in our efforts to advance pollution prevention is a willingness to take chances, to question established practices, and experiment with new ideas, and above all to co-operate with each other as we try to harmonise environmental protection with economic growth"
– U.S. EPA, 1996.

7.1 INTRODUCTION

The aim of this dissertation has been to assess the potential for SMEs in the South African metal finishing industry to reduce in a cost-effective manner, the waste that is generated or subsequently treated, stored or disposed of, in either total amount, hazardous nature, or both. In this final chapter, the findings from the literature review, research and case study results are discussed with the aim of testing the hypothesis against the success criteria. The conclusions drawn from the work are set out and the objectives and key questions are addressed, at least implicitly.

7.2 METAL FINISHING WASTE MANAGEMENT

7.2.1 International and local approaches to waste management

In Chapter 3, the trends in approach to waste management by the metal finishing industry in other countries was examined and it was found that over the past thirty years, the countries have responded to pollution and environmental degradation in four characteristic ways. First, by ignoring the problem, secondly, by diluting or dispersing the pollution so that its effects are less apparent; thirdly, by trying to control the pollution and the wastes through what is known as "end-of-pipe" or pollution control approach; and fourthly, and most recently, by cleaner production through prevention of pollution and waste generation at the source of production.

In Chapter 4, the current situation of waste management in South Africa was examined. It was found that outdated equipment, poor maintenance, poor worker skill and poor housekeeping practices lead to increased water and energy consumption and the generation of unnecessary waste. The most common areas of wastage were found to be excessive water consumption and loss of chemicals due to drag-out and spillage. The cost of water is low, providing no financial incentive to reduce water use in the industry. In addition, few metal finishing firms in South Africa actively practice effective on-site effluent management, and where it exists, it is usually not well organised, operated or maintained in relation to compliance with existing by-law quality standards, or disposal of waste sludges generated in the process. In addition, because enforcement of legislation is ineffective, many companies find it very easy to throw restricted effluents down the drains without being caught. General awareness of waste minimisation is practically non-existent within the industry. Outside of academic research projects, any specific attempts at waste minimisation within the industry have not been reported.

The industry is therefore considered to be in the dilution and control stage of waste management identified in the review of international trends. However, lack of enforcement of legislation has meant that effective pollution control is limited and is generally only implemented in the larger finishing shops.

7.2.2 Approach to waste management in the case-study companies

The wastes and emissions from Company 1 and Company 2 may be considered typical of wastes associated with powder coating and hot dip galvanising operations respectively, with some additional environmental effects related to the lack of required conventional treatment practices. In both Company 1 and Company 2 a significant amount of water is used for the rinsing stages during pre-treatment. Water costs are particularly low for Company 2 due to ineffective measurement by the regulatory authority. Loss of chemicals due to drag-out and spillage result in high volumes of dirty wastewater.

This wastewater is not treated but flows directly to sewer, and there is a reliance on dilution of contaminants and neutralisation of acid/alkali wastewaters in the sewer system to achieve compliance at both companies. Company 1 employs conventional pre-treatment only for the spent chromate bath and relies on a waste-hauler for removal of the hazardous sludge. Some wastes disposal is not in compliance with regulations, but this is undetected due to ineffective enforcement by the regulatory authorities. Therefore, for both case-study companies, the waste management style can be considered representative of the typical waste management style identified for the South African metal finishing industry.

7.3 METAL FINISHING INDUSTRY STRUCTURE AND KEY CHARACTERISTICS

7.3.1 A comparison of the industry in South Africa with other countries

In Chapter 3, the metal finishing industries in countries where waste minimisation has been applied, were examined with regard to structure and key characteristics. In Chapter 4, the structure and characteristics of the South African metal finishing industry were investigated and presented according to the same format as for other countries.

Only job-shop metal finishers are included in the statistical information that is generally available for the metal finishing sector in each case. Captive metal finishing operations are difficult to assess, owing to the wide range of products and hence industry sectors to which such shops belong. It is difficult to determine the true size of the industry and therefore values for total number of shops in each country are estimates based on the knowledge of key stakeholders in the industry. Additional statistical data for each country (Table 3.1 and Tables 4.1 to 4.4) was incomplete, and it was not possible to make conclusive comparisons. However, a number of similar trends were identified.

7.3.1.a Similar Processes

The results indicate that the most common processes are similar in each country where waste minimisation has been applied, and South Africa is no exception. Painting and powder coating combined, appear to make up the largest sector in terms of total number of firms in each case. Electroplating makes up the next largest group, and is probably the largest group if painting and powder coating are separated. Other significant sectors are anodisers and galvanizers, though they are much smaller in number (<10%). The most common electroplating types in South Africa (zinc, nickel, copper and chrome) were also found to be the most common in those countries where waste minimisation has been implemented.

In Chapter 2, a discussion of the nature of metal finishing processes lead to the conclusion that the technology used in the core metal finishing processes tends to be the same from country to country. It therefore appears that there are no major differences on a technical level that would indicate a limit to the potential for waste minimisation in the South African metal finishing industry. The technology in use at the case-study companies is in line with the general descriptions found in international literature.

7.3.1.b Key Characteristics

Key industry and firm characteristics and trends that may influence a company's decision-making process with regard to environmental activities were identified in Chapter 3. These are factors that are likely to affect both environmental and economic performance, and therefore the potential for adoption of waste minimisation. These aspects were therefore examined for South Africa in Chapter 4 for comparison with the countries where waste minimisation has been applied.

What can be concluded is that there are significant similarities between the metal finishing industry in South Africa and these countries in terms of structure & key characteristics. In each case:

- Over 90% of the metal finishing shops are SMEs, and the vast majority has less than 50 employees.
- Job shops tend to be small and generally have fewer resources available to address environmental concerns.
- Captive metal finishing operations are difficult to assess, owing to the wide range of industry sectors to which such shops belong.
- There is a general lack of technical knowledge amongst metal finishers which leads to reliance on external parties for technical advice and know-how, particularly on chemical and equipment suppliers, but also on industry associations (although such association support is offered to a much lesser extent in South Africa).
- The primary competitive factor is price, though quality is a consideration for some product markets, especially in the U.S.A.

7.3.2 Structure and characteristics of the case-study companies

Both Company 1 and Company 2 are SMEs with <50 employees, and both are independent job-shops located in heavy industrialised regions. The financial and constraints are typical of job-shop metal finishers, but Company 2 being larger than Company 1, is not as constrained by financial ability and management time. There is limited technical expertise readily available within both companies. Company 1, is highly dependent on its chemical, paint and equipment suppliers. Company 2 is dependent on its chemical supplier for operating specifications, but for unusual problems or circumstances are highly dependent on outside expertise, either from published information, or the Hot Dip Galvanizers Association (HDGASA).

The processes employed at both case-study companies do not utilise state-of-the-art technologies, but rather simple technologies that are considered typical of the processes employed (according to general practice manuals). The pre-treatment steps in both companies use processes such as degreasing, pickling, etching, and rinsing, which are common to many metal finishing processes. The post-treatment passivation and the problems associated with the use of chromium are also common to other metal finishing processes. Company 1 is a powder coating factory, and powder coating forms a significant section of the South African metal finishing industry in terms of number of facilities. Company 2 is a general hot dip galvanizing factory which also forms one of the more significant sections in the metal finishing industry.

The case-study companies can therefore be considered representative of a significant section of the South Africa metal finishing industry in terms of structure, key characteristics and processes used.

7.4 BARRIERS AND INCENTIVES AFFECTING WASTE MINIMISATION POTENTIAL

7.4.1 Comparison between South Africa and other countries

The following main barriers to adoption of waste minimisation for SMEs in metal finishing industry were identified in the international literature:

- Lack of technical skills
- Lack of capital and financial resources of company
- Lack of management time
- Lack of awareness, information and know-how of waste minimisation options
- Lack of clear environmental legislation

(Small companies are usually more constrained than larger companies in each case)
It was found that these barriers also exist for SMEs in the South African metal finishing industry with the additional barriers of:

- Ineffective enforcement of environmental legislation
- Low cost of water, electricity, and waste treatment (effluent charges)

Of the drivers identified in the literature for other countries, and for the South African metal finishing industry, the most common identified for SMEs are:

- Stringent environmental legislation and/or enforcement of legislation
- External assistance (both technical and financial)
- Cost savings associated with waste minimisation

It can be concluded that there are significant similarities between the metal finishing industry in South Africa and other countries in terms of initial barriers against environmental improvement in SMEs.

7.4.2 Barriers and drivers for the case study companies

Financial considerations are the primary constraints acting upon Company 1. Company 2 is more able to invest time and money in support of its business objectives, but is resistant to change with associated risks. The second constraint is the limited internal technical expertise. The owner/manager of Company 1 is also unable to find the time to consider business aspects other than those directly related to production. While the General Manager's time is limited at Company 2, the Operations Manager is able to concern himself with other issues around production. The lack of effective enforcement of environmental legislation allows the company to discharge restricted effluents down the drains. In addition, before joining the project environmental issues were given little recognition, and the company was not aware of the concept of waste minimisation.

These barriers to improved environmental performance in Company 1 and Company 2 are as identified for the typical South African small-sized and medium-sized metal finishers, respectively. The concern for future more stringent environmental legislation, as well as potential cost savings, were the main drivers for waste minimisation in both companies. These were main drivers identified for the typical metal finishing SME.

7.5 ROLES OF KEY PLAYERS

It can be concluded, based on international experience, that there is potential for these barriers to be overcome with the help of key players in the industry. The experiences from other countries indicate what roles key stakeholders in South Africa can play in order to exploit the potential for waste minimisation cost-effectively.

7.5.1 Lessons for South Africa from international experience

7.5.1.a Legislation

In South Africa, waste minimisation is being introduced by NGO's, research institutions, universities, and consulting engineering on a voluntary basis, while in the USA and Europe, the governments, local authorities and environmental agencies make waste minimisation mandatory and there is legislation to support these approaches. The single biggest influence in adoption of cleaner production in the metal finishing industries in each of the countries investigated appears to be legislation and strong enforcement of the legislation. The scope and stringency of environmental regulations applicable to the metal plating industry have increased substantially over the years, and the industry is now one of the most highly regulated industries in each country. Even though there is now a move towards self-regulation by industry in other countries, it appears that strict enforcement at first is a necessary step in the learning curve for the industry.

The NWMS for South Africa intends to address the existing regulatory problems and includes waste minimisation as a focus area. In addition, increases in water and effluent charges as well as waste disposal costs are expected in the near future. It is therefore likely that regulatory drivers that have influenced waste minimisation potential in the metal finishing industry in other countries, will exist in South Africa in the near future (though to a lesser extent). The NWMS should help to facilitate enforcement of legislation. There is however likely to be a continued absence of consistent enforcement and a greater level of self-regulatory legislation.

7.5.1.b External assistance and raising awareness

As the majority of metal finishers are SMEs, they tend to have limited resources to research waste minimisation opportunities, and in other countries have needed external assistance. There, governments have provided funding in the form of subsidies for waste minimisation projects and implementation of technology within industry, which have facilitated the adoption of waste minimisation particularly in SMEs. In South Africa, such funding is not provided by Government, but there are plans for subsidies from International donor organisations to promote waste minimisation in the metal finishing industry initially and this is expected to help to contribute strongly to the development of waste minimisation programs and technology transfer in the industry.

Industry associations, suppliers and consultants in other countries have played an active role in improving the potential for adoption by providing technical advice and information, assessing new technologies and working with government in ensuring that legislation matches the capacity of the industry. Due to low awareness of waste minimisation in the industry in South Africa, there is very little demand for Cleaner Technologies at present, and therefore no incentive for international suppliers to access the market here. This is likely to change in the future as demand increases with raised awareness and changing environmental legislation, improving the availability of Cleaner Technology, and hence the cost-effectiveness of waste minimisation potential.

International experience has shown that good examples of waste minimisation working in the industry, thanks to demonstration projects and the marketing of the success stories, have a significant influence for metal finishers to adopt cleaner production. This is necessary for the South African industry to build up local examples of its own. Donor organisations, along with local research institutions and universities are also initiating demonstration projects within the metal finishing industry. Marketing of good examples will be highly important for raising awareness within the industry.

Raising awareness and spreading knowledge on waste minimisation techniques has been achieved in other countries through demonstration projects, guide books, fact sheets, industry associations, consultants, and the Internet. Based on international experience, it is shown that SMEs in the industry are capable of conceiving and implementing waste minimisation projects if the methodology is delivered to them properly. The key lesson for assistance providers is to recognise the barriers and to implement waste minimisation accordingly in the appropriate manner.

Regulatory pressure and certain legislation have already driven some metal finishing companies in Durban to consider waste minimisation. The tough legislation in the Durban area coupled with external assistance from academic research with funding from local and international donor organisations has lead to cost-effective waste minimisation potential identified through the Waste minimisation Club attempt in the area.

7.5.2 Case study companies

7.5.2.a Influencing factors

Without the external assistance from this project, the company managers have admitted that waste minimisation would not have been considered. Apart from lack of awareness, the time and costs for undertaking the waste minimisation assessment would have been prohibitive for the companies on their own. The cost of undertaking the waste minimisation assessment at these companies was 'free' for the company by the use of a (donor funded) student carrying out the waste minimisation assessments. The cost of employing a consultant to do the job instead (and there are very few with waste minimisation experience in South Africa at present) is most likely to have been prohibitive.

For most of the potential options, the broader category was identified from international guidebooks. The companies were not aware of even simple to implement housekeeping improvement options, in particular spill and drag-out reduction. This highlights the fact that awareness of available options is beneficial in identifying potential for waste minimisation. In Company 1, the identification of specific technical waste minimisation options within the broader category of improving control and efficiency, were offered by the equipment supplier. This highlights the reliance of the company on its suppliers for technical know-how, and the ability of the supplier (external assistance) to improve the potential for waste minimisation.

The substitution of the degreasing chemical at Company 2 came about through consultation with the HDGASA as well as a chemical supplier (external assistance), and implementation was based on knowledge of successful use in another company in South Africa (demonstration). Eliminating flux dusting, and the improved ash collection method have been used in other countries, and were identified with the aid of local and international industry associations (external assistance). Free technical consulting advice from the electricity supplier (external assistance), improved the technical and economic feasibility of a technology option for Company 2.

The interest shown by the Operations Manager at Company 2 through his continual search for options and willingness to implement changes, served as a major driver to identifying waste minimisation potential. The owner/manager at Company 1 was more constrained by production concerns and could not afford as much time and effort to help with the search for options.

7.5.2.b Delivering the methodology

The pre-assessment served to raise awareness of the 'true cost' of the waste generated. Simple experiments that did not require much technical ability and could therefore be carried out by company staff were carried out during this stage. In Company 2 for example, reduction in flux dusting was implemented when the company manager realised that the 'true cost' of the waste included corrosion of expensive overhead cranes. The interest and active participation by the operations manager lead to increased potential for waste minimisation. The involvement of the entire workforce in the company brainstorm session helped raise awareness with regard to waste minimisation and served as impetus for implementing improved housekeeping option.

7.6 ADOPTION OF WASTE MINIMISATION

7.6.1 Success in other countries

In chapter 3, it was concluded that there has been significant potential for waste minimisation in the metal finishing industry in other countries and it has already been exploited cost-effectively. It was found that many metal finishing shops have implemented one or a combination of waste minimisation techniques in order to meet regulations or reduce treatment and disposal costs. Environmental legislation has forced metal finishers to increase investments in waste management, and this has lead to increased potential for cost-savings with waste minimisation. This coupled with non-regulatory aspects of environmental policies that have been developed to assist industry in identifying and implementing waste minimisation options (funded participation in demonstration projects, or the provision of subsidies for technology options, etc.) has improved the potential for SMEs to implement waste minimisation cost-effectively.

Since >90% of the metal finishing shops are SMEs, and the potential for waste minimisation is widespread in other countries, it can be concluded that there is potential for waste minimisation in SMEs in the metal finishing industry.

7.6.2 Local success

As discussed in chapter 4, the tough legislation (by-laws) in the Durban area coupled with external assistance have lead to cost-effective waste minimisation potential identified through the Waste minimisation Club attempt. Cost-effective waste minimisation potential has also been identified in 2 local representative electroplating companies with the help of external assistance through participation in larger research projects.

7.6.3 Success in the case-study companies

The assessments carried out at both case-study companies have identified potential for cost-effective waste minimisation. The identified options are expected to reduce the waste that is generated or subsequently treated, stored or disposed of, in either total amount or total environmental harmfulness, or both. Most of the potential waste minimisation options were identified based on their potential in the metal finishing industry in other countries, but the concrete ideas were essentially the companies' own with external technical assistance provided by suppliers or industry associations. As found in other countries, simple housekeeping, drag-out reduction, and process efficiency improvement options were found to have the highest potential, and to be cost effective. In both companies, the implementation of drag-out reduction stemmed from international experience, but the proposed methods were innovative company ideas in each case.

Drag-out reduction is expected to improve rinsing efficiency with possible associated reduction in water consumption. The low cost of water, however, leads to limited potential for other cost-effective options for rinsewater-use reduction. If Company 2 were charged for actual water usage, especially with expected future increases in water costs, this would improve the cost-effectiveness of additional investment in tanks to incorporate more efficient counter-flow rinse systems. For Company 1, potential options requiring significant investment (chrome-free with demineralised water and drying tank) are not cost-effective if the operating costs are simply weighed against the tangible savings at present. However, if the company were made to treat its effluents and carry the costs (internalise the waste treatment costs), then the technology investments would look a lot more attractive. Since very few companies in the South African metal finishing industry are believed to practice effluent treatment and other control practices, this is likely to be a characteristic factor for the South African metal finishing industry in general.

At Company 2, investment in commercially available technologies (e.g. flux drying oven and flux purification technology) was found to be not economically feasible. However, through active interest by the Operations manager and external assistance from the electricity supplier, the company came up with innovative alternative designs applying readily available low-cost equipment that the company could install itself, thereby making the options cost-effective. It appears therefore that in cases where technology may not be economically feasible, innovative ideas for the application of options can result in the option being cost-effective in the specific company.

7.7 CONCLUSION

The exploitation of the significant potential for waste minimisation in countries such as the U.S.A., Denmark, the Netherlands and the U.K, has been influenced by a number of factors, but the increasingly stringent environmental regulations accompanying national waste minimisation policies appear to have had the greatest influence. The South African metal finishing industry was found to be similar to the metal finishing industry in these other countries in terms of size, structure, and processes employed. But, the waste management style typical of the industry in South Africa is significantly behind that of other countries, mainly due to the lack of effective enforcement of environmental legislation.

Despite this, some of the waste minimisation options applied in other countries to address well-known problems in this industrial sector, have been applied in the case study companies. Most of these are in the areas of improved operations/process modifications which lead to process efficiency improvements. This potential results in reduction of waste volumes, hazardous nature, or both, as well as attractive savings for the owners. The main factor contributing to the exploitation of the existing potential in these companies was the external assistance in carrying out and financing the waste minimisation assessment.

The economic feasibility of options requiring substantial capital investment is company-specific and depends significantly on which costs are currently not internalised at the company. More stringent regulations, and higher water prices in the near future are expected to increase the internalised costs and improve the cost-effectiveness of such options. Without this key component, the potential for cost-effective options could be limited to low-cost or non-technology options. However, experiences in the case-study companies indicate that there is much room for innovative solutions that allow for cost-effective exploitation of technology options within SMEs, especially where there is interest within the company supported by external assistance from key players in the industry.

In conclusion therefore, it has been shown that there is potential for cost-effective waste minimisation, not only in the two case studies in the powder coating and hot-dip galvanising sub-sectors, but also in the electroplating sub-sector. These companies were also found to be representative of the South African metal finishing industry in terms of size, processes employed, key characteristics, waste management style, and barriers and incentives to environmental improvement.

From the above discussion it is clear that strong evidence in support of the hypothesis has been gathered and it is therefore concluded that there is potential for cost-effective waste minimisation in SMEs in the South African metal finishing industry. However, it must be noted that the cost-effective exploitation of this significant potential requires a clear understanding of the barriers and incentives for waste minimisation, and of the influencing roles that each of a number of key players in the industry have to make in this regard.

"The potential is there in any country as long as there is a change in attitude, because waste minimisation requires a complete attitudinal overhaul on the part of the industry, the government and the citizens"
- Lewin Mombemuriwo, Cleaner Production Centre of Zimbabwe, 1999

References

Akzo Nobel (1999),
Complete Guide to Powder Coatings, Interpon Powder Coatings, Akzo Nobel, Issue 1, November 1999.

Altmeyer, F. (1993a)
'Comparing Substitutes for Cr and Cu to Prevent Pollution', *Plating & Surface Finishing*, pp 40-43, February 1993.

Altmeyer, F. (1993b)
'Comparing Substitutes for Cr and Cu to Prevent Pollution – Part II', *Plating & Surface Finishing*, pp 32-37, March 1993.

ANZECC, 1998
Towards Sustainability: Achieving Cleaner Production in Australia, Australia and New Zealand Environment and Conservation Council, 16th Meeting, Hobart, Tasmania, December 1998.

Barclay, S.J., C.A. Buckley, N. Thambiran (1999)
Waste Minimisation Club for Metal Finishers - A First for South African Industry, Pollution Research Group, University of Natal, Presented at 2nd Asia-Pacific Cleaner Production Roundtable, Brisbane Australia, April 1999

Barnett, W (1998)
Personal Communication, correspondence by fax with Walter Barnett, Chairman of Hot Dip Galvavanizers Association South Africa, October 1998

Barnett, W. (1999a)
Personal Communication, Meeting held with Walter Barnett, Chairman of the Hot Dip Galvanisers Association South Africa, Cape Town International Airport, 5 August 1999

Barnett, W. (1999b)
Personal Communication, correspondence by fax with Walter Barnett, Chairman of Hot Dip Galvavanizers Association South Africa, 19 September, 2 November & 22 November 1999.

BECO (1999)
BECO Milieumanagement & Advies, company profile and product information brochure, Rotterdam, the Netherlands, 1999

Bibber, J. (1998)
Fax Communication, fax mail received from the R&D manager (John Bibber) for a US Chemical Supply Company (SANCHEM), regarding potential for supplying a chrome-free product in South Africa, 7 July 1998.

Bishop, C.V. and G. Loar (1993)
'Practical Pollution Abatement Methods for Metal Finishing', *Plating and Surface Finishing*, pp37-39, February 1993.

Bresnan, J.F. (1994)
'An Analysis of Private, Public, and Non-profit Industrial Pollution Prevention Initiatives', *The Environmental Professional*, volume 16 pp57-65, 1994.

Bruijn, T.D. , F. Coenen and K.Lulofs (1996)
'Pollution Prevention in Projects in the Netherlands', *Journal of Cleaner Production*, volume 4., No.1 pp41-53, 1996, as cited in Bruijn and Hofman, 2000.

Bruijn, T.D., P. Groenewegen and J. Grolin (1997)
'Global restructuring, A Place for Ecology', *Business Strategy and the Environment*, volume 6, 173-184, 1997, as cited in Bruijn & Hofman, 2000..

Bruijn T.D., and P. Hofman (2000)
'Pollution prevention and Industrial Transformation – Evoking Structural Changes within Companies', in *Journal of Cleaner Production*, volume 8/3, 2000, pp215-223.

Brummer, H. (1990)
'Chromating', *Products Finishing 1990 Directory*, pp200-207, October 1989.

CAMEX (1995)
Biological Degreasing for Hot Dip Galvanising Applications, New technology brochure from CAMEX.

CAMF (1995)
Metal Finishing Pollution Prevention Guide, Canadian Association of Metal Finishers, Ontario, Canada: Great Lakes Pollution Prevention Initiative, 1995.

Carnie, T. (1996)
'We're in the Muck Says Asmal', *The Mercury*, 18-9-1996, cited in (WRC, 1997).

CDTSC (1993)
Hazardous Waste Minimisation Checklist and Assessment Manual for the Metal Finishing Industry, California Department of Toxic Substance Control, Office of Pollution Prevention and Technical Development, Technical Clearing House Unit, 3rd Edition, October 1993.

Child, T. (1999)
Personal Communication, e-mail correspondence regarding Protecting Aluminium with Silane Treatments, February 1999.

CMC (1999)
Monitoring of Industrial Water and Effluent Discharge in the Cape Metropolitan Area, Summary from meeting held between Industrial Symbiosis Project Members from University of Cape Town, and representatives from the Cape Metropolitan Council, April 1999

Coleman, A. (1994)
An Assessment of the Potential for Waste Minimisation in small and medium sized enterprises in South Africa, MSc Eng Thesis, University of Cape Town, January 1994

Coni, N.N. (1994)
'Waste Minimisation in Dulux – A Case Study', from the *Proceedings of the Southern African Regional Conference on Cleaner Production*, Johannesburg, May 1998

Cook, M. and W. Smith (1999)
Personal Communication, meeting with the Technical Committeee of the Galvanizers Association, U.K., including chairman Murray Cook and secretary William Smith, Birmingham, U.K., 6 July 1999

Cowan, J.A.C. (1998)
The Development of Management Strategies and Recovery Systems for Heavy Metal Wastes, Report to the Water Research Commission on behalf of Steffen, Robertson and Kirsten, WRC Report No. 589/1/9, Johannesburg, 1998

CPA (1998)
Cleaner Production Checklists: Metal Finishing Industries, Cleaner Production Australia, The UNEP Centre for Cleaner Production and the CRC for Waste Minimisation and Pollution Control, Ltd., May 1998.

Cushnie, G.C. (1994).
Pollution Prevention and Control Technologies for Plating Operations, National Association of Metal Finishers, National Center for Manufacturing Sciences, Ann Arbor, Michigan, 1994

Daily News (1998)
'Urgent Need for Toxic Waste Site', *Daily News*, Durban, 28-7-1998

DANCED (1999)
Draft Project Document Cleaner Production in Metal Finishing Industry South Africa, Danish Ministry of Environment and Energy/DANCED, Ref No. M/123/138-0117, 1999.

Danish EPA (1997)
Evaluation of the Cleaner Technology Programme 1987-1992, Results, Diffusion and Future Activities, Danish Environmental Protection Agency, Environmental Review, No. 14, 1997, translated by D.L. Barry.

DCOC (1999)
Guidelines for the Management of Metal Finishing Effluent Developed by the Durban Chamber of Commerce Bylaws Working Group, Final Draft Document, Durban, May 1999

DEAT & DWAF (1998)
Draft National Waste Management Strategy Discussion Document for Hazardous and Related Wastes, Department of Environmental Affairs and Tourism and the Department of Water Affairs and Forestry, South Africa, 1998 cited in Barclay et al (1999)

De Hoo, S., & H. Dieleman (1992)
'Choosing prevention is winning: the organisation and results of the Dutch pollution prevention project PRISMA', *Industry and Environment*, June 1992

Dhliwayo (1998)
Waste Minimisation Assessment for a Metal Finishing Plant, Vacation Training Report, Chemical Engineering Department, University of Cape Town, February 1998

Dittke, S. (2000)
The Rising Cost of Waste, presented at a Waste Minimization Workshop for the Metal Finishing Industry, sponsored by Danced, organised by the University of Cape Town, Department of Chemical Engineering, Industrial Symbiosis Group, 13 March 2000.

DNRP (date unknown)
Pollution Prevention and Best Management Practices for Metal Finishing Facilities, Department of Natural Resource Protection, Pollution Prevention and Remediation Programs Division, Fort Lauderdale, Florida, USA, date unknown.

DTI (1998)
Financial Access for SMME's: Towards a Comprehensive Strategy, Draft Discussion Document, Pretoria, 1998.

DTU (1991)
The Institute for Product Development, IPU, English brochure, Danish Technical University, Copenhagen, Denmark, 1991

Du Mortier, J.W. (1999)
Personal communication, meeting with Hans du Mortier, Chairman of the Vereeniging voor Oppervlaktetechnieken van Materialen, Zoetermeer, the Netherlands, 8 July 1999 (meeting documented in Jansch, 1999).

DWAF (1998)
Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste, Department of Water Affairs and Forestry, South Africa, Second Edition, 1998.

EMG (1993)
Clean Production – A Preliminary Assessment of the Need and Potential for the Introduction of Clean Technology in Some Industrial Sectors in South Africa, Environmental Monitoring Group, 1993.

EMG (1998)
'Cleaner Production in South Africa', *Waste Talk*, Volume 2, Cape Town, October 1998.

ENVIROS (1999)
ENVIROS: Knowlege, Innovation, Solutions, Company Brochure, Manchester, 1999.

Ferro (1994)
Taking the Mystery Out of Powder Coating, Vedoc Powder Coating Division, Information Brochure from Ferro Industrial Products (Pty) Ltd, Brakpan, South Africa, 1994.

FME-CWM (1990)
Association FME-CWM Representing the metal and electrical engineering industries and allied sectors, English brochure, Association FME-CWM, the Netherlands, May 1999.

Freeman, H. (1990)
Hazardous Waste Minimisation, McGraw-Hill Publishing Company, USA, 1990.

Freeman, H. (1995)
'Pollution Prevention: The U.S. Experience', *Environmental Progress*, volume 14, No 41, November 1995.

Fuggle, R.F. and M.A. Rabie (1994)
Environmental Management in South Africa, Juta & Co Ltd., Wetton, South Africa, 1994.

GA (1981)
General Galvanising Practice, published by the Galvanisers Association UK, London 1981.

GA (1999)
GalvAction 21 Environmental Management, Benefits Awareness For the 21st Century, Project information brochure, Galvanizers Association U.K., June 1999.

Gallerani, P. and D. Brake (1993)
'Wastewater management For the Metal Finishing Industry in the 21st Century', *Plating and Surface Finishing*, pp 28 – 35, October 1993

Gillfillan (1997),
Water and Effluent Management in the South African Textile Industry, MScEng Thesis, University of Cape Town, *June 1997.*

Gombault, M. & Versteege, S. (1999)
'Cleaner Production in SMEs through a partnership with (local) authorities: successes from the Netherlands', *Journal of Cleaner Production*, July 1999

Gregersen, J. (1999)
Personal Communication, meeting with Johan Geregersen of the Danish Technical Universty's Institute for Product/Process Development, Lynby, Denmark, 15 July, 1999 (meeting documented in Janisch, 1999)

Groundwork (1995)
Small Firms and the Environment: A Groundwork Status Report, Groundwork Action for the Environment in association with Imperial College, Birmingham UK, November 1995.

Handberg, S., P. Christensen & S. Georg (1993)
'The Danish Experience of Cleaner Technology. Co-optimising environmental protection and working conditions', *Perspectives on the Environment*, Interdisciplinary Research Network on Environment and Society, Avebury, USA, 1993.

Hanson, M. (1995)
'Metal Finishing and The Environment – Is the Surface Finishing Industry Really "Bad" or Just Misunderstood & Maligned?', *Plating and Surface Finishing*, August 1995

Hinton, B.R. (1991)
'Corrosion Prevention and Chromates: The End of an Era', *Metal Finishing*, October 1991.

HWRP (1989)
Guidelines for Waste Reduction and Recycling: Metal Finishing, Electroplating, Printed Circuit Board Manufacturing, Hazardous Waste Reduction Program, a program of the Department of Environmental Quality, Oregan, July 1989

IAMS (1995)
A Pollution Prevention Resource Manual for Metal Finishers: A Competitive Advantage Manual, Institute of Manufacturing Sciences, Inc., Ohio Environmental Protection Agency, Cincinatti, Ohio, 1995, (Downloaded from IAMS Industry Sector web site: http://www.iams.org/)

Jackson, T. (1993)
Clean Production Strategies – Developing Preventive Environmental Management in the Industrial Economy, Stockholm Environmental Institute, Lewis Publishers, 1993.

James, D. (1999)
Personal Communication, meeting with David James, chairman of the Surface Engineering Association, Birmingham UK, 6 July 1999 (meeting documented in Janisch, 1999).

Jänisch, C.H. (1999)
Waste Minimisation in the Metal Finishing Industry: European Study Tour, June-July, 1999, Environmental Process Engineering Group, Department of Chemical Engineering, University of Cape Town, December 1999.

Jensen,E.H., P. Lukey and P. S. Sørensen (1998)
The DANCED Pilot Projects in Southern Africa, paper presented at the Southern African Regional Conference on Cleaner Production, Johannesburg, May 1998.

Jeppersen, S. (1999)
Environmental Management for Small and Medium Manufacturing Enterprises in South Africa – Potentials and Barriers, Project Outline, Institute of Development Planning and Research, University of Port Elizabeth, March 1999.

Jordon, P. (1998)
Address by the Deputy Minister of Environmental Affairs And Tourism, Mr Peter Makoba, at the Official Opening of The Southern African Regional Conference On Cleaner Production. *Speech read on behalf of the Deputy Minister By Dr Willem Scott of the Department of Environmental Affairs & Tourism, May 1998.*

Kirk & Othmer (1995)
Encyclopaedia of Chemical Technology, 4th Edition, Wiley International Science, 1995.

Kniel (1999)
Personal Communication, Ed Kniel, Gibb Africa, February 1999.

Kostura, J. (1990)
'Recovery and Treatment of Plating and Anodising Wastes', *Plating and Surface Finishing*, pp52-54, August 1990.

Kothuis, B. and Petrie, J. (1997)
An Industrial Symbiosis View of SMEs: Targeting Greater Eco-Efficiency through Innovative Business Practice, Project description, University of Cape Town, February 1997

Kothuis, B. (1998),
Cleaner Production Initiatives in South Africa, Paper presented at the Southern African Regional Conference on Cleaner Production, Johannesburg, May 1998

Kothuis, B., C. Janisch, D. van Beers (1999)
Barriers and Drivers to Cleaner Production and Industrial Symbiosis for Small and Medium Sized Enterprises in South Africa, Industrial Symbiosis Project, Department of Chemical Engineering, University of Cape Town, included in The Second Industrial Symbiosis Workshop Report, November 1999

Kothuis (1999b)
Personal Communication, Industrial Symbiosis Project Meeting, Cape Town, 2 November 1999

Lazarus, P., I. Currie, R. Short (1997)
'The Legislative Framework', published in *The Bottom Line – Environmental Law, Investment and Practice*, edited by Bethlehem and Goldblatt, South Africa, 1997

Licis, I.J. (1995)
'Pollution Prevention Possibilities for Small and Medium-Sized Industries: Analysis of the WRITE Projects', *Environmental Progress*, Volume 14, No 4, November 1995.

Lindsay, J.H. (1995)
'Special Conference Comes to Grips with Hexavalent Chromium', *Plating and Surface Finishing*, pp19-23, February 1995

Loekkegaard, K. (1999)
Personal Communication, meeting with Kristiaan Loekkegaard of Ernst & Young, Copenhagen, Denmark, 14 July 1999 (meeting documented in Janisch, 1999).

Lord, J., P. Ponech, P. Gallerani (1996)
'Process Analysis for Optimization & Pollution Prevention', *Plating & Surface Finishing*, pp 28-37, January 1996.

Lord, J., P. Gallerani (1998),
'Alternatives in Air Emission Modelling for Characterisation of Processes & Process Change', *Plating & Surface Finishing*, January 1998.

Mercer, D. (1999)
Personal Communication, meeting with David Mercer of EnvirosMarch Consulting, Manchester, U.K., 28 June 1999 (meeting documented in Janisch, 1999)

MEZ, MVROM (1992)
Handboek voor Preventie van Afval en Emissies in de Metaalproduktenindustrie, Ministerie van Economische Zaken, Ministrie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, and IVAM Environmental Research, The Netherlands, 1992.

Meuser, K. (1999)
Waste Minimisation/ Pollution Prevenetion Options at the chrome plating plant of an Automotive Component Manufacturer in South Africa, Diplomarbeit, University of Cape Town and Rheinische-Westfalischen Technischen Hocshule Aachen, March 1999.

MFA (1992)
A Checklist & Assessment Manual for the Metal Finishing Industry, The UK Metal Finishing Association, Issue No. 1, Birmingham, November 1992.

Mombemuriwo, L. (1999)
Metal finishing industry in Zimbabwe, Cleaner Production Centre in Zimbabwe, e-mail correspondence to C Janisch, Department of Chemical Engineering, University of Cape Town, 18 February 1999.

Murchison, C. (1999)
Business and the Environment in the UK, Glasgow Caledonian University, e-mail correspondence Colin Murchison to D. van Beers, University of Cape Town, Chemical Engineering Department, February 1999.

NATSURV2 (1987)
Water and Waste-water Management in the Metal Finishing Industry, Prepared for the Water research Commission by Binnie & Partners Consulting Engineers, WRC Project no. 145, Pretoria, October 1987.

Naumann, E. (2000)
Overview and Economic Review of the South African Metal Finishing Industry, Department of Economics, University of Cape Town, report written for the Industrial Symbiosis Project, February, 2000.

NDCEE (1994),
Chromate Conversion Coating Alternatives, Technology Abstract, National Defence Center for Environmental Excellence, Concurrent technologies Corporation, www.ndcee.ctc.com, December 1994.

NEWMOA (1998)
Pollution Prevention for the Metal Finishing Industry – A Manual for Pollution Prevention Technical Assistance Providers, North East Waste Management Officials' Association and U.S. EPA, February 1997.

NJDE (date unknown)
Waste Reduction For Metal Finishers, New Jersey Department of Environmental Protection, Division of Hazardous Waste Advisement Program, New Jersey, date unknown.

NOVEM (1998)
Warmterugwinning bij thermische verzinkerijen maakt badverwarmingsketel praktisch overbodig, Industriële Energie-Efficiency Projecten, Nederlandse Onderneming Voor Energie en Milieu bv (Novem), Haalbaarheidsstudie en demonstratieproject, projectnummer 382120/1061-382120/1006-392117/7136, uitvoer door het Ministrie van Economische Zaken, 1998.

OEA (date unknown)
Pollution Prevention Handbook: Degreasing Operations, No. 19 in a Series of Fact Sheets, Department of the Interior, Office of Environmental Affairs, USA.

OhioEPA (1994)
FACT SHEET: Source Reduction and Metal Recovery Techniques for Metal Finishers, State of Ohio Environmental Protection Agency, Number 24, September 1994.

Oldenberg K.U. & K. Geiser (1997)
'Pollution Prevention and... or industrial ecology?', in *Journal of Cleaner Production*, volume 5, No.102, 1997, pp103-108. As cited in Bruijn and Hofman (2000)

OTA (1994)
Industry, Technology and the environment: competitive challenges and business opportunities, Office of Technology Assessment, OTA-ITE-586, Washington, USA, cited in - van Berkel 1996.

OWMC (1993)
Industrial Waste Audit and Reduction Manual – A Practical Guide to Developing and Conducting a Manufacturing Process Survey for Waste Minimisation Opportunities, OWMC, 3rd Edition, 1993.

P2IRIS (1997)
What is Metal Finishing?, Institute of Advanced Manufacturing Sciences/GRC International, Inc., 1997 (Downloaded from IAMS Industry Sector web site: http://www.iams.org/p2iris/de/P2IRIS.htm)

Park, F. (1994)
'Pollution Prevention in Mass-Finishing Operations', pp14-23, *Metal Finishing*, November 1994.

PCI. (1996)
Engineering the Cyclone Separator, Powder Coating Institute 'Powder Coating 1996' Conference Proceedings, September 17-19, 1996, Indiana USA.

Pearson, C. (1999)
Personal Communication, Fax correspondence regarding Chemetall's Chrome-free Conversion Coating, September 1999.

Pearl, R., Z. Patel (1998)
How Decisions on The Adoption of Cleaner Technologies Are Made by Firms in South Africa: A Case Study of the Chemical, Food and Textile Industries, CSIR, Water, Environment and Forestry Technology, Paper presented at the Southern African Regional Conference on Cleaner Production, Johannesburg, May 1998.

Penning, P. and G.H. Kristensen (1999)
Cost Savings through environmental improvements - A case study at Meco Metal Finishing Engineers (M) Sdn Bhd, Slides and background information, MECO MFE & the Danish VKI, 1999.

Petrie, J.G. (1994)
The Need and Potential for the Introduction of Cleaner Technologies Across the South African Industrial Sector, Department of Chemical Engineering, University of Cape Town, Paper presented at WASTECON Conference, 1994.

Piatkiewicz, W. (1999)
Galvanizing and Environment: Communicating Benefits; Managing Operations, address to members by William Piatkiewicz, Manager – Health & Environment, at the AGM of the Galvanizers Association, Royal Aeronautical Society, London, 24 June 1999.

PMG (1998)
National Waste Management Strategy And Action Plans for South Africa - Situation Baseline Analysis Phase: Waste Minimisation, Report Version a, Job 970296, Ref No. 4.1.4 Sit Bas Rep Annexure C Prep. Waste Min Team., Ed. Version a Contr. PMG/ QA Ramboll., March 1998.

PREPARE (1991a)
Manual for the Prevention of Waste and Emissions, translated from Dutch by Line Out Network microtext, compiled by TEBODIN Consultants & Engineers and sponsored by the Dutch Ministry of Economic Affairs, June 1991.

PREPARE (1991b)
Manual Experiences – Part A: Choosing for Prevention is Winning, translated from Dutch by Line Out Network microtext, compiled by TEBODIN Consultants & Engineers and sponsored by the Dutch Ministry of Economic Affairs, June 1991.

PRG (1987)
Investigations into water management and effluent treatment in the South African Metal Finishing industry, prepared for the Water Research Commission by the Pollution Research Group, Department of Chemical Engineering, University of Natal, WRC Report no. 106/2/87, Durban, 1987.

PRG (1999)
Waste Minimisation and Effluent Treatment Clubs –Phase 1: Initial Assessment and Pilot Study, Water Research Commission Project No. 973, Pollution Research Group, Chemical Engineering, University of Natal Durban, May 1999.

ProEnviro (1998)
SEA Partners in Change, Changing the Process, Pro Enviro and the Surface Engineering Association, Birmingham, UK, 1998.

Reeve, D. (1998)
Environmental Benchmarking in Metal Finishing, UNEP Metal Finishing Network, November 1998.

Reimerink, G. (1999)
Personal Communication, meeting with Gerard Reimerink, Chairman of the Stichting Doelmatig Verzinken, Amsterdam, the Netherlands, 9 July 1999 (meeting documented in Janisch, 1999).

Reiner, M. (1999)
Waste Minimisation – Two Durban Case Studies, Personal communication in the form of a presentation of results at Industrial Symbiosis Project meeting, 14 May 1999.

ReSource (1999)
'Development of a National Waste Management Strategy for South Africa, Waste Management, pp22-26, *ReSource*, August 1999.

RIVM (1992)
Thermisch Verzinken, Samenswerkensproject Projectbeschryvingen Industrie Nederland, RIVM, January 1992.

Robinson, B. (1998)
Pathways to Cleaner Production – The Victorian Experience, by Brian Robinson, Chairman of the Protection Authority, Victoria, Australia, 1998.

Rowe, J. & D. Hollingsworth (1996)
'Improving the Environmental Performance of small- and Medium-sized Enterprises: A study in Avon', *Eco-management and Auditing*, volume 3, pp97-107, 1996.

Schwartz, S and R. McBride (1997)
'Pollution Prevention in the Metal Plating and Finishing Industry: Progress and Obstacles', *Environmental Engineering Science*, Vol 14, No.4, 1997

SEA & UK DTI (1998)
Waste Minimisation in the German Surface Finishing Industry, Best Practice Mission, Surface Engineering Association & DTI Technology Service, U.K., 1998.

SEA (1999)
Surface Engineering Industry: Statistical Report 1999, UK Surface Engineering Association, Benchmark Research, Birmingham

Smith, E. and A. Schung (1994)
'Application of Material Balance Concept in Waste Minimisation Assessment of a Metal Finishing Process', *Environmental Progress*, volume 13, No.3,, August 1994

SRK (1991)
National Industrial Water and Waste-water Survey, Final report to the Water Research Commission by Steffen, Roberston and Kirsten Consulting Engineers, WRC Report no 145/1/91, Johannesburg, 1991.

Statistics South Africa (2000)
National Census of Manufacturing 1996, Statistics South Africa, Pretoria, released January 2000.

Steenveld, G. S. Barclay and C. Buckley (1998)
Waste Minimisation Clubs: Introducing the Concept to South African Industry, Pollution Research Group, Department of Chemical Engineering, University of Natal Durban, paper presented at WISA, Cape Town, May 1998.

Such, T. (1999)
Personal Communication, meeting with Tony Such of T.Such International Consultants, Redditch, U.K., 6 July 1999 (meeting documented in Janisch, 1999).

Sullivan, G.M. (1993)
Non-chromating Conversion Coatings, VP Technology Information, Novamax Technologies Corporation, 1993.

Tyler, T. (1999)
Personal Communication, Meeting with Trevor Tyler of the Gold Reef Branch of the AESF, Edenvale, Johannesburg, 18 May 1999

Uittenbroek, Dr. P. (1999)
Personal Communication, meeting with Dr. Uittenbroek, head of the Stichting VOM Certificaat (Certification Board of the VOM), Zoetermeer, the Netherlands, 8 July 1999 (meeting documented in Janisch, 1999).

UK DTI (1991)
UK Industry and Cleaner Technology Developments, UK Department of Trade and Industry report, 1991

UNEP CP (date unknown)
Industrial Sector Guide - Electroplating Industry, UNEP Cleaner Production, Final Version, prepared by Ernst & Young, Denmark.

UNEP ICPIC (1995)
Case Studies from the Metal Finishing Industry, United Nations Environmental Program, International Cleaner Production Clearing House, Database, 1995.

UNEP WG (1998)
A Cleaner Production Manual for the Metal Finishing Industry, Prepared by The UNEP Working Group for Cleaner Production, the CRC for Waste Minimisation and Pollution Cotrol, Ltd., Department of Environment, Brisbane City Queensland, Australia, May 1998.

U.S. EPA (1989)
Waste Minimisation Opportunity Assessment Manual, U.S. Environmental Protection Agency, Government Institutes, Inc., June 1989.

U.S. EPA (1992)
Guides to Pollution Prevention: The Metal Finishing Industry, U.S. Environmental Protection Agency, Office of Research & Development, Report No. EPA/625/R-92/011, Washington D.C., 1992

U.S. EPA (1994)
Sustainable Industry: Promoting Strategic Environmental Protection in the Industrial Sector: Phase I Report Metal Finishing Industry, U.S. Environmental Protection Agency, Washington D.C. Office of Policy Planning and Evaluation, 1994

U.S. EPA (1996)
International Waste Minimisation Approaches & Policies to Metal Plating, U.S. Environmental Protection Agency, Hazardous Waste Minimisation and Management Division, Report No. EPA530-R-96-008 PB-196 753, August 1996.

U.S. EPA (1998)
Fabricated Metal Products Notebook, U.S. Environmental Protection Agency, Office of Enforcement and Compliance Assurance, May 1998.

van Berkel, C.W.M. (1996)
Cleaner Production in Practice – methodology development of environmental improvement of industrial production and evaluation of practical experiences, Ph.D Thesis, University of Amsterdam, 1996.

van Berkel, R., E. Willems and M. Lafleur (1997)
The Relationship between Cleaner Production and Industrial Ecology, Journal of Industrial Ecology, Volume 1, Number 1, 1997

van der Meer, J. (1998)
Waste minimisation in the Metal Finishing Industry, Industrial Symbiosis Workshop Report, Cape Town, March 1998

van der Klis, T. & J.W. du Mortier (1997)
Handboek Afvalwaterbehandeling, Vereniging voor Oppervlaktetechnieken van Materialen, 3e uitgawe, 1997

van Engelen, A. (1999)
Personal Communication, meeting with Adriaan van Engelen of Stimular, Rotterdam, the Netherlands, 12 July 1999 (meeting documented in Janisch, 1999)

van Ooij, W.J. and T. Child (1998)
Protecting Metals with Ssilane Coupling Agents, Developing Technology, Chemtec, American Chemical Society, February 1998

Versteege, S. (1999)
Personal Communication, meeting with Stephan Versteege of BECO, Rotterdam, the Netherlands, 12 July 1999 (meeting documented in Janisch, 1999)

VOM (1998)
Economische Aspecten van Oppervlaktechnieken, IOP Oppervlaktechnologie, Slide Presentation, Vereeniging vor Oppervlactechnieken van Materialen, 1998

Walpole, K. (1999)
Personal Communication, Questions regarding Cr(VI) limits to sewer, Telephone conversation, Keith Walpole, Scientific Services, Cape Metropolitan Council, August 1999

Wilk, L.F. and R.S. Capaccio (1990)
'Application of Ion Exchange Technology in Pollution Prevention', *Metal Finishing*, pp25-28, April 1990

WRC (1994)
Microbiological Transformation of Metal Contaminated Effluents, WRC Report 357/1/94 as cited in WRC 1997

WRC (1997)
Laboratory and Pilot-Plant Bioreactor Development for Remediation of Metal-Contaminated Wastewater Using Activated Sludge as Bioadsorbent, Water Research Commision, Gauteng, Report No. 688/1/97, 1997

WRITAR (1995)
Profile of the Metal Finishing Industry, Waste Reduction Institute for Training and Applications Research. Prepared for the Cleveland Advanced Manufacturing Program under contract to the Energy Environment and Manufacturing project of the Technology Reinvestment Program, April 1995, (cited in UNEP WG 1998)

Yau, T and K W Bird (1995)
'Manage Corrosion with Zirconium', *Chemical Engineering Progress*, p42, January 1995

Zalk, A. (2000)
Personal Communication, Telephone conversation regarding the South African Electroplaters Association, 25 January 2000

INTERNET SOURCES

www.AESF.org
Website of the American Electroplating and Surface Finishing Society

http://www.Bammensgroep.nl
Information on hot dip galvanising Cleaner Technologies.

http://cage.rti.org
Research Triangle Institute CAGE (Coating Alternatives Guide) access to an interactive pollution prevention information base designed to recommend low-emitting alternative coating technologies. Also a list of alternative coatings, summaries of various coating techniques and links to many coating associations and agencies

http://www.chmr.org/ppmfi.html
Pollution Prevention Strategies for the Metal Finishing Industry, Center for Hazardous Materials Research, 1996.

www.EGGA.org
Website for the European General Galvanizers Association, with general information on galvanising and links to websites for individual associations around Europe

http://www.environment.gov.au/portfolio/epg/environet/ncpd/auscase_studies
Australian Cleaner Production Case Study Directory

http://es.epa.gov/comply/sector/fab/fabtitles.html
OECA Fabricated Metal Products Notebook, U.S. EPA, Office of Enforcement and Compliance Assurance (OECA), December 14 1995

http://es.epa.gov/es-guide/metals/metals.htm
EnviroSen$e Metal Finishing Content Guide

http://es.epa.gov/techinfo/facts/california/metal-fs.html
Fact Sheet. Hazardous Waste Generated by Metal Refinishing Facilities, California Department of Health Services Toxic Substacnes Contol Program Alternative Technology Division

http://www.iams.org/p2iriside/metalfin.htm
The Institute of Advanced Manufacturing Sciences (IAMS). A pollution prevention Resource Manual for Metal Finishers, A Competitive Advantage Manual

http://www.nmfrc.org
NMFRC (The National Metal Finishing Resource Center): includes the Common Sense Initiative (CSI) R&D page, variety of technical resources (articles from various trade journals) and numerous compliance assistance links. Also the Merit Partnership Pollution Prevention Project for Finishers page

http://www.pfonline.com/environmental/links.html
Products Finishing Online - Environmental Zone Links

http://www.powdercoating.org
The Powder Coating Institute

http://www.unido.org/services/environment/envncpc/temperature/casestudy
UNIDO Case Studies

http://www.usaep.org/reports/metal.htm
Clean Technology in US industries: Focus on Metal Fabrication, USAEP, 1996

http://www.yarranet.swin.edu.au/yarranet/bu/pages/cpaust/welcome.htm
Website for the UNEP Working Group for Cleaner Production in the Metal finishing industry

A - GLOSSARY

Word	*Description*
anode	The positive electrode of an electrolytic cell, usually composed of the metal to be electro-deposited.
anodising	A process generally applied to aluminium and its alloys to produce an adherent oxide film to impart corrosion resistance or surface hardness.
barrel plating	Plating in which the work is processed in bulk in a rotating container.
barrier	An excuse (constraint) for a company not to undertake Cleaner Production in the first place or a factor that might limit or even block the progress of the assessment process in a company in the industry segment.
base metal	A metal that readily oxidises or dissolves to form ions.
bronzing	A chemical process generally applied to steel to impart the appearance of bronze (antimony chloride in hydrochloric acid followed by ammonium chloride in dilute acetic acid). The resulting "bronze" film does not have the corrosion resistance of true bronze.
captive shop	In-house operation performing metal finishing activities on the parts that they manufacture and/or they subsequently use in downstream manufacturing.
case hardening	A family of surface hardening processes generally applied only to steel.
cathode	The negative electrode of an electrolytic cell which, in electroplating, receives the metallic deposit.
cation	A positively charged ion.
chelation	Process of ring formation with inclusion of metal ion within the ring resulting in stable complex formation.
chromate coating (chromating)	A corrosion protection technique which has many variations and can be applied to steel, aluminium, magnesium, and zinc. It results

	in the formation of metal oxide on the surface of the work-piece that reacts to form metallic chromates.
chromium plating	The electrodeposition of chromium is generally applied to steel in all its forms. It is usually done for decorative purposes (decorative chromium) or to provide a hard surface for engineering purposes (hard chromium). Chromium plate is nearly always deposited on top of a nickel deposit which supplies corrosion resistance.
Cleaner Production	The continuous application of an integrated preventative environmental strategy to processes, products and services so as to increase eco-efficiency and reduce the risks to humans and the environment (according to the NWMS for South Africa).
Cleaner Technology	A production process or equipment with a low rate of waste production. Treatment and recycling plants are not classed as cleaner technologies.
complexing agent	A compound that will combine with metallic ions to form soluble ions.
conductivity	Refers to the ability to transfer electricity – measured in Siemens (inverse ohms).
conversion coating	A coating produced by chemical or electro-chemical treatment of a metallic surface that provides a superficial layer containing a compound of the metal.
cyclone efficiency	A ratio of the amount of powder recovered versus the amount of powder entering the unit.
drag-in	The water or solution that adheres to work-pieces introduced into a bath.
drag-out	The solution that adheres to a work-piece removed from a bath that will be carried through to the next bath (drag-in), and that may drip between baths.
driver	A specific activity undertaken to alleviate a-set of- barrier(s) or to empower a –set of – incentive(s) to Cleaner Production.
Eco-efficiency	Maximisation of industrial output from a given level of resource input, thus ensuring Cleaner Production and appropriate use of renewable, non-renewable and human resources.
effluent	Any gas or liquid emerging from a pipe or similar outlet; usually refers to waste products from chemical or industrial plants as

	liquid mixtures or stack gases.
electroplating	The process of depositing metal from an aqueous solution using an external potential (electrical current) for the metal cation reduction process.
emulsion cleaning	A cleaning technique which acts by emulsifying contaminants. Emulsions are mixtures of two liquids, with one liquid holding the other in suspension similar to colloidal suspension. The liquids will typically have different polarities and will dissolve different types of materials. One of the liquids is usually water and the other will have non-polar properties. They can therefore be used to dissolve non-polar contaminants like oil and grease from metal surfaces.
end-of-pipe	Treating pollutants at the end of a process, for example, by filters, catalysts and scrubbers, instead of preventing their occurrence.
Environmental Management System (EMS)	A management system aiming at facilitating improved environmental performance that involves a complete review of the environmental effects produced by a company, the production of an environmental policy designed to ameliorate the identified effects and procedures to achieve the aims and objectives of the policy.
external recycling	Is recycling where the materials are re-used or reprocessed outside the company where it was originally retrieved. The recycled materials may or may not return to the company of origin.
first transfer efficiency	The relation between the amount of powder coating material deposited on a substrate to be coated and the total amount that was directed towards the substrate by the spraying gun(s).
general waste	Waste that does not pose an immediate threat to man or to the environment, i.e. household waste, builder's rubble, garden waste, industrial and commercial waste. It may, however, with decomposition, infiltration and percolation, produce leachate with an unacceptable pollution potential (DWAF, 1998).
hard chromium	Chromium plate for engineering rather than decorative applications; not necessarily harder than the latter, but generally thicker and heavier.
hazardous waste	Waste that may, by circumstances of use, quantity, concentration or inherent physical, chemical, or infectious characteristics, cause ill-health or increase mortality in humans, fauna and flora, or

	adversely affect the environment when improperly treated, sorted, transported or disposed (DWAF, 1998).
incentive	A motivation for a company to undertake Cleaner Production or a factor that might spur the progress of the assessment process in a company in the industry segment.
independent metal finisher	Job-shop metal finisher.
Integrated Pollution Control (IPC)	A national practice or system which takes into account the effects of activities and substances on the total environment as well as the whole commercial and environmental life cycles of substances when assessing the risks they pose and when developing and implementing controls to limit their release.
Internal recycling	Recycling in general is defined as follows: The retrieval of materials or products for re-use in their original form or for reprocessing into other products, e.g. recycling of aluminium cans, paper etc. Internal recycling represents those cases where the recycling takes place within an individual company.
ion exchange	A reversible process by which ions of opposite charges can be exchanged by adsorption onto charged resin material.
job-shop	Job-shop (independent) metal finishing operations do not manufacture parts or use their products in other manufacturing applications. They are separate entities offering the service of metal finishing to other manufacturers and the public.
Life Cycle Assessment (LCA)	A systematic inventory and comprehensive assessment of the environmental effects of two or more activities involving a defined space and time including all steps and co-products in its life cycle, from the cradle to the grave.
metal finishing	The process of coating a metallic (or plastic in the case of electroless plating) object with one or more layers of another metal, paint, plastic, or ceramic to enhance, alter, or finish its surface.
pickling	A chemical treatment which removes oxide or scale from the surface of a metal. It most often refers to the use of sulphuric or hydrochloric acid to remove scale formed on mild and low-alloy steel.

Pollution prevention	See Cleaner Production and waste minimisation
Prevention Quick Scan (PQS)	A short investigation (waste minimisation assessment) of a company (approximately ½ day) based on rough guidelines used to obtain insight into the waste and emission prevention possibilities of the company, including possibilities for cost reduction.
SME	Small and medium enterprises are companies with fewer than 250 employees. Medium sized companies have between 40 and 250 employees and some form of middle management. Small size companies have fewer than 40 employees and lack a formal management structure.
substrate	Surface material or electroplate upon which a subsequent electrodeposit or finish is made.
ultrafiltration	The process that uses membranes to achieve separation of various constituents; a typical ultrafiltration membrane allows water, ions, and small molecules (<1micron) to pass through while rejecting larger molecules and suspended solids.
waste	All solid, liquid and gaseous materials introduced into the air, water and soil.
waste audit	A thorough account of the wastes from an industry, a plant, a process or a unit operation resulting in the identification of wastes, their origin, quantity, composition and their potential for reduction.
waste minimisation	The reduction, to the extent feasible, of waste that is generated or subsequently treated, stored or disposed of. It includes any source reduction and recycling activity undertaken by a waste generator that result in either (i) the reduction of total volume or quantity of waste, or (ii) the reduction of toxicity of waste, or both, so long as such reduction is consistent with the goal of minimising present and future threats to human health and the environment (PMG, 1998). (According to the NWMS for South Africa).
waste minimisation assessment	A systematic planned procedure with the objective of identifying ways to reduce or eliminate waste (waste audit).
waste segregation	The act of separating process chemical effluents or wastes at each individual point of origin to facilitate materials recovery.
wetting agent	A substance that reduces the surface tension of a liquid, causing it to spread more readily on a solid surface without it beading up.
work-piece	The part that is being finished, electroplated, etc.

B APPENDICES FOR CHAPTER 2

B.1 Summary Of Main Wastes From Typical Metal Finishing Processes

Table B1: Summary of main wastes from typical metal finishing processes

PROCESS	AIR EMISSION	WASTEWATER	SOLID WASTE
SURFACE PREPARATION			
Solvent Cleaning or Emulsion cleaning	Vapour degreasing results in significant Volatile Organic Compound (VOC) emissions. Agitation used with immersion cleaning may increase vapour losses. Vapour losses may occur during distillation.	Contaminated spent solvent. Solvent distillation equipment to separate the contaminants from the solvent. Scrubber blowdown from scrubbing of solvent fumes.	- Still bottoms from solvent recovery. - Oily/greasy rags from wipe cleaning.
Alkaline Cleaning	Caustic mists.	Liquid effluents generated from cleaning are primarily contaminated rinse waters, which are often combined with other metal finishing wastewaters. Spent treatment baths.	- Wastewater treatment sludges. - Cleaning tank residues/sludges. - Filters and filter sludges from oil filtering.
Acid Cleaning/Pickling	Acid fumes.	Some acids and bases may etch away some of the metal being pre-treated resulting in dissolved metals in the spent solutions.	- Wastewater treatment sludges. - Tank residues/sludges.
Abrasive Cleaning	Dust and fumes.		- Abrasive blasting residue.
SURFACE TREATMENT			
Plating Operations			
Electroplating	Humid mists/aerosols arising from electroplating fluids and process gases (hydrogen and oxygen evolving at an electrode and bubbling to surface) which may contain metals, cyanides and acids.	- Electroplating rinse waters containing acids/alkalis, cyanide and metal salts. - Spent process solutions discarded periodically when contaminants inhibit proper functioning of the solution. - Scrubber blowdown from scrubbing of mists.	- Sludges from treatment may contain significant concentrations of toxic metals. They may also contain complex cyanides in high concentrations if cyanides are not properly isolated during the treatment process. - Filters and filter sludges from filtering of plating solutions.

PROCESS	AIR EMISSION	WASTEWATER	SOLID WASTE
Electroless Plating/ Immersion plating	Metal ion-bearing mists, and acid mists.	- Spent plating solution and rinse water. (The extent to which plating solution drag-out adds to the wastewater and enters the sludge depends on the type of product being plated and the plating method used.)	Wastewater treatment results in solid-phase metal sludges which may contain significant concentrations of toxic metals.
Chemical Conversion Treatments			
Phosphating	- Metal ion-bearing mists. - Acid mists.	Rinsing and batch dumping of spent process baths containing metal salts (zinc or iron phosphates), acid, and dissolved basis materials	Wastewater treatment sludges.
Chromating	- Metal ion-bearing mists. - Acid mists.	Contaminated rinse water and batch dumping of spent process baths, containing metal salts (chromates), fluorides and dissolved basis materials	Wastewater treatment sludge from reduction of hexavalent chromium to trivalent chromium and hydroxide precipitation.
Passivation	Fuming from nitric acid.	Spent nitric acid which may also contain hexavalent Cr.	
Metal Colouring		Wastewaters may contain nickel-acetate, non-nickel sealers, or substitutes from dyes.	
Electrochemical Conversion Treatments			
Anodising	Mist and gas bubbles arising from heated fluids which may contain metals, acids or other substances present in the bath.	- Wastewaters contain chromium and acids.	Wastewater treatment sludges, and bath cleaning residues.

PROCESS	AIR EMISSION	WASTEWATER	SOLID WASTE
Other Processes			
Wet Painting	- Air emissions from wet painting processes consist primarily of the organic solvents used as carriers for the paint. - Cleanup processes can also result in the release of organic solvents used to clean equipment and painting areas (paint strippers).	- Wastewaters from wet-painting processes are due primarily to the discharge of water from water curtain booths and equipment washing. - Excess paints discarded after completion of a painting operation. May contain metals from metal pigments, and organic solvents (from paint and cleaning).	- Treatment of wastewater generates a sludge which requires disposal. - The solvents (paint strippers) and materials for cleaning painting equipment or spray booths may also contribute organic solid waste to the wastes removed from painting areas. - Paint residues.
Powder Coating	Powder coating may result in fine powder paint dust released to air owing to the inefficient overspray-collection equipment.		- Spent paint collected in paint booth collection systems, and ventilation filters. - Paint residues. - Filters and filter sludges from filtering of powder dust emissions.
Hot dip Coating	Air emissions include acid fumes from the pickling baths and fumes given off above the galvanizing bath when the dried flux on the parts volatilises in the hot molten zinc.	- Wastewater from rinses in pre-cleaning stages and for quenching after coating which generate metal-bearing wastewaters. - Spent acids (HCl or H_2SO_4) which can be regenerated.	- Zinc-oxide ash that is periodically skimmed off the heated tank. - Dross (iron/zinc alloy) formed by carry over of iron from the pickling tank. - Filters and filter sludges from flux filtration and fume control.
Cladding	Emits less waste than electroplating.		
Case hardening (diffusion coatings)	This method has relatively low waste generation.		

PROCESS	AIR EMISSION	WASTEWATER	SOLID WASTE
Etching	Caustic or acid mists.	Spent etching solutions may contain high concentrations of metals and acids	Residual sludge from spent baths contain base metal.
Electropolishing	Caustic or acid mists.	Spent concentrated acid or alkaline solutions	
Polishing and buffing	Particulates which may become airborne	washdown following polishing operations	Metal polishing rags.
Metal Spraying	Generation of dust, fumes and overspray.	"Water curtain" which may be used to capture the overspray and fumes, periodically discharge contaminated wastewater.	Spent gas cylinders, spent exhaust filters from dry filter exhaust hoods which may be used to capture overspray and fumes.
POST TREATMENT			
Rinsing		- Wastewater containing metals, cyanide and used process chemicals - Ion exchange resin regenerants from demineralisation of process water.	Wastewater treatment sludge.
Colouring		Wastewaters produced may contain nickel-acetate, non-nickel sealers, or substitutes from the dye.	
Anti-corrosion treatment		Spent dilute chromate solutions.	Residual sludge from spent baths containing metals and hexavalent chromium.

The references used in compiling this table are generally the same as those used in compiling Table 2.1, in Section 2.1.

B.2 Common Waste Minimisation Options for Metal finishing Processes

The following summary list of waste minimisation options for metal finishing processes has been compiled from an extensive review of the literature mentioned in Section 2.3.1. For ease of reference, it is structured similarly to the U.S. EPA's (1989) Environmental Management Options Hierarchy. The options are therefore grouped into two main classes: Source Reduction, and Recycling/Recovery. Source Reduction and Recycling are then further classified into sub categories of options (e.g. General Waste Reduction Practices, etc.). For each category examples are given and comments on application and limitations of the options are included. The summary -Table B2 - follows on the next page.

Table B2 - Summary table of common waste minimisation options for metal finishing processes

Category	Examples	Applications/ Limitations
I. SOURCE REDUCTION		
A **General Waste Reduction Practices**		
A1 Good Housekeeping Practices	• *Workshop tidiness* to reduce the risk of accidents and damage to stock or equipment as well as creating smooth work flow throughout the facility to increase efficiency of operation. • *Preventive maintenance* to minimise leaks and other potential losses of resources, and to ensure equipment is operating at optimal efficiency. • *Inventory management and control* to match purchases with operational needs • *Chemical tracking and record keeping* to prevent cross contamination and identify practices tat need to be improved • *Spill prevention and control* by using drain boards or splashguards on tanks or providing adequate freeboard • *Employee awareness, education and training* for health and safety, to understand why and how wastes are generated, to ensure proper operation of process equipment, and to provide information and incentive for minimising waste generation in daily activities • Return to the process bath the unused portion of analytical *samples*	• Applicable to all conventional metal finishing operations. • Should be considered standard operating practices or the first step in an effective waste minimisation program. • Cost benefit typically outweighs any necessary expenditure • Can reduce the need for more expensive recovery, recycle and treatment technologies. • In addition, can provide product quality improvements and operating cost reductions, as well as generally improve the working environment, including health & safety aspects • Small companies may not have the time, or financial, personnel resources to develop or implement some of these procedures.
A2 Production planning	• *Improving process layout* to ensure smooth flow can greatly affect waste generation and improve production • *Forward planning and production scheduling* (e.g. powder coaters schedule to paint all products of the same colour at the same time so that the need to clean equipment between batches is reduced) • Carefully inspect parts before they are coated to *avoid* processing substandard parts that are likely to become *rejects*. • *Avoid requirement to clean* by having parts delivered just-in-time to avoid the use of rust inhibitors, only degreasing parts that really need it, or requesting suppliers to supply parts that are easier to clean • *Reduce the number of different cleaning agents* used by selecting those with a wide range of applications	• Used to ensure that only necessary operations are performed and that no operation is needlessly reversed or obviated by a following operation. • Applicable to all conventional metal finishing operations. • Not possible for fixed unit facilities. • Existing facilities only able to accommodate process layout changes during shut down time

Category	Examples	Applications/ Limitations
B. Improved Operations/ Process modification		
B1. Drag-out reduction		Extends bath lives and reduces waste volumes.
B1.1 Minimising drag-out	• *Control Plating Solutions* concentration, temperature and additives to reduce viscosity and surface tension. • *Workpiece orientation* and position on rack for optimum drainage while still ensuring proper exposure for optimal coverage and uniform thickness of coating (e.g. tilt all solid objects so that the clinging fluid will flow together and off the part by the quickest route). • *Design and maintenance of racks and barrels* to minimise entrapment and promote drainage of bath materials. • *Workpiece withdrawal* at slower rate. Most of the time allowed for withdrawing and draining the item should be used for withdrawal (to reduce viscosity force effect). • *Product modification* to minimise entrapment of solution in cavities.	• These drag-out reduction methods are inexpensive to implement and are repaid through savings in chemicals/water. • Additives like wetting agents can create foaming problems and may interfere with wastewater treatment systems. • May need to examine operators' production procedures such as withdrawal speed and drain time for manual processes. • Slower withdrawal rate will interfere with production time, and optimisation will be necessary.
B1.2 Direct drag-out return	• Draining/ rinsing over tank with *increased dwell time* to route drag-out back into tank. • While draining over the tank, *rinse with small amounts of water* (spray) to prevent the part from drying and to increase the drag-out removal rate. • *Drain board/drip trays* (plastic or metal) between tanks and tilted to route drag-out into correct process tank (prevents drips to floor). • Provide *drain bars* over the tank from which the rack can be hung to drain briefly, or rotate barrel over plating tank to remove excess solution. • *Air knife* with oil-free compressed air to knock plating films off parts and back into tanks.	• These can save chemicals by making up for evaporative losses, reduce rinse requirements and prevent unnecessary floor wettings. • Use of air knives is limited due to the potential to dislodge parts from racks and the drying effect of the air stream. • Facilities may not be able to accommodate changes because of process configuration and interference with production time.
B1.3 Drag-out recovery and return	• *Drip tank* prevents drips to floor and captures the majority of the drag-out for evaporation replacement (particularly suitable for unheated solutions because drag-out is not mixed with water in the drip tank). • *Drag-out tank* is a static rinse tank initially filled with pure water and concentration increases as more work is processed. Efficiency can be increased significantly by adding a second drag-out tank. • *Double dipping* (drag-in/drag-out rinsing) involves rinsing in the same solution before and after plating, either in a single rinse tank or using two hydraulically connected rinse tanks located on opposite sides of the process tank. The advantage is that process chemicals rather than pure rinse water are transferred into the process tank by incoming racks.	• Simplest form of metal/chemical recovery. • Existing facilities might not be able to accommodate changes because of space constraints. • Reducing drag-out results in reduced purging of bath contaminants. Using de-ionised water for rinsing and bath maintenance can minimise the impacts of contaminants.

Category	Examples	Applications/ Limitations
B2 Improved rinsing operation/ Rinse-water Reduction		• These options will reduce the water and sewer bills, cost of treatment of wastewater and sludge disposal fees. • The required quality of rinse water is central to the reduction of rinse water use.
B2.1 Avoid the need to rinse	• Rinse between a soak cleaner and an electrocleaner may be eliminated if the two baths are compatible. • Rinse between degreaser and acid pickle may be eliminated if biological degreasing system is used in galvanising applications.	• Usually requires a subsequent modification or change in the process/ input material.
B2.2 Improving Rinsing efficiency	• *Rinsewater agitation* can be obtained by manually moving the workpiece, or by creating turbulence by pumping either air or water into the tank or using a mechanical agitator. • *Double dipping* in same rinse bath can be up to 10 times more effective than a single dip. • *Spray rinsing* instead of immersion (for flat surfaced parts) uses less water. Fog rinsing is water spray combined with air pressure. • Use of *ultrasonics* can improve rinsing effectiveness by loosening soil particles that are not completely removed during the cleaning step.	• These are generally good operating practices and help to achieve overall production efficiency and product quality.
B2.3 Optimise Rinse tank design	• Select the *minimum size rinse tank*. • Locate water inlet & discharge points at opposite positions in the tank to *avoid short-circuiting*. • Use *flow distributor* to feed the rinse water evenly.	• Usually for new facilities, but can also be applied to existing facilities.
B2.4 Controlling flow rate of rinse water use	• *Flow restrictors* which limit the volume of rinse water flowing through by maintaining a constant flow at the optimal flowrate. • *Manual control* of water flow (dependent on operator adjusting flow with taps/valves). • Pressure-activated flow control devices (such as foot pedal activated valves or meters) can be used to *stop water flow during non-operation*. • *Conductivity control* of fresh water flow through sensor that measures the ion level and activates a flow according to pre-set concentrations. • *Timer rinse controls* which turn water on and off based on a pre-set time period (timer setting selected through trial and error). • *Flowmeters & accumulators* do not reduce water use by themselves but make the operator aware of use rates and help identify specific locations of excessive water use.	• Regulates the feed rate of water to an optimum level. • The optimum flow rate may need to be determined through measurements and calculations. • Flow restrictors are inexpensive, but can only be effective for rinse water control lines that have a constant production rate (automatic operations). • Conductivity controllers are expensive, require frequent preventive maintenance, and do not sense non-ionic contaminants like dust. • Meter readings over time show trends in water use.

Category	Examples	Applications/ Limitations
B2.5 Alternative rinsing configurations	• *Counterflow rinsing* (where workpiece flow moves in opposite direction to rinse water flow) with multiple tanks. Water flows from furthest tank towards closest to process bath by gravity or pumping and each added tank can reduce water use by 50%. • *Cascade rinsing* method uses the overflow from one rinse tank as the water supply for another compatible or less critical rinsing operation. • *Reactive rinsing* where a chemical reaction takes place as a result of using the rinse water for multiple purposes (e.g. neutralisation when reusing acid rinse water as alkaline rinse water). • *Dual purpose rinsing* uses the same rinse tank for rinsing following more than one process tank (same results as cascade or reactive rinsing but using fewer tanks). • *Chemical rinsing* where rinsability of work-piece in the second rinse is improved by changing the chemical nature of the film or reducing film concentration before attempting to rinse by diffusion (e.g. static sodium bisulphite rinse to reduce Cr^{6+} to Cr^{3+} followed by flowing water rinse). • *Static (recovery) rinse* tank with purified water used prior to the flowing water rinse tank. The concentration in the static rinse will build up over time and can be returned to the bath to make up for evaporation losses. • *Spray or fog rinsing* (for flat-surfaced parts) can be installed above heated process tanks if the volume of water lost to evaporation is ≥ volume used in spray/fog. The run-off replenishes the bath. • *Combined spray and dip rinsing.* Spray rinsing over tank with deionised water if the evaporation rates are sufficient to accommodate the added volume of spray water.	• Requires drag-out and water use data and rinse water quality criteria to evaluate alternatives and determine optimum option. Drag-out data in particular are difficult and/or expensive to obtain. • These systems generally allow for greater contact time between the workpiece and the rinse water and greater diffusion of process chemicals into the rinse solution. • Negative aspects include cost of additional rinse tanks, loss of valuable production space, and an increase in production time/labour. • Air agitation or a wetting agent may need to be used to aid the rinsing process in a static rinse tank. • Spray rinsing reduces both drag-out loss and rinsewater use, and typically uses from 1/8th to 1/4th the amount of water that would be used for equivalent dip rinsing. Spray nozzle selection and water pressure spray need consideration, as nozzles often clog and need to be cleaned or replaced. • Can combine drag-out reduction/ rinse water reduction arrangements.
B3. Reduce Air emissions	• *Foam blankets* or floating polypropylene *balls* can be used in some cases on bath surfaces to reduce mists (air-borne concentrations of metals reduced by 13% c.f. without). • *Updraft ventilation* allows mist to be collected in the ductwork and flow back to the process tank. • Process baths that generate mist or solvent degreasers should be in tanks with *increased freeboard* to reduce amount of mist reaching the ventilation system (e.g. hexavalent Cr baths or air agitated Ni/Cu baths). • Cover baths with *lids* when not in use to reduce loss through evaporation. • Wetting agents or *chemical mist suppressants* help to reduce acid mist formation (down to 1% c.f. without) during plating.	• No significant benefit of using both the suppressants and balls vs. suppressants alone.

Category	Examples	Applications/ Limitations
B4. Reduced energy usage	• Heated tanks should be *insulated* to minimise heat loss. *Covers* should be used when not in use. • *Floating balls and satchels* are commonly used to minimise heat (and vapour) losses.	• Insulation can have a payback period of only a few months.
B5. Reduce/ eliminate the need for cleanup or improve cleanup methods	• *Avoid leaks/spills and drips* to floor to prevent need for floorwash and cleanup. • *Minimise the volume of water or absorbent used* during cleanup (eg use trigger mechanism on floorwash hoses)	• Generally good operating practices
B6. Improved process efficiency	• Cleaning bath *agitation*. • *Ultrasonic* degreasing for high levels of cleanliness is capable of removing extremely small particles (good for parts with complex geometries). • *Electrocleaning* to remove all soils through H_2 and O_2 gas evolution and a reverse current which prevents deposition of any metallic film and activate the metal surface. • *Reduce paint overspray by decreasing atomising air pressure in spray paint equipment (spray guns).*	• Ultrasonic cleaning is very expensive. • Ultrasonic and electrocleaning allow aqueous cleaners to be used where solvents have previously been the only effective degreasing tool.
B7. Extending Bath Life		
B7.1 Preventive process solution maintenance	• *Monitoring and control of bath conditions* by testing indicator parameters (pH, temperature, concentration, metals) to determine when chemicals/water should be replenished or when metal contaminants should be removed. • Prevent contamination of solution by *masking areas not to be plated* with tape/wax to limit corrosion there. • *Racks/barrels* should be *kept clean* and free of contaminating material. • Using *purer anodes* and cloth bags around anodes in electroplating to prevent insoluble impurities from entering the bath. • Use *deionised/softened water* instead of tap water for makeup and as rinse water, so that hard water contaminants (calcium, magnesium, chlorine, carbonates) don't reduce rinse water efficiency, interfere with drag-out recovery or contribute to wastewater treatment-sludge volume. • *Mechanical agitation* vs. air agitation prevents contaminants such as oil from the compressor and carbon dioxide. • Electroless plating bath-life can be considerably extended (up to tenfold) by addition of *reducing agents* such as hypophosphate.	• Practices that avoid bath contamination or involve monitoring and adjusting solution chemistry. • These are generally good operating practices and should be considered standard operating practice. • Methods and techniques of solution maintenance are typically procedural in nature.

Category	Examples	Applications/ Limitations
B8. Corrective Bath Maintenance	• *Common corrective measures* such as filtration which have been in use for many years. • More sophisticated *advanced maintenance technologies* developed as a result of rising costs of chemicals, energy and treatment/disposal and more stringent environmental requirements which mean that solution maintenance is becoming a greater priority.	• Practice of removing contaminants from the bath, whether they are dissolved or particulate, organic or inorganic. • In addition to extending bath lives, the average operating efficiency and effectiveness of a process solution is improved, therefore improving production rates and finish quality.
B8.1 Common corrective maintenance methods	• *Filtration* to remove suspended solids from solutions. Filter media are selected according to chemical nature of bath (more common for process baths, but can be used for rinse baths). • *Carbon treatment* (e.g. carbon adsorption) for removing organic contaminants present as a result of oil introduction or the breakdown of bath constituents (most commonly used for Ni, Cu, Zn and Cd plating). • *Electrolysis* (dummying) where metallic contaminants are either plated out using low current density (for Cu, Zn, Fe or Pb) or oxidised using high current density methods (for oxidising Cr^{3+} to Cr^{6+} in chromic acid baths). • *Carbonate freezing* (or crystallisation) for excessive carbonate build-up in cyanide-plating baths. • *Precipitation treatment* (usually batch treatment in spare tank or process tank) used for potassium cyanide baths, amongst others. Precipitation chemical (lime, CaOH, sodium sulphite, calcium sulphate, etc.) depends on salt/metal to be precipitated.	• In some cases, batch treatment may be performed in the process tank but this requires downtime. Continuous treatment is usually performed in a side-tank and the solution is returned to the process tank through a filter. • Typically low capital items that can be implemented with a relatively short payback. • Replacing filter media generates a solid waste that adds to operating costs, though some filters use a cleanable and reusable filter medium.
B8.2 Advanced corrective maintenance methods	• *Microfiltration* applied to aqueous and semi-aqueous degreasing baths for the removal of emulsified oil and grease. Also applicable to the recovery of cleaning solution drag-out from rinse waters. • *Ion exchange* for tramp metal removal, mainly used for the removal of tramp metal cations from hard chromium, decorative chromium, chromic acid anodise, and chromic acid copper strip solutions (since chromate is an anion). • *Acid sorption* or retardation process to remove dissolved metal contaminants from dilute to moderately concentrated acid solutions such as H_2SO_4 anodising baths and HCl pickling baths (can reduce total acid usage by approx. 30-65%)	• Advanced methods may require significant changes in process design, operation, and chemistry (e.g. changing to an alternative cleaner in order to implement microfiltration). • Technologies are generally equipment packages that have a moderate to high capital cost and payback periods of >1 year. • Application limited for some plating process/technology combinations (e.g. microfiltration should not be used for copper or aluminium).

Category	Examples	Applications/ Limitations
B8.2 Advanced corrective maintenance methods continued.	• *Ion transfer* is a continuous maintenance method for removing dissolved Fe and other tramp metals from mostly hard and decorative chrome plating baths, as well as chromic acid anodising, and chromic acid etch baths. • *Membrane electrolysis* also for maintenance of chromic acid solutions. It may be applied to non-chromium solutions, including those formulated with H_2SO_4 and NaOH. Primary function is to lower concentration of metallic impurities which combine with the acid and form metal salts. • *Diffusion dialysis* is an ion exchange membrane technology that competes with acid sorption as a purification method for acids that have become contaminated with metals.	• Ion exchange and ion transfer generate a significant waste load (therefore questionable as pollution prevention methods). • Membrane electrolysis is capital intensive and can have significant operation and maintenance problems. • HCl solutions containing Zn and Pb should not be purified using acid sorption as the metals form a strong chloride complex which inhibit the resins. • Pre-filtering is usually needed to prevent fouling of resins/membranes (generating filter-related wastes).
C. Substitute Techniques/ Technologies		
C1 <u>Product modification/ Changes</u>	• Manufacturer can change the composition or use of the intermediate or end products in order to reduce waste from manufacture, use or ultimate disposal of the products. Examples for metal finishing include: – Review *design or modify parts to reduce drag-out* (e.g. drilling drain holes in hollow workpieces). – Constant customer education for part modification & design. – *Changing material of construction* e.g. from mild steel construction to stainless steel construction may eliminate all finishing steps for a given product.	• Captive shops: manufacturers might be able to explore product changes. • Limited use for job-shops which usually have little or no control over the design of the parts they process. • Product changes might need to be evaluated in terms of customer preference.
C2 <u>Cleaning material/chemical Substitution</u>	• Use *soluble oils/ non-petroleum machine lubricants* which are simpler to recover from cleaning solutions. • Substitute *aqueous, semi-aqueous* cleaners or alternative *VOC-free* solvents for solvent degreasing. • *Bacteriological cleaners* to replace aqueous cleaners and the need for oil filtration (most applicable in large-scale galvanising operations). • *Specialty Alternatives:* – Vacuum furnace de-oiling to vapourise oils from parts. – Laser Ablation is short pulses of high peak power laser radiation to vapourise oil from part (localised cleaning in small areas possible). – Pressurised gas guns physically remove the contaminant, or plasma cleaning where gas is electrically charged.	• Changes mainly to eliminate use of chlorinated solvents. • Substitutes are generally commercially available and practical. • For speciality alternatives, the parts need to be able to withstand the required temperatures and pressures, but no solvents or even aqueous solutions are needed. • The speciality alternatives are expensive and generally still being refined for general commercial use (low operating costs).

Category	Examples	Applications/ Limitations
C3. Process material/chemical substitution	• *Non-cyanide* substitutes for cyanide-based electroplating - Substitute low cyanide concentration bath for high cyanide concentration bath - Brass pyrophosphate or zirconium nitride substitutes for brass-cyanide plating. - Zinc chloride, zinc sulphate, or zinc alkaline plating to replace zinc cyanide. - To replace cyanide copper: Cu sulphate, alkaline non-cyanide copper with cupric ions, high pH nickel for Cu strike on zinc - Gold sulphite, or palladium to replace gold-cyanide - Silver iodide, silver ammonium for silver-cyanide replacement. - Acid tin chloride to replace *cyanide* tin. • Alternatives to *cadmium* electroplating - Use zinc, cobalt-zinc and zinc-iron to replace *cadmium* on tin and tin-alloys - *Low cadmium* concentration bath for high cadmium concentration bath • Alternatives to *Hexavalent Chromium* - Trivalent chromium chloride/sulphate for hexavalent chromium in decorative plating and conversion coatings. - Substitute nickel-tungsten alloy and silicon carbide, or electroless Ni for hard chromium. - Chrome-free substitute for hexavalent chrome conversion coating - In some cases, chromium plating can be replaced with organic coatings (paint) - Sulphuric acid and hydrogen peroxide as substitutes for chromic acid in bright pickling. - Sulphuric Boric Acid Anodising (SBAA) as a direct replacement for conventional chromic acid anodising. • Alternatives to *Nickel Plating* - yellow/white bronze for decorative applications, - palladium as substitute for Ni as an intermediate layer • Substitute aluminium etch cleaner for a *non-etch* to reduce mass of metal in wastewater or etch caustic substituted for a non-dump etch • *Carbon technology* as alternative to electroless Cu in PCB manufacture • Use *non-chelating* compounds to improve performance of metal precipitation operations.	• Changes mainly to eliminate cyanide, cadmium and chromium. • Substitutes may not be commercially available in some countries. • May solve one problem yet create another by resulting in a lower quality finish or creating new health, safety or environmental problems (e.g. filtration to extend bath life involves filter element replacement, disposal and maintenance). • May therefore require LCA to objectively identify and evaluate substitutes. • Tighter chemical controls may be required for bath. • Product quality or production rate may be affected. • Cost may increase or decrease. • There is no single universal substitute for cadmium plating currently available. Primary problems include customer acceptance, quality of finish, and higher cost. • Some shops completely eliminate cadmium or chromium plating without attempting to find substitutes. • Failures are generally related to characteristics of the coating.

Category	Examples	Applications/ Limitations
C3. Process Substitution	• Usually for replacement of wet-processes. Although not generally available, they have proven as viable technologies (mainly in the USA) and are therefore worthy of consideration.	• These processes/ technologies reduce pollution or energy or material of the technologies that they replace.
C3.1 Alternative Cleaning Methods	• *Physical cleaning methods* such as wiping, blowing with air, scraping scrubbing or blasting, heating/ burning to reduce the use of cleaning solutions (e.g. blasting systems instead of paint stripping). • *High-pressure* hot water or steam cleaning also replaces solvent cleaning. • *Aqueous parts washers* can replace other cleaning systems using hazardous cleaning agents, and the detergents used in these systems are typically biodegradable. • *Pyrolysis* is a controlled burning method for powder-paint stripping that can replace the use of solvents.	• Product specifications might eliminate consideration of some process substitutes.
C3.2 Alternative processes	• *Thermal Spray Technology* is a dry process that produces a dense metal coating equal to or surpassing those of hard chrome plating. A metal rod, wire or powder is melted in a flame and atomised by a high velocity gas/air stream which propels the material from a gun onto the prepared part. There are three basic categories: – Combustion torches (High Velocity Oxy-Fuel (HVOF)), electric (wire) arc, or plasma arc (good as hard Cr plating replacements). • *Vapour deposition* processes condense materials in a vapour state through condensation, chemical reaction, or conversion to form a solid material: – In *physical vapour deposition* (PVD) the workpiece is subject to plasma bombardment, and includes: ion plating, ion implantation, sputtering and sputter-on deposition, and laser surface alloying (laser cladding). Ion VD is an alternative to anodising or decorative and tool electroplating (e.g. IVD of Al can replace Cd-, Cr-plating, or of Cu, Au to replace Cu-,Au-cyanide plating). – In *chemical vapour deposition* (CVD), thermal energy heats the gases in the coating chamber and drives the deposition reaction. CVD includes sputtering, ion plating, plasma enhanced CVD, low pressure CVD, and laser evaporation. • *Electrocoating* in brass colour to replace brass-cyanide electroplating • *50/50 Zn-Cd alloy* applied using dry plating technique to replace Cd electroplating • *Autophoretic* (electroapplied organic) coatings to replace Zn plating.	• Primarily repair operations although they are now being incorporated into original manufacturing. • Primarily high-technology applications that can bear extra costs. • Expected to improve product quality and durability. • Technologies in varying states of development; commercial availability might be limited in certain cases. • Expense often limits applications to expensive parts (e.g. aerospace, military, and electronics). • Might require improved process controls, employee training, and automation. • Start-up costs are typically very expensive. • The key advantage is virtual elimination of wet processes (especially rinse waters), though these are usually still required in pre-cleaning and posttreatment. • CVD is used primarily for corrosion & wear resistance in electronics.

Category	Examples	Applications/ Limitations
II. RECYCLING AND RESOURCE RECOVERY		
D. On-site Recovery and Recycling		
D1 Waste segregation	• *Segregate* hazardous from non-hazardous, liquids from solids, chlorinated solvent from non-chlorinated solvent, and waste streams containing recoverable metals from those containing chelating agents. • Nickel solutions separate from cyanide and ammonium solutions (nickel chelates with these making precipitation of the nickel very difficult) • Condensate from exchangers and coils in chromium/ cyanide streams separately directed to chromium/ cyanide treatment.	• Recycling and resource recovery technologies require waste streams segregation. • This will greatly improve the ultimate treatment efficiency.
D2 Reusing waste material in-process without prior treatment	• *Multiple-use rinse water* where contaminated rinse water from one process may be useful for another rinse process (e.g. acid cleaning rinse water effluent can be used as influent to an alkaline rinse system or use the same rinse bath to rinse parts after both acid and alkaline baths, or acid rinses can be used for pH adjustment in chromium reduction treatment and alkaline rinses can be used for pH adjustment in a precipitation tank) • In some cases shops are able to *reuse spent solution for a less critical application* (e.g. spent acid used for stripping, spent solvent from a precision cleaning operation as a cleaner for another process that does not require a high purity solvent), *or as a treatment reagent* (e.g. spent acid for pH adjustment).	• The subsequent waste material will be further contaminated, but in a lower volume than if additional material was used.
D3 Wastewater recycling and chemical/metal recovery (Open- or closed-loop)	• *Treated wastewaters* can potentially *be recycled back in non critical processes* such as rinsing, cleaning, pickling tanks or for floor cleaning. • Even *conventionally* (precipitation) *treated* water can be reused in non-critical rinse tanks (may need to be filtered before reuse). • More extensive treatment is necessary to produce a suitable quality of water for most rinsing needs. This involves the use of *more advanced recovery technologies*. In many cases this is the specific application of corrective maintenance technologies as treatment and recycle technologies (often the difference between continuous vs. batch application).	• Conventional treatment process generates effluent that is high in dissolved solids that will contaminate subsequent process tanks. • Recovery technologies result in additional wastes such as spent filters, membranes, cathodes, resins, and regenerant wastes. • On-site recovery technologies may prove to be only feasible for those waste streams that are expensive to dispose of and have high replacement cost.

Category	Examples	Applications/ Limitations
D4. Chemical/metal recovery processes/ technologies	- *Evaporation* (vacuum or atmospheric) where rinse water is boiled to concentrate the process solution. Steam from the process is condensed and reused for rinsing. Can be performed at low temperature under vacuum, which will prevent degradation of additives. Examples include drag-out recovery of rinse water from hot chromium baths, ambient nickel baths, and metal cyanide baths. Also used to concentrate liquid process wastes prior to hauling off-site for treatment/ disposal. - *Ion exchange* where chemical solution is passed through a series of resin beds that selectively remove cations and anions. The metals and anions are recovered by regenerating the resins (e.g. for recovery of plating chemicals from rinsewater, purification of plating solutions, and wastewater treatment). - *Electrowinning/electrolytic recovery* where a cathode and an anode are placed in the rinse solution tank, obtaining a solid metallic deposit on the cathode, that can be reclaimed or used as an anode in an electroplating tank (e.g. applied to recover the metallic content of rinse water and of spent process bath prior to bath treatment in the wastewater treatment system. Typically used to recover more valuable metals like silver and gold). - *Electrodialysis* where water is separated from dissolved salts using alternately-spaced anion-permeable and cation permeable membranes. An electric potential is applied across the membranes reverse osmosis provide the driving force (e.g. applied for regeneration of chromic acid anodising solutions and etchants, drag-out recovery of rinsewater from chromium, nickel, gold, silver, tin and zinc baths). - *Reverse osmosis* where water is separated from dissolved metal salts by forcing the water through a semi-permeable membrane at high pressure to produce a concentrated solution (returned to process bath) and purified water (reused for rinse) (e.g. it is most commonly used to purify rinse water from acid nickel baths). - *Ultrafiltration* where a solution is filtered through an extremely fine filter to remove solids, emulsions, and high molecular weight organics (e.g. applied for regeneration of alkaline cleaners, coolants, or process baths requiring removal of particles and emulsified oils). - *Diffusion dialysis* limits are 80-95% for acid recovery with 60-90% of metal contaminants removed. The recovered acid my need concentrating to permit reuse.	- To separate or concentrate chemicals/metals from rinsewaters, or other solutions, thereby making them available for reuse/recycle. - Requires significant engineering, planning, and characterisation of process chemistry. - Costs are highly variable for advanced methods. - Recovered process solutions can be returned to baths as makeup, recovered metals can be sold or returned to suppliers, and elemental metal can be sold to a reclaimer or reused on-site as plating metal anode materials. - General and site-specific factors to be considered include the advantages and disadvantages of the recovery system, the metal plated, drag-out rates, concentration of metals in the rinsewater, rinsewater flow-rates, space requirements, personnel requirements, energy requirements, and cost and payback period of the recovery system. - Ion exchange is generally not a good choice as the treated wastewater will contain a high concentration of anions that must be removed. - Reverse osmosis is not suitable for solutions with high oxidation potential such as chromic acid.

Category	Examples	Applications/ Limitations
D5 Sludge Reduction	• *Mechanical dewatering devices* to reduce sludge volumes (e.g. centrifuges, filter presses, vacuum filters, sludge dryers). • *Chemical treatments* for precipitating dissolved metals out of solution. Some chemicals produce less sludge when compared to other chemicals of comparable removal efficiency (e.g. caustic soda instead of lime, magnesium hydroxide instead of calcium hydroxide, polymers instead of ferrous sulphate and alum).	• For sludges produced in process baths and as a result of wastewater treatment processes, such as hydroxide sludges from precipitation processes
E. Off-site Recycling and reuse		
E1 Off-site Recycling	• *Centralised waste treatment* for wastes of similar type from different shops (e.g. Spent HCl pickle for steel can be regenerated at a central facility). • Can *return* spent plating solution *to manufacturer* who will reclaim the waste	• Waste materials must be acceptable to *recyclers* (e.g. chemical packaging material). • Especially for metal bearing wastewater treatment sludge, spent solvents, and spent acid • Combining wastes of similar type for centralised treatment can achieve much better economies of scale thereby rendering recovery feasible.
E2. Off-site reuse of waste material	• Use *waste* from one process *as raw material* for another process (e.g. metal wire used for jigging can be sold as scrap). • *Recover valuable materials* from a waste stream before disposal. Recovered metals may be *used as feed material* for manufacturing processes, e.g. - Copper, cadmium, and zinc feed materials for primary metals manufacturing; - Chromium for stainless steel manufacturing; and - Wood treatment chemical reagents	• Limited possibilities at present. • It is possible for metal finisher to become part of a waste exchange program.

The three primary literature sources used in compiling Table B2 were the NEWMOA (1997), UNEP WG (1998), U.S. EPA (1996) Manuals and Cushnie's US survey report (1994).

C APPENDICES FOR CHAPTER 3

C.1 Data sources for metal finishing industry statistics from other countries

Some quantitative information regarding industry structure in the US, was obtained from the '*Profile of the Metal Finishing Industry*' reported by the Waste Reduction Institute for Training and Application Research (WRITAR, 1995). Additional quantitative and qualitative information was obtained from a report entitled: *Sustainable Industry: promoting Strategic Environmental Protection in the Industrial Sector: Metal Finishing Industry* (U.S. EPA, 1994). Statistical data on the breakdown of the metal finishing industry by process was not obtained, however, this is believed to be contained in a new report soon to be made available on a Market Survey of the US surface finishing industry carried out in 1999.

For the *U.K.*, a recent statistical report by the Surface Engineering Association (SEA, 1999) indicates the total size and general breakdown of the surface finishing industry. The statistical figures, however, include supply houses, consultant organisations, printed circuit board manufacturers, as well as both in-house and job-shop surface finishers. In addition surface engineering involves more than just metal finishing and also includes plastic, wood and ceramic finishing. The statistics are therefore not specific to the metal finishing industry, however the metal finishing sector is by far in the majority. Therefore, an earlier SEA document (SEA & UK DTI, 1998) comparing the UK aqueous surface finishing industry with that of Germany was referred to for estimates on the number of both in-house and job-shop metal finishers, and these are the figures given in Table 3.1. The figures on % split between process types from the statistical report (SEA, 1999) are however considered representative, and have been used. Information regarding hot dip galvanizing (not part of the SEA) was obtained from the Galvanizers Association.

In *the Netherlands* information regarding the structure of the industry according to number of shops, was obtained from estimates given by representatives of the national metal finishing associations (du Mortier, 1999). These were only estimates and there is no guarantee of the accuracy of the figures. Statistics regarding the structure of the industry according to contribution of processes to turnover is available from additional literature obtained from the association (VOM, 1998), but this is not useful for comparison to the other countries for which similar information is not available.

Information for the *Danish* metal finishing industry was obtained from rough estimates in a report published by the Danish EPA in 1997 which included an evaluation of cleaner technology programs in the metal finishing industry (Danish EPA, 1997). No more accurate information could be gathered from the contacts on the European study tour.

There is very limited information about the profile of the metal finishing industry in *Australia*, it has been stated that the information available for the US 'is considered to be strongly indicative of the industry in Australia' (UNEP WG, 1998). The same source provides a description of the industry in the State of Queensland. Though it cannot be said that this description exactly represents the structure in Australia as a whole, it is the only information obtainable and is included as an indication of the structure.

C.2 Well-known national organisations and associations relevant to the metal finishing industry in some countries

These are presented in the table below, together with a brief description of their main functions. It was not possible to determine the membership numbers in each case, but this information is included, where available. Thereafter additional functions applicable to their roles in promoting waste minimisation are described.

Table C2: Metal finishing industry associations and organisations in some countries

Association	Function
U.S.A	
National Association for Metal Finishers (NAMF)	
American Electroplaters and Surface Finishers Society, Inc (AESF)	An international, individual-membership, non-profit professional society. 78 Branches and more than 7,000 members, worldwide.
American Galvanizers Association (AGA)	
Chemical Coaters Association International (CCAI)	A technical and professional organisation that provides information and training on surface coating technologies.
Electrocoat Association	Formed to promote the use of electrocoating and communicate the *economic and environmental* benefits of electrocoating technology to manufacturers, consumers, and the government.
Society of Vacuum Coaters (SVC)	A non-profit professional, trade and educational organisation, dedicated to the development of equipment and processes for high-volume production of coatings using vacuum-based processes. SVC seeks to disseminate knowledge, experience, and techniques to the vacuum coating industry through a variety of forums.
Institute of Corrosion	
Metal Finishing Supplier's Association	
The Powder Coating Institute	
U.K.	
Surface Engineering Association (SEA) - 2400 surface engineering members - 400 members in the MFA section	The umbrella association for the majority of the metal finishing industry associations, namely the Metal Finishing Association (MFA), British Surface Treatment Suppliers Association, and the Paint and Powder Finishing Association. There are other associations under the SEA. The range of activities of the association includes Marketing, Training, Health, Safety and Environment, Best Practice Techniques, amongst others.

Association	**Function**
Galvanizers Association (GA) - 71 members (out of a total of 85)	Part of the Zinc Development Group, and linked to the European General Galvanizers Association (EGGA) which serves as an umbrella association for the majority of European galvanizers associations. GA promotes best practice, raises awareness, and provides extensive guidance and training for member companies. It operates with a permanent staff of nine providing technical and marketing support and information.
The Institute of Metal Finishing (IMF)	
THE NETHERLANDS	
Stichting Doelmatig Verzinken (SDV) - 18 members (out of a total of 30)	The SDV is part of the umbrella organisation EGGA. Offer general advice and technical and marketing assistance.
FME-CWM - 2,400 companies in the mechanical metalworking, plastics, electronic and electrical engineering industries and allied sectors	The association representing the metal and electrical engineering industries and allied sectors. A significant number of their members perform some type of metal finishing operation - mainly electroplating in the electronics and printed circuit board industries. 60% economic, technical and environment focus.
Vereniging voor Oppervlaktechnieken van Materialen (VOM)	The surface finishing association
Stichting VOM Certificaat (SVC)	Certification board of the VOM which helps companies attain quality and environmental certification. Responsible for helping companies with quality systems, process control tests, practical improvements intended for production and attaining ISO9000 certification.
DENMARK	
Danish Galvanizers Union	Linked to the Zinc Development Corporation of the Nordic countries.
Danish Electroplating Society - approximately 50 members	Advice, marketing and training benefits for members. Members work together on projects.
AUSTRALIA	
Australian Institute of Metal Finishers (AIMF)	
Galvanizers Association Australia (GAA)?	
GERMANY	
German Society for Electroplating and Surface Technology (DGO)	To further, consolidate and disseminate knowledge in the field of electroplating and surface technology. Similar function as the UK Institute of Metal Finishing (SEA & UK DTI 1998).
The National Association of engravers, galvanizers, artisans and other related professions (BIV) - 650 members	The organisation is a grouping of artisans.
The German Electrical and Electronic Manufacturer's Association (ZWEI) - 30 members (60% of all suppliers)	To safeguard the common professional interests of its members, especially through co-operation with public authorities, organisations and other institutions, and through participation in legislation.

(Sources include: www.pfonline.com; SEA & UK DTI, 1988; Jänisch, 1999; www.EGGA.org)

C.3 Published studies on the adoption of waste minimisation within the metal finishing industry

Studies have been undertaken in a number of countries to assess the actual adoption and success of specific waste minimisation options in the metal finishing industry. The main findings from the following literature on studies in the USA, the UK and Denmark were used in Section 3.4.

The US study was a project designed to capture the collected experience of hundreds (320 respondents) of individual *electroplating* facilities in adoption of pollution prevention and control technologies. The National Association of Metal Finishers (NAMF) and National Council of Manufacturing Sciences provided assistance to the project and Cushnie (1994) compiled a report on the results of this survey. The results show which treatment, recovery and bath maintenance technologies have been adopted and which have been most successful for different plating processes. It also discusses trends in chemical substitution. It is important to note that the survey covers the electroplating sector only.

The UK Surface Engineering Association (SEA) undertook an industry statistical survey in 1997/1998 (SEA, 1999) in order to be in a position to quantify the industry sector in detail. The areas covered by this survey are electroplating, engineering painting and powder coating, and heat treatment. Amongst other topics, the survey covered waste minimisation issues in these sectors. There were more than 500 respondents. The SEA, together with the DTI International Technology Service undertook a trade mission to Germany in March 1998 to examine waste management and effluent treatment in the German metal finishing industry, with the focus on aqueous surface finishing processes. The mission hoped to learn what cleaner technologies were being used to meet the very stringent environmental standards in Germany. The findings from the Mission have been presented in a report available from the SEA (SEA & UK DTI, 1998). As a result of the findings, the SEA through its Best Practice Groups is developing process design data and investment-benefit analyses for a computer-model integrated concept plating/effluent treatment plant following German principles.

Information for Denmark was obtained from the Danish EPA's evaluation of their Cleaner Production program in the metal finishing industry between 1987-1992 (Danish EPA, 1997).

C.4 Summary list of barriers and drivers to waste minimisation in the metal finishing industry identified in international literature

The following list of barriers & drivers are applicable to general manufacturing industries, and specifically to the metal finishing industry, and were identified in the literature and during the European study tour.

Table C4: Barriers & drivers to waste minimisation in the metal finishing industry identified from experiences in other countries

Barriers to waste minimisation	Drivers for waste minimisation
Regulatory: - restrictive regulations - uncertainty and competitive imbalances due to inconsistency in existing regulatory requirements - overlap of requirements - many countries abdicate responsibility to local levels often resulting in inconsistent regulation of wastes	*Regulatory:* - stringent regulations - mandated pollution prevention - self-regulation through voluntary agreements with government - effluent charges based on load and volume so that significant savings can be made by reducing contaminants in effluent - health & safety regulations encourage Cleaner Production to improve working environments
Economic: - lack of capital and financial resources - lack of personnel - conventional cost accounting practices which do not take the wider environmental costs into account - financial risk associated with new technologies	*Financial:* - reduced compliance costs - reduced raw material and utility costs - cost savings through improved efficiency, reduced liability - federal and state loans and grants - understanding the "true" cost of wastes
Technological: - unproven technologies - poor competitiveness of alternative technologies in terms of finish quality and cost - lack of access to or availability of new Cleaner Technologies - lack of technical expertise to recognise, evaluate, or implement changes - reliance on suppliers for process optimisation - Lack of skills and facilities to test and prove production scale changes - industry diversity	*Technological:* - off the shelf technologies - R&D activities to develop new metal finishing processes to achieve source reduction

continued….

Barriers to waste minimisation	Incentives for waste minimisation
Corporate: - Management resistance to change - lack of understanding of the benefits associated with waste minimisation - lack of senior management interest and support - organisational difficulties - lack of management time (particularly in SMEs) - short-term planning frame - focus of management on lowering price - not prepared to compete on anything but price - generation of waste has been regarded as peripheral to the production process	*Corporate:* - outside-help (e.g. consultants) give an external "push" to overcome attitudinal barriers - waste minimisation option is a business opportunity
Cultural: - perception of risk with new technologies (easier to simply remain in baseline compliance) - Customer resistance to changes in the finish which result from the use of different metals or processes - waste reduction could slow down production - WR could hurt quality of product - Belief that company cannot raise prices to cover the added cost of WR, because shops that do not comply with regulations would undercut their prices	*Cultural:* - corporate image - Commercial pressure - if larger firms have an Environmental Management System, it might cascade out to their suppliers. - Management and employee training - Award schemes - improved competitiveness
Availability of information: - lack of methods to measure progress - lack of information and know-how regarding waste minimisation options - lack of trust in available information - low awareness of alternative processes	*Availability of information:* - information networks - free and easily accessed information on the internet - demonstration projects - marketing of cost benefits - good examples (case studies) - industry-specific waste minimisation opportunity guides and waste minimisation assessment manuals
Enforcement: - Inconsistent enforcement	*Enforcement:* - flexible enforcement strategies

(Source: DTI, 1991; U.S. EPA, 1996; SEA & UK DTI, 1998; ANZECC 1998)

C.5 The current organisational structure of governments and the environmental regulations affecting the metal finishing industry in some countries

The following list is not comprehensive, but provides an indication of the type and extent of environmental legislation in each country as well as an outline of the organisational structure of governments.

Table C5: The current organisational structure of governments and environmental regulations affecting the metal finishing industry in some countries

Organisational Structure	Environmental regulations (affecting the metal finishing industry)
USA	
• Pollution prevention is institutionalised within the Environmental Protection Agency (U.S. EPA). The Office of Pollution Prevention established within the agency: - co-ordinates the EPA's PP programs, - provides grants to States for establishing these programs, - develops strategies to promote WM, - encourages the incorporation of PP in the regulatory process, - undertakes co-operative efforts with industrial and professional organisations, and - Promotes prevention through outreach, education, and training (Bresnan, 1994). • Pollution prevention in the US is a co-operative effort between the U.S. EPA and the various State pollution prevention programs. States are often more in touch with industry and public needs and how best to meet them (Freeman, 1995). • The metal finishing industry is regulated on a federal, state and local level.	1. *Pollution Prevention Act* (PPA) encourages that the preferred method of pollution prevention is to reduce the volume of waste generated at the source and to perform reuse (closed loop recycling) whenever possible). Under this facilities are required to: - report releases to the U.S. EPA for the TRI (Toxic Release Inventory), - provide documentation of their procedures for preventing the release of these materials or for reusing these materials 2. The Clean Water Act (CWA) gives the U.S. EPA authority to require pollution prevention measures and raises the cost of treatment and disposal thereby creating financial incentive for waste reduction, 3 The Clean Air Act as amended in 1990 (CAA) includes requirement for the phase-out of CFCs (which are used by metal finishers in degreasing). 4. Resource Conservation and Recovery Act (RCRA) requires that facilities with permits for treatment, storage, or disposal implement a program to reduce the volume or quantity and toxicity of these wastes. (Directly regulates several metal finishing wastes as hazardous waste). It therefore creates strong financial and liability incentives for metal finishers to pursue source reduction (U.S. EPA, 1996). 5. CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) requires generators of hazardous waste to evaluate and document their operations. 6. Toxic Substances Control Act (TSCA), 7. Superfund Ammendments and Reauthorisation Act (SARA), 8. Emergency Planning and Community Right-to-Know Act (EPCRA),

continued. ..

Organisational Structure	Environmental regulations (affecting the metal finishing industry)
UK	
• Department of the Environment (DOE) is responsibility for environmental protection. • Its Protection Group inter-alia both develops policy and legislation on waste and enforces parts of the legislation through Her Majesty's Inspectorate of Pollution (HMIP). • HMIP is responsible for enforcing laws relating to industrial pollution. • The Waste Regulations Authorities (WRA's) are local authorities responsible for enforcing legislation relating to the management of controlled waste. • The government is considering bringing HMIP, NRA, and the WRA's together in one organisation - The Environmental Agency. • The Department of Trade & Industry (DTI) is responsible for encouraging sound waste management practices, especially waste minimisation and recycling, in the industrial sector. • The DOE, the NRA, and the DTI all have substantial research programs to underpin their waste policies and activities on the management of waste.	1. The *Environmental Protection Act of 1990* introduced the concept of *Integrated Pollution Control* (IPC), which applies to the release of pollutants to air, water, and land from certain processes. These processes will have to apply to HMIP and be required to meet statutory emission standards. To operate many of the prescribed processes, a company needs to obtain a license for which there is a fee and annual policing charges. To obtain and keep this license, the company must demonstrate that the process meets the environmental standards. The legislation allows for regulations to be gradually tightened to take into account emerging technologies. (The metal finishing industry was directly affected because of certain prescribed activities, including industrial cleaning and finishing). • The new European directive or Integrated Pollution Prevention and Control (IPPC) legislation (due to come into action in November 1999) requires any installation that can pollute (multi-media) to have a permit to operate. To obtain the permit, the company has to demonstrate that the plant complies with BAT (The Best Available Technology). The BAT will be decided by a European technical working group who submit a best reference Paper (BREF) – prepared as a rules document for each sector.
THE NETHERLANDS	
• The Department of Environmental Affairs falls within the Ministry of Housing, Spatial planning and the Environment. • The environmental policy is based on the National Environmental Policy plan, which was established in 1991 and is updated regularly. • Enforcement is largely carried out by the provincial and local governments. Only for very large industries, is enforcement carried out by national government.	1. The importance of cleaner production and the prevention of waste and emissions is anchored in the Wet Milieubeheer (Environmental Management Act of 1993) which requires every environmental permit issuer is to give thought to the possibilities for cleaner production and for the reuse of wastes. 2. Integrated Pollution Prevention and Control (IPPC) (1995) is an EU directive that requires that operators of industrial installations in specific categories with a high potential to cause pollution, obtain a permit in order to operate. Permit applications are expected to provide evidence that the installation meets at least the emission limit values required to give a high level of protection to the environment.

continued….

Organisational Structure	Environmental regulations (affecting the metal finishing industry)
DENMARK	
• *Danish Ministry of Environment* is responsible for environmental protection, including waste management. • The executive responsibility for waste management lies with the municipalities. • In accordance with the Environmental Protection Act, the municipal authorities are responsible for directing waste to appropriate treatment or disposal facilities and for the adequate provision of such facilities. • The National Agency of Environmental Protection administers action plans for both cleaner technology and waste and recycling. • The funding of individual projects is the responsibility of the Danish Recycling and Cleaner Technology Council. This council comprises representatives from the Ministry of Environment, industrial organisations, municipalities, counties, non-governmental organisations, and two experts on recycling and cleaner technology (Danish EPA, 1997). • The Danish Environmental Protection Agency (EPA) enforces environmental legislation. There are 17 provinces, and each province has its own way to enforce legislation.	1. The Environmental Protection Act (1992) address waste disposal, and calls for prevention and reduction of pollution of air, water and earth, as well as the waste of raw materials and energy through the adoption of cleaner technology. Pollution permits are an integral part of this Act. In the new Environmental Protection Act, the Minister for Environment can negotiate "voluntary agreements" with industry. 2. In May 1999, there was a revision of the Environmental Protection Act: - polluting companies have to involve employees in environmental work - with a focus on improvement in good housekeeping (Gregersen, 1999).
GERMANY	
The Federal government sets the general framework with regard to factory discharges. Within the general framework, individual States may set more stringent limits. Individual towns can also call for specific deviations in accord with local conditions (SLA & UK DTI, 1998).	
AUSTRALIA	
The Commonwealth government set regulations and each State is responsible for the enforcement thereof.	1. Hazardous Waste Act 1989, bans particular types of waste and waste disposal methods. 2. Environmental Protection Act (EP Act) of 1994 states that a person carrying out an activity that could cause harm to the environment has a General Environmental Duty to conduct that activity so that harm does not occur. The EP Act includes provisions for licensing of activities and enforcement. It is supported by a number of Environmental Protection Policies (EPP). 3. An EPP for Waste Management will embrace the waste management hierarchy, the basis of Cleaner Production. The proposed policy includes the provision that under certain circumstances a business may be required to prepare a Cleaner Production Plan. (ANZCC, 1998)

(Source: U.S. EPA 1996 plus others cited within the table.)

D APPENDICES FOR CHAPTER 4

D.1 Method in which the survey of the South African metal finishing industry was carried out

A list of company names to which survey would be sent was compiled from a number of sources:

- Companies already connected to the Industrial Symbiosis Project
- University of Natal Durban Pollution Research Group Waste Minimisation Club Members
- Industry association related to the metal finishing industry
- DEAT, DWAF, and municipal council databases on industries
- Chemical supply houses
- Western Cape Yellow pages (electronic yellow pages)

All company names obtained were checked and sorted to eliminate all duplicates. An attempt was then made to obtain up-to-date contact details for all companies. Assistance in entering company address data into the database was offered by other Industrial Symbiosis Project members.

A survey questionnaire was compiled based on a similar survey undertaken by the U.S. EPA and the US National Association of Metal Finishers (NAMF, 1995). Advice in setting up the questionnaire was obtained from a previous project member who undertook a similar survey of the Textiles Industry (Gilfillan, 1997). The questionnaire was also tested on two of the project member companies and given for comments to a representative from the Hot Dip Galvanizers Association South Africa (HDGASA) and members of the University of Natal Durban, Pollution Research Group (PRG). The result was a 6-page survey questionnaire consisting mainly of tables where companies were only required to tick off appropriate categories. A copy of the survey questionnaire is included in Appendix D2.

The main information requested was company characteristic data. The primary business area of the company was also requested e.g. main product market as well as process identification to determine which processes were undertaken in each of the companies. The aim was to determine the structure of the industry according to province and process type. The survey also aimed to determine the type and amounts of wastes and emissions generated by the metal finishers as well as how wastes are managed by companies. Waste and emission data was requested by asking for quantity and treatment/disposal methods for each of the liquid, solid, and air emissions from the factory. If actual figures were unavailable, best estimates were requested. Information regarding annual water consumption and energy usage was also requested, and a number of miscellaneous questions regarding awareness of Cleaner Production and industry association membership were included at the end.

In an effort to ensure as good a response as possible, chemical supply houses and industry associations were contacted and asked to supply cover letters giving their support to the survey. Four (of 6) of the supply houses contacted, and the Hot Dip Galvanizers Association South Africa (HDGASA) complied with the request. These had knowledge of the DANCED project on Cleaner Production in the South African metal finishing industry and were therefore willing to co-operate.

To further encourage companies to reply, a return-of-address envelope was provided with all questionnaires sent by post. Confidentiality was assured by keeping the company identification information on a separate page of the questionnaire and assigning code numbers to the companies in the database. Over 250 surveys were sent out by the 20 September 1999, with a requested final return date of 20 October 1999. Owing to a very low response (only 13%), in January 2000 it was decided to phone the remaining companies and request that they supply the critical information for the survey (i.e. process type, main products and size of the company) over the phone. A number of companies were found to not undertake metal finishing at all, or to outsource metal finishing activities, and so the database was reduced. However, companies were also asked to supply names of any other metal finishing companies that they were aware of in order to expand the original database. The University of Natal Durban Pollution Research Group were also contacted and asked to supply information in addition to the address data, which they had for their Waste Minimisation Club members (i.e. regarding process type and number of employees).

It was not possible to employ just any person to conduct the phone-survey as it was found that it required knowledge of process types and an understanding of the dynamics of the industry. Time constraints for all other project members, meant that the bulk of the survey had to be undertaken without assistance. This was a large task for only one person (also with time constraints) and it could not carried out as extensively as would have been liked to yield significantly representative results.

D.2 Questionnaire for the mail survey of the South African metal finishing industry

The 6-page questionnaire is included in pages D-3 to D-8.

SOUTH AFRICAN METAL FINISHING INDUSTRY SURVEY

ENVIRONMENTAL PROCESS ENGINEERING GROUP
DEPARTMENT OF CHEMICAL ENGINEERING
UNIVERSITY OF CAPE TOWN
Private Bag, Rondebosch, 7700
Tel: (021) 469-9230, Fax: (021) 424-6709

INSTRUCTIONS

All information and data contained in this survey form is ***confidential****. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form. To assure confidentiality is maintained, questions identifying your firm's name and location of the survey form (on this page) will be separated from the remaining portions of the survey form when it is received for data capturing. A code number will be assigned to each survey form. The data will be entered into a database using a code number, not the facility name. If you wish to remain completely anonymous please leave out your company name and indicate a rough location of your company (e.g. an industrial area of Cape Town) as this is needed for the analysis of the distribution of companies. The results of the survey will be sent to all companies participating in the survey that give contact details.*

The survey has ***6 pages*** *and covers the entire metal finishing industry. Therefore bear in mind that not all sections are applicable to your operations. Section 1 of the questionnaire involves facility identification and characterisation. Section 2 covers process identification. Section 3 is for questions relating to wastes and emissions, and the final Section 4 is for miscellaneous questions. Please fill in all relevant sections and* ***return to the address (a return addressed envelope is included), or fax number given above before the 21 January 2000.***

If your responses do not fit into the spaces provided, please use ordinary paper and clearly indicate which questions the response applies to. Your co-operation will be much appreciated and will contribute to a better understanding of the structure and wastes generation of the South African metal finishing industry.

Estimated time for completion of survey depends on availability of data but should not take longer than 1 hour.

SECTION 1.0 FACILITY IDENTIFICATION DATA

Name of company or corporation	
Company site/address: Street:	
City, province, postal code:	

Person that can be contacted regarding this survey (optional)

	Primary	Alternate
Name:		
Title:		
Tel no.:		
fax no.:		
e-mail:		

SECTION 1.1 FACILITY CHARACTERISATION DATA

Year of commencement of metal finishing operations on this site:
Total number of employees on this site:
Factory area (including offices on site) (m²):
Type of plating operation: Captive or Contract[a]

Primary business areas (tick all significant areas that apply):

Fabricated metal products (e.g. metal cans, fasteners, tools, metal furniture)	
Common machinery (e.g. engines, farm/construction equipment, manufacturing machinery)	
Electronic machinery (e.g. office equipment, computers, audio and visual electronics)	
General/structural hardware (e.g. gates, bars, columns, peilins, rafters, panels, grids)	
Automobiles, trucks, rail vehicles, boats (e.g. cylinders, panels, parts)	
Aerospace equipment (e.g. aircraft, satellites)	
Miscellaneous manufacturing (e.g. jewelry, toys, musical instruments)	
Household appliances (e.g. washing machines, fridges, small kitchen appliances)	
Continuous (e.g. pipes, wire, etc.)	
Other[b]	

[a] *Captive shops perform finishing activities on the parts that they manufacture and/or they subsequently use in downstream manufacturing. Contract operations or job shops do not manufacture parts or use their products in other manufacturing applications, but are separate entities offering the service of metal finishing for manufacturers. If both, indicate percentage of work that is captive or contract.*

[b] *Please specify*

SECTION 2.0: PROCESS IDENTIFICATION

2.1 Surface Preparation

2.1.1 Metal cleaning/degreasing

Type	No. of tanks	Tank volume (L)
Alkaline, immersion clean (non-cyanide)		
Alkaline, electrolytic clean (non-cyanide)		
Alkaline, descaling/desmutting/deoxidising		
Alkaline, cyanide		
Emulsion cleaning		
Spray washers		
Salt bath descaling		
Tumbling		
Abrasive blasting		
Solvent Cleaning		
Other*:		
Acid cleaning/pickling descaling/desmut/deoxidise	Fill for specific acids	
- Hydrochloric acid		
- Sulphuric acid		
- Phosphoric acid		
- Hydrofluoric acid		
- Other*		

* Please specify

2.1.2 Solvent Use

Solvent Type	Process Type [c]	Method of controlling emissions [d]
1,1,1-Trichloroethane		
Trichloroethylene		
Perchloroethylene		
Metylene Chloride		
Chlorofluoro-carbons		
Methyl ethyl ketone (MEK)		
Toluene		
Other[e] :		

[c] e.g. vapour degreasing, cold dip, spray, hand wipe, etc

[d] e.g. increased freeboard, automatic roll top, control hoist speed, added refrigeration zone, etc

[e] Please specify

2.2 Surface Finishing

2.2.1 Electroplating/Electroless Plating

Type	No. of tanks	Tank volume (L)
Brass		
Bronze		
Cadmium, Cyanide (CN)		
Cadmium, Non-Cyanide		
Chromium, Decorative (Cr^{6+})		
Chromium, Decorative (Cr^{3+})		
Chromium, Hard		
Copper, (CN)		
Copper, Pyrophosphate		
Copper, Sulphate		
Copper, Fluoborate		
Coper, Strike (CN)		
Copper, Strike (Non-CN)		
Copper, Electroless		
Copper, Other *		
Gold, Cyanide		
Gold, Non-Cyanide		
Iron		
Lead		
Lead-Tin		
Nickel, Watts		
Nickel Fluoborate		
Nickel, Electroforming		
Nickel Electroless:		
- Phosphorous		
- Boron		
- Other		
Nickel, *		
Nickel, *		
Platinum		
Rhodium		
Silver, Cyanide		
Silver, Non-Cyanide		
Tin, Acid		
Tin, Alkaline		
Tin-Lead (printed circuit boards)		
Zinc, Cyanide		
Zinc, Non-Cyanide		
Other *		

2.2.4 Chemical Conversion Coating

Type	No. of tanks	Tank volume (L)
Phosphate Coatings		
- Iron		
- Manganese		
- Zinc		
- Other*		
- Other*		
Chromate Coatings:		
- On Aluminium *		
- On Aluminium *		
- On Cadmium Plate *		
- On Magnesium *		
- On Magnesium *		
- On Zinc plate *		
- On Other *		
- On Other *		
Passivation, Type*		
Passivation, Type *		
Metal Colouring, Patina copper		
Metal Colouring, Patina steel		
Metal Colouring, Other *		
Other *		

2.2.5 Electrochemical Conversion Coating

Anodizing:		
- Boric/Sulphuric Acid		
- Chromic Acid		
- Hardcoat		
- Oxalic Acid		
- Phosphoric Acid		
- Sulphuric Acid		
- Other *		
- Other *		

2.2.6 Painting

Wet coating	
Powder coating	
Other *	

2.2.2 Stripping

Type	No. of tanks	Tank volume (L)
Anodize		
Brass		
Bronze		
Cadmium		
Chromium		
Copper		
Nickel		
Silver		
Tin-Lead		
Zinc		
Other*		

2.2.3 Case Hardening

Carburising		
Carbonitriding		
Nitriding		
Microcasing		
Other*		

* Please specify general chemistry or type

2.2.7 Hot Dip Coating

Type	No. of tanks	Tank volume (L)
(KETTLE SIZE)		
Hot Dip Galvanising		
- pipe (continuous)		
- wire		
- sheet		
- in-line		
- general		
other*		
Other *		

2.2.8 Other Surface Finishing

Bright Dipping		
- Cu/Cu Alloys *		
- Cadmium *		
- Aluminium *		
- Nickel *		
Electropolishing/ Polishing*		
Etching*		
Black Oxide		
Mechanical Plating *		
Mass Finishing		
Seal*		
Quench*		
Dye*		
Other*		

SECTION 3.0 WASTE AND EMISSIONS DATA

Please fill in the tables below for all significant waste streams, giving best estimates where actual data is unavailable:

3.1 Wastewater (Liquid Effluent) (please fill in only where applicable to your operations)

Source of wastewater	Quantity (litres/ annum)	Kept separate or mixed with other waste streams before treatment/disposal	Treatment method[f] (indicate whether onsite or off-site)	Disposal/ Recycling method[g]
Contaminated rinse water				
Spent baths (*specify all types) 1. 2. 3.				
Scrubber blowdown				
Cooling water				
Floor wash				
Other[h]				

[f] e.g. chromium reduction, metal sludge precipitation, clarification, filtration, oil removal, acid regeneration, ...

[g] e.g. spent acid removed by waste-hauler, regenerated acid reused in process, etc.

[h] Please specify

Water use and effluent:

Water source (municipality, borehole, etc.):	
Water consumption (Litres/annum):	
% water used for rinsing:	
Effluent discharged to: sewer, sea, river, other	

3.2 Solid Waste (please fill in only where applicable to your operations)

Type of solid waste	Quantity (kg/ production unit) (specify units)	Kept separate or mixed with other waste streams before treatment/disposal	Treatment method (indicate whether on-site or off-site)[i]	Disposal[j]/ Recycling method[k]
Wastewater treatment sludge				
Residues/sludges from tank cleaning (*specify all types) 1. 2 3				
Oily sludge				
Still bottoms from solvent recovery				
Metal shavings				
Scrap metal				
Dross				
Ash				
Other[l]				

[i] e.g sludge dewatering, metal recovery, stabilisation etc.

[j] e.g. removed by waste-hauler for treatment/dumping, incinerator, disposal in municipal bin, etc. (please give an indication of the cost of disposal in R/kg or R/L)

[k] e.g. zinc in dross recovered for reuse

[l] Please specify

3.3 Air Emissions (please fill in only where applicable to your operations)

Type of Air Emission	Tick	Control/Treatment Method[m]
Solvent vapour releases from degreasing operations		
Chromium (mists) from plating/anodising operations		
Powder paint dust		
Acid fumes from pickling baths (e.g. HCl fumes)		
Fumes from flux burning during hot dip coating		
Other[n]		

[m] e.g. extraction fans, scrubber for solvent vapour, mist eliminator, cyclone separator, filter, etc.

[n] Please specify

3.4 Waste Stream Components

Tick the heavy metals and other significant contaminants that are present in the solid wastes, liquid effluent (wastewater), and air emissions:

Heavy Metals	**Present in Solid Wastes**	**Present in Liquid Wastes**	**Present in Air Emissions**
☐ Chromium (Cr^{6+} or Cr^{3+})			
☐ Cadmium			
☐ Nickel			
☐ Aluminium			
☐ Copper			
☐ Iron			
☐ Lead			
☐ Tin			
☐ Zinc			
☐ Other*			
Other Contaminants			
☐ Cyanide			
☐ Oil/grease			
☐ Solvents			
☐ Acids			
☐ Alkalis			
☐ Dyes			
☐ Other*			

* please specify

3.5 Energy usage

Energy	**Usage (units/annum)**
Electricity (KWh and/or KVA)	
Gas (kg or m^3 or L) (please specify units)	
Other*	

* please specify

4. Miscellaneous (please give best estimates if actual data unavailable)

4.1 Please indicate at what % of design/max capacity your factory has been operating for the past 2 years.	1997 1998
4.2 Do you believe the industry is growing, in a good financial state, or otherwise? For what reason?	
4.3 Have you experienced any particular problems with waste/pollution from your factory? If yes, please explain briefly.	
4.4 What percentage do your waste disposal costs make up of total costs for operations? i.e. are your waste disposal costs significant?	
4.5 How do you regard your company's relationship with your local Municipal Council?	
4.6 How do you regard your company's relationship with your chemical supplier?	
4.7 Are you aware of cleaner production/ waste minimisation techniques and technologies for the metal finishing industry? If yes, please specify which ones?	
4.8 Which industry journals or newsletters does you/your company subscribe to (e.g. 'Metal Finishing', 'Aluminium News')?	
4.9 To which industry association does the company belong?	
4.10 Any other comments?	

END OF QUESTIONNAIRE – Thanks for your co operation.

D.3 The main metal finishing industry organisations and associations in South Africa

The *Hot Dip Galvanizers Association South Africa* (HDGASA) is the largest and most active metal finishing association in South Africa. It has nearly 100% membership coverage and is active in promoting the interests of its members and in helping to stimulate awareness of new potential and opportunities for its members. The HDGASA offers individual consulting for galvanizers and users of galvanized products.

The *South African Electroplater's Association* (SAEA) is an employer's body that looks after the interests of its members and the industry as a whole. It falls under SEIFSA (Steel and Engineering Industries Federation of South Africa) which is the umbrella association for the engineering industry. The SAEA is not large with only 12 members in the Johannesburg area and 1 in the Cape Town area. Its main functions have included wage negotiations with employee bodies/unions, lobbying of government/local authorities, and dissipation of advice, e.g. relating to labour issues.

The Gold Reef Branch of the *American Electroplaters and Surface Finishers Association* (AESF) has recently discontinued, as membership had declined (represented less than 20% of the sub-sector) mainly due to high membership fees (in US$) (Tyler, 1999). The AESF is in the process of breaking with the American association and re-forming itself into a purely South African Association (DANCED, 1999).

Another active association specific to the metal finishing industry is the Aluminium Surface Finishers Association (ASFA) though it has less than 5 members (membership usually gives credence to quality). Other associations related to the industry include the National Association of Automobile Component Manufacturers (NAAC), the National Association of Automobile Manufacturer's (NAMSA), and the Association of Architectural Aluminium Manufacturers (AAMSA). SEIFSA is also expected to have a number of metal finishers other than electroplaters in its various subsectors.

D.4 Barriers and drivers to waste minimisation in the metal finishing industry

Table D5a: The strongest barriers and drivers for waste minimisation in SMEs in the metal finishing industry identified by key stakeholders

BARRIERS	DRIVERS
Lack of understanding of CP principles & Lack of information	Cost savings associated with waste minimisation
Lack of finance for waste minimisation options Perceived cost implications	Use of economic instruments
Unclear legislation and definition of standards Lack of enforcement of legislation No consistent enforcement of legislation	Regulatory pressure from the government through more stringent and effective legislation
Lack of knowledge on environmental effects	Introduction of environmental specifications ISO 14000
Low water, energy, materials and effluent disposal prices	Improved environmental performance
Company culture/resistance to change	External pressure

The method of selection of these is reported in Kothuis et al (1999). The extended list of barriers and drivers from which the above were originally chosen is also included below.

Table D5b: Barriers and drivers to waste minimisation for SMEs in South Africa

BARRIER	DRIVER
CORPORATE	
Low business confidence	External pressure (e.g. clients, public)
Low business profitability	Non-tariff drivers (e.g. eco-labelling)
Lack of external pressure (e.g. clients, society, neighbours)	ISO 14000 (international standards for environmental management)
	Global competition
AVAILABILITY OF INFORMATION	
Perceived costs implications	Availability of new technology
Lack of technical knowledge	
Lack of knowledge on environmental effects	
Lack of understanding and awareness of cleaner production principles	
Perception of high risk in adopting unproven Cleaner Production options	
PRODUCTION ENVIRONMENT	
Lack of management time/surplus to address waste minimisation issues	
Working traditions and procedures	
Company culture / resistance to change	
Operational complications and technology constraints	
Perception that high flexibility is required	
REGULATORY	
Unclear legislation	Regulatory pressure from the government
Lack of enforcement of legislation	
FINANCIAL ASPECTS	
Payback periods longer than investment frame	Costs benefits (e.g. water, energy, chemicals)
Lack of access to finance / high interest rates	Economic instruments
Low costs of raw materials	

Source: (Kothuis et al. 1999)

D.5 Organisational structure of South African Government

In South Africa, the Constitution provides for concurrent legislative competence by both national and provincial government in respect of the environment. It is quite likely that some provinces will set more stringent standards than the nationally required minimum (as is the case in the Durban Metropolitan area regarding heavy metals), which may require the use of different technology by industries operating in more than one province (e.g. metal finishing industry).

The role of the Department of Trade and Industry (DTI) includes, amongst others, the planning and promotion of South African industrial sectors.

Pollution control is administered by a number of national, provincial and local government departments. Responsibility for air quality is presently administered by the Department of Environmental Affairs and Tourism (DEAT). Hazardous substances are regulated by the departments of Health and Labour. Freshwater pollution is controlled by the Department of Water Affairs and Forestry (DWAF), and seawater pollution by the DEAT and DWAF. For the control of solid waste at present, some aspects fall under the DEAT, others under the DWAF, and most aspects are taken care of by local authorities with little or no guidance from central government (Lazarus et al. 1997).

Local authorities are responsible for ensuring that discharges from local sewage plants are within the limits set by DWAF. The metal finishing effluents discharged to sewer must comply with limits set by local authorities, which in turn, must comply with the requirements set by DWAF. Industries discharging directly to the marine environment must answer to the DWAF (DANCED, 1999).

E APPENDICES FOR CHAPTER 5

E.1 Chromium Surface Conversion Chemistry

Compositions of the conversion chemicals are proprietary and there is little known about the exact composition of the chemicals used due to confidentiality on behalf of the supplier. Therefore, information on the chemistry of the chromate conversion reaction is based on explanations given in the technical literature.

The substrate metal participates in the coating reaction and becomes a component of the coating; and it has a profound influence on the properties of the coating. Normally a given chromate is designed to work on a particular metal; but in a few cases there are solutions that will work on two or more (Brummer, 1990).

Chromates for aluminium fall into two categories: chrome-phosphates, primarily those used on architectural aluminium extrusions to provide a paint-bonding coat, and Chrome-oxides applied to almost every type of aluminium for paint bonding and corrosion resistance (Kirk & Othmer, 1995). The proprietary solution in the company contains both chromic acid and phosphoric acid and initially believed to be a chrome-phosphate type. The chemical supplier however confirmed it to be the chrome-oxide type. Since the final film on the products is golden-yellow, this confirms that it is the chrome-oxide type, as chromium-phosphate films are greyish-green in colour.

The chemistry involves reaction between the metal surface and an aqueous solution containing chromates and certain activator ions. Activators include: sulphates, chlorides, fluorides, phosphates and *complex cyanides*. The solutions for chromating are acidic Chrome-oxide baths are acidic and made up from sources of hexavalent chromium, complex fluoride, fluorsilicates, fluorzirconate, and silicofluorides (Kirk & Othmer, 1995).

A simplified reaction proceeds along these lines:
1. Metal at the interface is dissolved by the acid and enters the solution as metal ions.
2. There is a local rise in pH (lowering acid content) in the immediate vicinity of the interface.
3. Base metal ions combine with chromate ions to form a compound that is insoluble at the local (higher) pH. This compound precipitates on the metal surface as an adherent coating.
4. Reaction by-products enter the main solution.

(Brummer, 1990).

The sequence of reactions in the chromium chromate process on aluminium are as follows (Kirk & Othmer, 1995):

Oxide removal: $Al_2O_3 + 6HF \rightarrow 2ALF_3 + 3H_2O$
Redox reactions: $HCrO_4^- + 7H^+ + 3e^- \rightarrow Cr^{3+} + 4H_2O$
$Al^0 \rightarrow Al^{3+} + 3e^-$
Cr reduction: $8H^+ + 2HCrO_4^- + 2Al^0 \rightarrow 2Al^{3+} + Cr_2O_3.3H_2O + 2H_2O$
(Kirk & Othmer, 1995)

The film's structure can be described as a cross-linked Cr(III) polymer, that uses anion species to link chromium centres. These anions may be hydroxide, chromate, fluoride, and/or others depending on the composition of the bath. Although the solution contains chromium in the hexavalent form chemical reduction takes place on the metal at the point of application, so that the chromium in the coating is essentially all trivalent chromium (Brunner, 1990).

The corrosion inhibition is due to the formation of a protective mixed chromium/metal oxide film which forms as a result of the electrochemical reduction of the chromate ion. Additional corrosion protection is provided by chromate ions entrapped in the coating. These ions are readily leached from the coating and act as corrosion inhibitors (Hinton, 1991). The chromate coating's ability to improve the adhesion of paint coatings is related to the cellular structure of the mixed oxide film that provides a base with more attachment points (Ibid.).

E.2 Chemistry of Passivation

The chromic acid rinse serves the following purposes (Brunner, 1990):

1. It dissolves any trace of water-soluble salts in the pores of the chromate/phosphate coating, or converts them to water insoluble salts.
2. Trace amounts of soluble chromate are left on the surface, which effectively improves the salt spray resistance.
3. It forms a thin passive oxide film in the pores of the phosphate

Chromic acid (CrO_3) dissolves in water to yield the theoretical H_2CrO_4. The $HCrO_4^-$ ion shows a distinct tendency to dimerise to $Cr_2O_7^{2-}$ at low total Cr(VI) concentrations. The exact concentration of chromate(VI) anions present in aqueous solution is a function of both pH and hexavalent chromium concentration. However, when the pH is between 2 and 6, an equilibrium mixture of $HCrO_4^-$ and $Cr_2O_7^{2-}$ is present (Kirk & Othmer, 1995).

E.3 Hazardous nature of input materials

The (DWAF, 1998) definition of hazardous is based on the chemical reactivity or toxic, explosive, corrosive or other characteristics which cause, or are likely to cause, danger to health or to the environment, whether alone or when in contact with other waste.

A Hazard Rating is a system of classifying and ranking hazardous waste according to the degree of hazard they present. This is based on Mammalian Acute and Chronic toxicity, Ecotoxicity, and Environmental Fate. Based on this hazardous waste is classified as:
Hazard rating 1 = Extreme hazard
Hazard rating 2 = High Hazard
Hazard rating 3 = Moderate hazard
Hazard rating 4 = Low hazard

SODIUM HYDROXIDE -NaOH
Hazard rating = 3 (Severe-Poison)
Excessive inhalation of dust is irritating and may be severely damaging to respiratory passages and/or lungs. Contact with skin or eyes may cause severe irritation or burns. Ingestion is harmful; may be fatal or cause severe burning of mouth and stomach or cause nausea and vomiting. Acute toxic effects may include the death of animals, birds, or fish, and death or low growth rate in plants. NaOH has high acute toxicity to aquatic life. Chronic toxic effects may include shortened life span, reproductive problems, lower fertility, and changes in appearance or behaviour.

CHROMIUM -Cr
Acute and chronic toxicity:
Chromium is non-volatile and is very insoluble in water. Therefore, if spilled on land it tends to stay in the top five centimetres. Chromium is highly persistent in water, with a half-life of greater than 200 days. It is toxic to plants at concentrations higher than 0.2 to 0.4%. Chromium can bio-accumulate in plants and animals. Acute toxic effects (those seen in two to four days after contact) may include the death of animals, birds, or fish, and death or low growth rate of plants. Chromium is more toxic in soft water than hard water. The primary routes of entry for animal exposure to chromium compounds are inhalation, ingestion, and, for hexavalent compounds – skin penetration. This last route is more important in industrial exposures. Most hexavalent chromium compounds react with cell membranes. Although hexavalent compounds are more toxic than those of Cr(III), an overexposure to compounds of either oxidation state may lead to inflammation and irritation of the eyes, skin, and the mucous membranes associated with the respiratory and gastrointestinal tracts. Skin ulcers and perforations of nasal septa have been observed in some industrial workers after prolonged exposure to certain hexavalent chromium compounds i.e. to chromic acid mist or sodium and potassium dichromate

All chromates are acidic and will attack living tissues. Damage to eyes can be especially severe. Skin burns may be slow to heal and secondary infections can result. Materials high in fluoride can cause sores that are even more resistant to healing. In addition to their acid properties, chromates are strong oxidisers and may cause spontaneous combustion if the concentrated products are mixed with other substances, especially paper wood or flammable solvents.

HEXAVALENT CHROME Cr^{6+} or Cr(VI)
Hazard Rating – 1 (Extreme)
Hexavalent chromium is a recognised toxic material with carcinogenic properties. Hexavalent chromium compounds are corrosive and cause chronic ulceration and perforation of the nasal septum when inhaled. They also cause chronic ulceration of other skin surfaces. Chromium (VI) has high acute toxicity to aquatic life.

TRIVALENT CHROMIUM Cr^{3+} or Cr(III)
Hazard Rating – 3 (Moderate)
Trivalent chromium compounds are naturally occurring and are considerably less toxic than the hexavalent compounds and are neither irritating nor corrosive. Chromium will convert from hexavalent to trivalent form naturally over a long period of time in the presence of organic matter. Chromium (III) has moderate acute toxicity to aquatic life. No carcinogenic potency has been demonstrated for Cr(III)

compounds. While Cr(III) can be removed more readily, accumulation of chromium in biological treatment sludges contaminates the wasted sludges.

FLUORIDE –F^-

Not listed as hazardous and not monitored.

POWDER PAINT

(According to the material Safety Data Sheet from the paint supplier)

Based on the composition and performed toxicity studies with the product, the preparation can be considered as an inert dust. Total dust content (TLV) 10mg/m^3 (50% fine dust). Precautions should be taken to prevent the formation of dust in concentrations above flammable, explosive, or occupational exposure limits. Ignition temperature of dust is 500-600°C. Avoid inhalation of dust. Where reasonably practicable, this should be achieved by use of local exhaust extraction and good general ventilation. If these are not sufficient to maintain exposure below the exposure limits, suitable respiratory protection must be worn (e.g. dust masks). Lower exposure limit of dust/air mixture is 35-90g/m^3. Recommended value for powder in air for plant design: not to exceed 10g/m^3. pH value in water will not change.

Toxicological information: There is no further data available on the preparation itself. Animal tests and long term use of powder coatings containing no dangerous substances have shown no specific risk. Powder coatings can cause localised skin irritation in folds of skin or in contact with tight clothing.

TRIGLYCIDYL ISOCYANURATE –TGIC

TGIC is the cross-linking compound used in the powder paints. It has a number of occupational health effects. Lately (since May 1998) this has resulted in reclassification of TGIC according to EEU occupational health marking. The health effects of TGIC are allergic dermatitis among workers exposed to TGIC or TGIC powder paints. Nasal, eye and throat irritation, skin rash and nose bleeds have also been documented.

Ecological Information: There is no data available on the preparation itself. Tests and long term use of powder coatings have, in general, shown no specific risk. If powder coatings are applied and stored according to the recommendations, emissions will be within the legal limits. The extract of a typical powder coating with rainwater shows that a deposit will not affect ground or surface water substantially.

Sources:

http://www.epa.gov/chemfact/ - U.S. EPA OPPT Chemical Fact Sheets

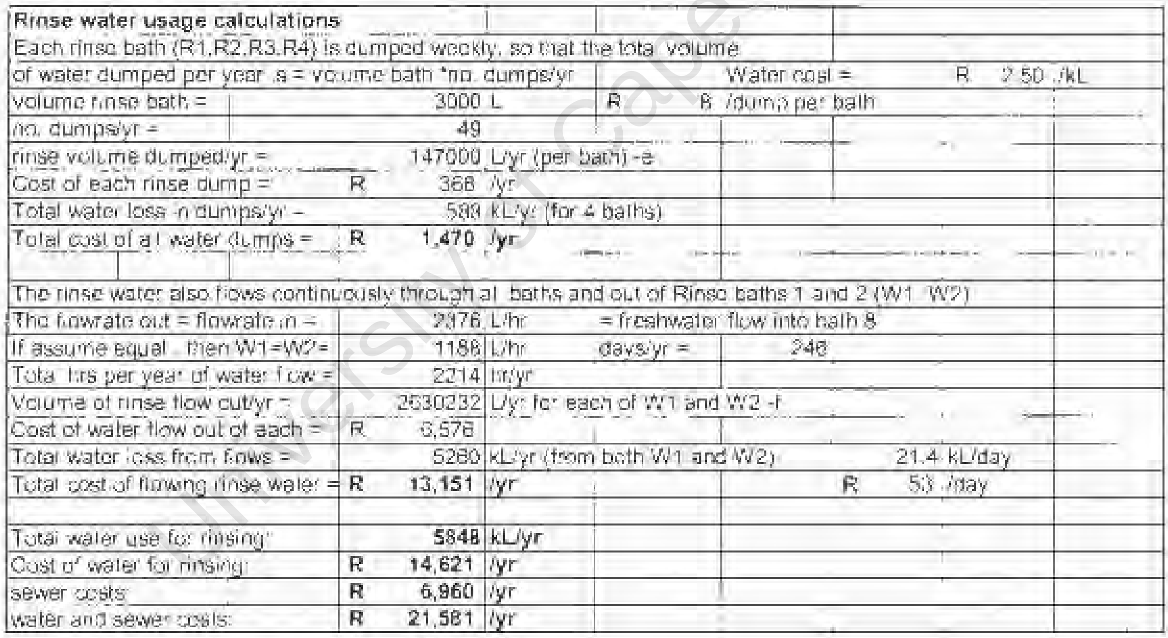
http://www.nsc.org/EHC/ew/chems – Environment Writer *Chemical Backgrounders*, Chemical Information Environmental Health Center, A division of the National Safety Council, USA

Prager, J. (ed.) - Dangerous Property of Industrial Materials Report, as cited in UNEP WG (1998).

E.4 Water Consumption Measurements and Calculations

The water flowrate through the rinse system needed to be measured, as only total water usage (according to municipal meter) is known. The method used was the bucket & stopwatch method, and was applied to the incoming waterflow (into Rinse bath 4). It is assumed that the flowrate into and out of the baths is equal. Two sets of measurements were taken by Dhliwayo (1998) during the pre-assessment. An average of 9.9L was collected in 15 seconds. The flowrate was therefore determined to be 2376L/hr, or 5260kL/yr

Although the capacity of each of the baths is 3700L, the solution volume in each bath is assumed to be 3000L and all chemical additions are made based on this (chemical supplier recommendation). The rinse baths are therefore assumed to contain 3000L water each on dumping at the end of each week. Number of rinse bath dumps was estimated at 49/yr (based on operating weeks/yr and input from the manager). The total volume of water dumped per year per bath was therefore calculated and multiplied by 4 to give the total water used in this way (i.e. for refilling rinse baths). The working was carried out in the spreadsheet below;



Rinse water usage calculations							
Each rinse bath (R1,R2,R3,R4) is dumped weekly, so that the total volume							
of water dumped per year is = volume bath *no. dumps/yr				Water cost =		R	2.50 /kL
volume rinse bath =		3000	L	R	8 /dump per bath		
no. dumps/yr =		49					
rinse volume dumped/yr =		147000	L/yr (per bath) -e				
Cost of each rinse dump =	R	368	/yr				
Total water loss in dumps/yr =		588	kL/yr (for 4 baths)				
Total cost of all water dumps =	**R**	**1,470**	**/yr**				
The rinse water also flows continuously through all baths and out of Rinse baths 1 and 2 (W1, W2)							
The flowrate out = flowrate in =		2376	L/hr	= freshwater flow into bath 8			
If assume equal, then W1=W2=		1188	L/hr	days/yr =	246		
Total hrs per year of water flow =		2214	hr/yr				
Volume of rinse flow out/yr =		2630232	L/yr for each of W1 and W2 -f				
Cost of water flow out of each =	R	6,576					
Total water loss from flows =		5260	kL/yr (from both W1 and W2)			21.4 kL/day	
Total cost of flowing rinse water =	**R**	**13,151**	/yr			R	53 /day
Total water use for rinsing:		**5848**	**kL/yr**				
Cost of water for rinsing:	**R**	**14,621**	**/yr**				
sewer costs:	**R**	**6,960**	**/yr**				
water and sewer costs:	**R**	**21,581**	**/yr**				

Water use as solvent in process baths:

The chemical baths need to be maintained in a given concentration range (chemical supplier specifications). Thus since chemicals and water are lost through usage, drag-out and evaporation, regular additions of chemicals and water are made to each bath. The chemical additions are recorded, but the water additions are not. However, the water additions may be roughly estimated based on calculations that take the total chemical additions made per bath for the year and divide these by the initial bath concentrations. Although there is room for error, the result at least will indicate order of magnitude of water use. The calculations used to determine water use in this way were carried out using the spreadsheet below.

WATER USE As Solvent							
Process Bath	content	concentra	unit	additions per annum	unit	equivalent water (kL)	
Degreaser	sodium phosphate	0.03	kg/l	444	kg	14.8	
Etch	sodium hydroxide	0.03	kg/L	1414	kg	47.1	
Desmut	Nitric acid	0.06	L/L	1330	L	22.2	
Chromate	Chemical 1	0.044	L/L	1393	L	31.6	
Passivation	chromic acid	0.0003	L/L	38	L	125.7	
TOTAL WATER for additions		**(loss through drag-out and evaporation)**				**242**	**kL/yr**
TOTAL WATER for bath make-up						**21**	**kL/yr**
SUBTOTAL						**263**	**kL/yr**
Water additions are determined as such: if chemical additions are known and concentration is maintained, then water additions							
must be such as to keep concentration. Therefore, water = chemical (kg)/ concentration (kg/L)							
Note: only the one chromate chemical is used in calculations since a single amount of water is added for the two chemicals							
Note: the amount of water added to the passivation bath cannot be calculated in this way, since the bath is replaced every week							
and water is added to replace evaporation							

Total water usage:

The total water usage was measured through water meter readings. A mass balance was then used to determine 'other' water usages (domestic,etc.) The spreadsheet used for these calculations is included below:

Total water usage Calculations:						
	kL/yr		% of tota			
bath make-up =	21		0.3%			
bath additions =	242		3.2%			
rinse dumps every week =	588		8%			
continuous rinsing =	5260		69%	Cost		
Total =	6112	kL/yr	80%	R	2.50	/kL
days of operation:	246			R	15,280	/yr
Usage per day =	24.8	kL/day		R	62	/day
Water meter readings taken for a period of 1 week:						
	reading	unit	usage			
Mon am	76059	m3	33 Monday+night			
Tues am	76092	m3	30 Tuesday+night			
Wed am	holiday					
Thurs am	76122	m3				
Thurs pm	76144	m3	22 Thursday day			
Fri am	76152	m3	8 Thursday night			
			30 Thursday+night			
	average:		31 kL/day			
			246 days/year of operation			
			7626 kL/year	R	19,065	/yr
This seems to indicate that there can be 8kL used over night?						
				water cost:		
Other usage is therefore:	1514	kL/yr	20%	R	3,785	/yr
	6	kL/day(and night)				
33%	of this is usage for overtime runs for pre-treatment					
500	kL/yr used for domestic and 'other' uses		7%	R	1,249	
Effluent charges are based on:			75% of incoming water usage			
	at a rate of:	R	1.70 /kL			
Effluent charges therefore:		R	9,723 /yr			
Total water bills should therefore be:		R	28,788 /yr			
Actual water bills for 1999 were:		R	30,207 /yr			
This is considered close enough considering room for error in each of the calculations.						
		R	1,419			

The high volume of 'other' water uses was queried. The water meter readings indicate that much of this water is used over nightshift and the manager indicated that 1/3rd of this is mostly due to overtime runs of pre-treatment, which are required when an order needs to be completed in a shorter time, or production is very high.

E.5 Sewer Limits and charge formula according to local by-law

The Cape Metropolitan Council (CMC) controls any direct or indirect industrial effluent discharge in the Cape Town region. On 1 July 1997, the "Industrial Effluent By-Law" came into effect. It incorporates a metal loading factor (MLF) to calculate effluent charge. The following charge formula is applied:

$$Charge[R] = V * \left[R + T\left((\frac{1}{3} + \frac{COD}{1500} + MLF \right) \right]$$

Where
V = total volume, expressed in kL, of industrial effluent discharged from the premises during the cycle concerned
R = cost of conveying one kL of sewage (R0,45)
T = cost of treating one kL of sewage (R0,76)
COD = chemical oxygen demand of such effluent in mg/L
MLF = metal ion loading factor of such effluent calculated according to the formula:

$$MLF = \left(\frac{Fe-50}{50} + \frac{Cr-10}{10} + \frac{Cu-20}{20} + \frac{Zn-30}{30} + \frac{Cd-5}{5} + \frac{Ni-5}{5} \right)$$

where
Fe = iron concentration of such effluent in mg/L
Cr = chromium concentration of such effluent in mg/L
Zn = zinc concentration of such effluent in mg/L
Cd = cadmium concentration of such effluent in mg/L
Ni = nickel concentration of such effluent in mg/L

The total volume of effluent is classified or measured by the CMC for each single company individually. The volume of effluent is estimated as a percentage (about 70-75% for the two companies concerned) of the total fresh water consumption. In theory, the water consumption is calculated by the local municipality as the total water consumption (as per meter readings) minus the estimated domestic usage (based on the number of people and average usage/person). If more direct industrial usage values are known (sub-meter readings), these are used instead.

The table below shows the CMC regulations for various parameters regarding effluent discharged to sewage works:

Table E5: Effluent limits for discharge to sewer

Parameter	Unit	Limit (not to exceed)
Temperature at point of entry	°C	40
Electrical conductivity at 25°C	MS/m	300

Parameter	Unit	Limit (not to exceed)
pH at 25°C		Between 5.5 and 12
COD	mg/L (ppm)	5000
Iron as Fe	mg/L (ppm)	50
Chromium as Cr	mg/L (ppm)	10
Copper as Cu	mg/L (ppm)	20
Zinc as Zn	mg/L (ppm)	30
Total of Fe +Cr + Cu + Zn	mg/L (ppm)	50
Nickel as Ni	mg/L (ppm)	5

According to a representative from the local council (Walpole, 1999), the existing City of Cape Town bylaw (prior to the new proposed bylaw of 1997 which is yet to come fully into effect), specifies a sewer limit for hexavalent chromium in effluent of 0.05ppm. This is because hexavalent chromium is not precipitated and goes straight through the sewage treatment works. The city of Cape Town by-law, although operating in the Cape Town region, is not operable in the industrial regions where the case-study companies are located. The new proposed by-law (outlined above) only specifies a limit for total Cr of 10ppm, and does not refer to Cr(VI) content. However, the by-law does regulate according to the BATNEEC principle, and according to the council representative it is considered reasonable to request that hexavalent chromium be treated using conventional treatment methods, as the chromium can be effectively reduced at low cost in this way.

In theory, effluent analysis is performed by the CMC four times during a six month period. The effluent quality is determined as the average of the 4 samples (or the median if there are far outlying values). Effluent charges are based on the charge formula, which takes into account the total volume of effluent discharged. This is then multiplied by a factor incorporating the conveyance and treatment costs, the COD content and the metal loading factor. In practise, the frequency of sampling seems to depend on the company.

Changes in the future:
It is planned by the CMC in the near future to change the metal loading factor (MLF) into a general loading factor (GLF). This formula will take into account, both the metal limits mentioned above, as well as pH, temperature, and conductivity. Therefore, exceeding any of those limits would have a direct consequence in the calculated effluent charge (CMC, 1999).

E.6 Calculations to determine chemicals lost in wastewater.

It is difficult to measure the actual drag-out from the baths owing to considerable variation in type and rate of production which means that it is unclear how representative any drag-out measurements are. Measurements of drag-in are even more complicated since the drag-out from every bath is combined in the counterflow rinsewaters and it is difficult to pinpoint the source of a particular contaminant, especially acid/alkali. The exception is for the chrome, as there is only one source of chrome dragged into the rinsewater.

Cr content of the rinse water was measured by Dhliwayo and further samples were taken as checks on the findings. The results are presented below.

Measurements of Cr content of the rinse baths										
Sample source		RESULTS FOR DHLIWAYO					CHECK RESULTS			Combined Average
		Dhliwayo1	Dhliwayo2	Dhliwayo3	Dhliwayo4	Cr(VI) ave	CJ1	CJ2	average	
R1	Cr(tot)	4.52	5.22	5.32	5.0		4.54	3.20	3.9	4.4
	Cr(VI)	4.00	4.91	5.18	4.7					
		89%	94%	97%	94%	94%				
R2	Cr(tot)	4.39	6.32	5.70	5.5		3.77	2.90	3.3	4.4
	Cr(VI)	3.66	5.39	5.15	4.7					
		83%	85%	90%	87%	87%				
R3	Cr(tot)	4.89	6.27	6.31	5.8		4.35	3.60	4.0	4.9
	Cr(VI)	3.11	5.00	4.60	4.3					
		64%	80%	74%	73%	73%				
R4	Cr(tot)	12.29	10.05	10.80	11.0		13.33	13.20	13.3	12.2
	Cr(VI)	11.56	9.02	10.03	10.2					
		94%	90%	93%	92%	92%				
W1	Cr(tot)	4.57	5.51	5.50	5.2		4.60	3.32	4.0	4.6
	Cr(VI)	4.11	5.24	5.17	4.8					
		90%	95%	94%	93%	93%				
W2	Cr(tot)	4.49	6.64	6.00	5.7		3.81	3.14	3.5	4.6
	Cr(VI)	4.42	4.09	5.63	4.7					
		98%	62%	92%	82%	82%				
					average	90% Cr(VI)				

Based on the measured concentration of Cr(VI) in the wastewater (from Dhliwayo's measurements), and the known quantity of Cr(VI) in the chromate chemical 1 (given by supplier), the amount of chromate chemical lost to drain per year was calculated. It was necessary to assume that all the Cr(VI) arose from chromate chemical 1 (i.e. chromate chemical 2 was not taken into account as it Cr(VI) content is unknown and assumed to be small in comparison to chemical 1). The calculations were performed using a spreadsheet which is included below.

RINSE WATER				
Loss of chromate chemical 1 in rinse water				
Chrome content of conversion chemical 1 =	c		63.3	g of Cr(VI)/L concentrate
	d		2.79	g of Cr(VI)/L solution
Cost of chem 1/L =	l	R	11.00	/L
Total usage of chemical 1/yr =	m		1393	L/yr
Total cost of chem 1 usage/yr =	n	R	15,318	/yr
Cr and Cr(VI) content in rinse water has been analysed by Dhliwayo				
R1 to R4 are the contents in the rinse bath. W1 & W2 are the contents of rinsewater leaving baths 1 and 2.				

Rinse bath	Cr (mg/L)	Cr(VI) (mg/L)	Total Cr g/yr	Total Cr(VI)g/yr	L of chem 1 lost in rinse/yr	% of total chem 1usage	Cost/yr of wasted chem1 in rinse		
	a	b	=a*e	=b*e =g	=g/c =j		=j*l		
R 1	5.02	4.70	738	690	10.9	0.8%	R	120	
R 2	5.47	4.73	804	696	11.0	0.8%	R	121	
R 3	5.82	4.27	855	627	9.9	0.7%	R	109	
R 4	11.05	10.20	1624	1500	23.7	1.7%	R	261	
subtotal 1			**4022**	**3513**	**55**	**4.0%**	**R**	**610**	0
			=a*f	=b*f=h	=h/c =k		=k*l		
W1	5.19	4.84	13650	12730	201.1	14.4%	R	2,212	
W2	5.74	4.71	15098	12397	195.8	14.1%	R	2,154	
subtotal 2			**28757**	**25127**	**397**	**28.5%**	**R**	**4,367**	
Total		5.58	**32779**	**28640**	**452**	**32.5%**	**R**	**4,977**	0
If it is assumed that the majority of the Cr(VI) comes from chemical 1, then the volume of concentrate									
in each rinse can be determined by dividing the Cr(VI) mass (g and h) by c									

The drag-in from the etch and desmutting baths was estimated based on this result for the chromate bath. Based on rough indications of comparative viscosity, the drag-in for the other baths was estimated. The working is presented in the spreadsheet below.

DRAG-OUT losses:		
DRAG-OUT loss from chromate bath:		
this has been calculated at	32%	of total usage.
It is difficult to compare this value to the drag-out from other baths since viscosity of different chemicals affect d-o		
However, as a rough estimate based on order of magnitude, and making allowances for increased concentration		
and temperature, the following drag-out volumes are estimated:		
Etch bath:		
Concentration is 30% lower and temperature is 40degC higher than chromate bath		
Therefore drag-out is expected to be lower.		
As a rough estimate assume 50% decrease in drag-out		
Therefore, loss of Etch chemical through drag-out to rinsewater is estimated at:	16%	of total usage
	274	kg/yr
	R 2,320	/yr
Acid bath:		
Concentration of acid is 40% higher and temperature is same as chromate.		
Drag-out from desmutting tank to rinsewater is assumed to be approximately equal (viscosity not taken into account)		
Therefore, loss of Nitric acid through drag-out to rinsewater is estimated at:	30%	of total usage.
	399	L/yr
	R 1,061	/yr
Therefore total loss of chemicals through drag-out into rinsewater	R 8,358	

There is no indication as to how accurate these figures are, and they can only be considered very rough estimates. However the estimates were discussed with the Manager and considered sufficiently representative for the purpose of these calculations.

E.7 Measurement of Chrome Content of Passivation Solution

Samples of the passivation bath were taken at the end of the week prior to dumping after 2 relatively high production weeks. These were then analysed for total Cr content by the UCT main laboratory personnel. The analysis results are considered to be within 90% confidence. The representative nature of the samples is considered sufficiently accurate to prove the Cr content is above the 10ppm limit. The results are as follows:

Sample from Passivation Bath	**Measured Cr content in ppm**
Sample week 1	42.66
Sample week 2	36.36
Average	**39.51**

E.8 Chemistry of spent chromate bath treatment

Unlike most heavy metals which are precipitated readily as insoluble hydroxides by pH adjustment, Cr^{6+} must first be reduced to the trivalent state because Cr^{6+} forms the chromate complex which behaves as an anion (CrO_4^{2-}) and cannot form an insoluble hydroxide (Cushnie, 1994). Conventional chromium reduction is achieved by reaction of Cr^{6+} with a reducing agent. The reducing agent used at Company 1 is

sodium metabisulphite dry granular powder. This hydrolyses in water to form the hydrogen sulphite ion which is readily oxidised to sulphate:
$Na_2S_2O_5 + H_2O \rightarrow 2Na^+ + 2\,HSO_3^-$
$SO_3^{2-} + 2OH^- \rightarrow SO_4^{2-} + H_2O + 2e^-$
This reaction shows that oxidation is favoured by alkaline conditions. However the Cr(VI) reduction half reaction is favoured by acidic conditions, in accordance with the following reaction:
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

Cr(VI) is reduced with much greater difficulty in alkaline solutions. Hence conventional Cr(VI) reduction is normally carried out in the pH range 2-3. The treatment of the chromic acid with sodium bisulphite involves the following reaction:
$2H_2CrO_4 + 3NaHSO_3 + 3H_2SO_4 \Leftrightarrow Cr_2(SO_4)_3 + 3NaHSO_4 + 5H_2O$

The reaction takes place almost instantaneously at a pH of 2.5. The low pH of the reaction is a drawback since the subsequent metal removal step is performed at an elevated pH (typically 7-8). The Chromium reduction process is capable of producing an effluent with <0.1mg/L Cr^{6+}. Subsequent neutralisation is achieved by adding lime to precipitate the Cr^{3+} as chromium hydroxide:
$Cr_2(SO_4)_3 + 3Ca(OH)_2 \Leftrightarrow 2Cr(OH)_3 + 3Ca_2SO_4$

This needs to be carrid out at max pH=8, since the Cr^{3+} redissolves at pH 9. The lime dissolves slowly, so a little is added at a time and mixed in over a period of a few days. Water-treatment Lime is used, as it is stronger than regular lime and will therefore produce less bulk for the same pH adjustment. The theoretical quantity of sodium bisulphite required to reduce 1 kg of hexavalent chromium is approximately 3kgs. Though actual chemical requirements for chromium reduction and pH adjustment are generally much greater than theoretical or estimated quantities presented by most references. They can be up to 5 to 10 times more than theoretical dosages (Cushnie, 1994).

There are a number of other options e.g. magnesium hydroxide, calcium chloride, sodium carbonate. Each alkali has advantages and disadvantages. E.g. lime has the advantage of lower cost/unit of neutralising capacity, metal hydroxides produced have a faster settling rate, and settled sludge from lime treatment is higher in solids content and much more amenable to dewatering. However, lime takes longer to react than NaOH and it generates a considerably higher mass of sludge solids.

E.9 Paint usage measurements and calculations

It was decided to measure the **cyclone efficiency** directly, by spraying a known amount of powder directly into the extraction duct in the spray booth. In order not to waste valuable powder and to minimise loss in production time, these test samples had to be small in size (2kg). A known amount of paint (2kg – weighed before hand) was placed in the hopper. The spray gun was then pointed directly at the exhaust hole in the spray booth leading to the cyclone, and the cyclone system was run. When the hopper was emptied, the amount of paint collected in the reclaim bin was weighed again. The first test was done with a leaking hopper extension pipe and loss was high.

It was then redone with non-leaking spray equipment. The results for each test are set out below:

DIRECT MEASUREMENT OF CYCLONE EFFICIENCY			
	Test 1	Test 2	Test 3
mass in (kg)	2	2	2
recovered (kg)	1.5	1.78	1.71
loss (kg)	0.5	0.22	0.29
efficiency:	75%	89%	86%
For test 1 there was a leak from the hopper connective tube			
Therefre, average is for Test 2 and 3 only:			
Average:	87%		
Loss due to leak:		12%	

It would have been better to use a higher mass of paint, but this could not be done due to the effect on quality and the time taken for the test. Although there is room for much error in the results, they serve as an indication of the loss of paint in the recovery system (whether on the walls of the cyclone, the insides of the reclaim bin, or out the exhaust to atmosphere). These were rough measurements to give a working value for efficiency of the cyclones in the pre-assessment.

Direct measurements of **coating thickness** were carried out on extrusion samples. A pretreated sample was weighed before painting (after pre-treatment), and after painting and curing. The difference in these two masses, gives the mass of paint on the sample. The sample area was calculated. The weight/area gives the coating thickness (g/m^2). The resulting loss depends to a great extent on the actual usage on the product. Dhliwayo measured coating thickness on an extrusion test sample where the sample was weighed before and after painting. These results were confirmed by performing additional tests on 2 further extrusion samples in this way and the results were found to be consistent at an average coating thickness of ~80μm. Results from Dhliwayo (1998) are compared to 2 additional samples taken as a check in the spreadsheet below:

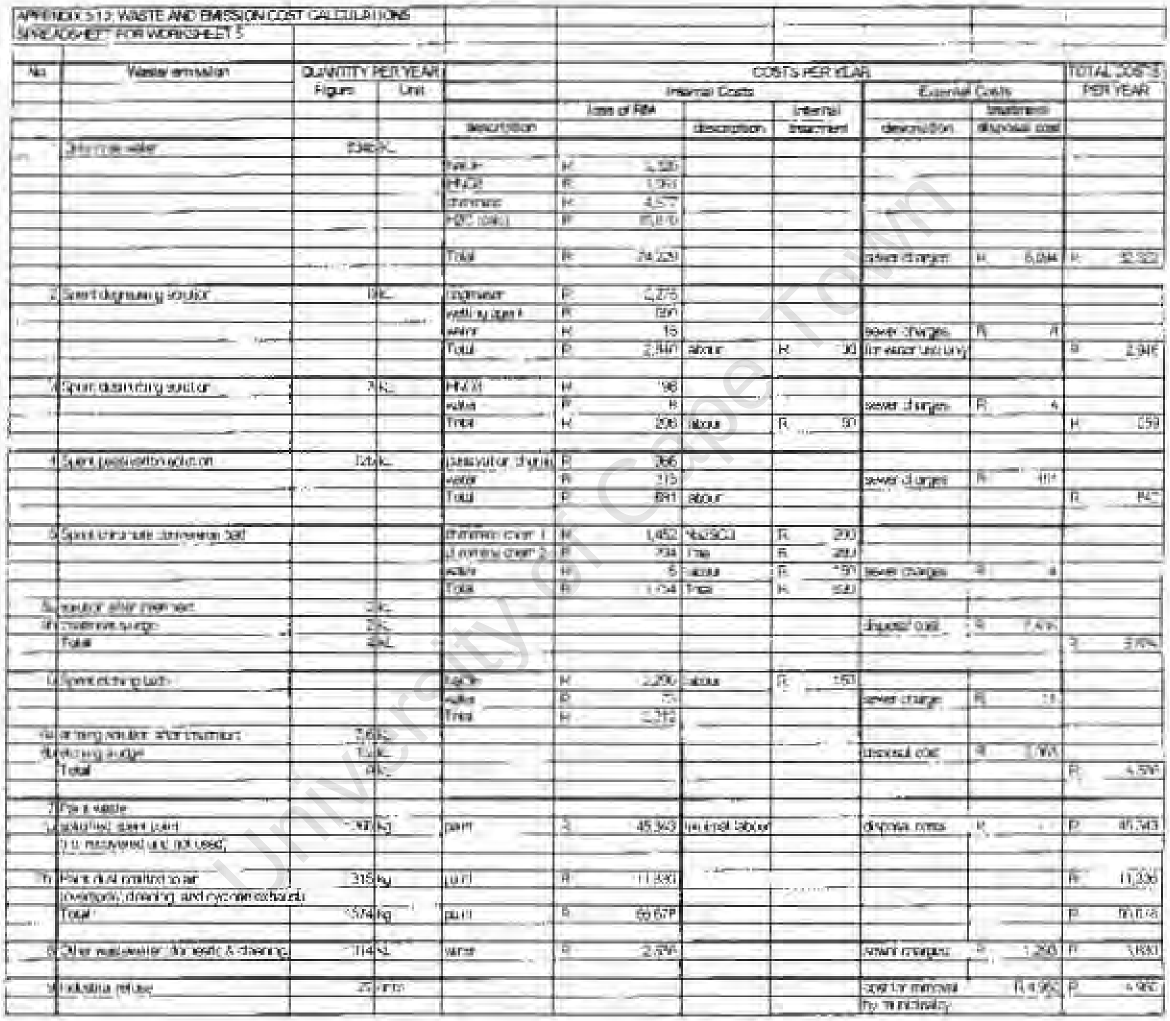
TESTS on COATING THICKNESS				
on extrusion samples				
Powder Paint Mass Balance				
Mass balance for white powder VP1001 (most used powder at 50% of total usage)				
POWDER PAINT THICKNESS				
Powder on product:				
samples:	1	2	3	average of all 3
mass of sample initially:	23.983 g			
mass of sample after clean & etch	23.717 g			
mass loss (Cr and Al in etch)	0.266 g			
mass of Cr-coated sample:	23.725 g	12.7247 g	12.8165 g	
mass of Cr coating	0.008 g			
mass of powder-coated sample:	26.247 g	14.88 g	14.864 g	
mass of powder used:	2.522 g	2.1553 g	2.0475 g	
sample area:	0.0212 m2	0.0186 m2	0.0186 m2	
Cr film mass/area	0.397 g/m2			
powder paint mass/area	119 g/m2	116 g/m2	110 g/m2	115 g/m2
	85.1 microns			82.3 microns
		Average of 2 and 3:	113 g/m2	
			80.8 microns	

However, extrusions form only 80% of the total products coated. The remaining 20% (furniture, etc.), have a much thicker coating. The coating thickness used for these calculations is based on tests performed on actual parts (the tests were done to determine optimum spray gun air pressure). The coating thickness on extrusions was found to be in the range 65-95μm, with the average at 80μm, while for 'other' parts the average is estimated at 140μm. A simple mass balance calculation was used to determine average percentage paint loss per annum. The balance: waste/yr – total paint usage/yr less total paint on product/yr. Where, paint on product is determined by multiplying average paint thickness and density by total area of aluminium processed per year. Detailed workings are included in the spreadsheet below, but annual paint usage in terms of kg and Rand values are not included for confidentiality reasons. As an assumption for the sake of pre-assessment calculations, the manager offered an estimate of 20% loss as air emissions, and 80% loss as solidifed paint. The manager also gave the calculated average usage of colour paint vs. white paint as $5m^2$/kg vs. $9m^2$/kg respectively, while 50% of the paint is used for white painting and 50% for colour paints combined. This was used to calculate the split between white paint and colour paint losses.

POWDER MASS BALANCE		
PAINT IN		
usage:	143	g/m2
115 paint colours used	1997	
white paint:	50%	
colours (114):	50%	
mass per colour:	70	kg/yr
TOTAL PAINT USAGE:		
m2 painted per kg used:		
white paint:	9	m2painted white/kg white paint
colours:	5	m2 painted colours/kg coloured paint
Therefore: m2 white painted/total m2 painted =	64%	m2 painted white/total m2
	36%	m2 painted colours/total m2
Total m2/total kg:	= (%m2painted white/%kg white paint)/(m2/kg white paint)	
	143 g/m2	
PAINT ON PRODUCT		
Coating thickness on Al extrusions:	80%	of total products
Tests on actual coating thickness were peformed by the foreman:		
when pressure is 2 bar	=80-95 microns	
when pressure is 1.1 bar:	=65-85 microns	
average coating thickness:	80	microns
Average paint density:	1400	kg/m3
Coating weight:	112	g/m2
Coating thickness for other products:	20%	of total products
Average is much thicker on furniture, etc.:	140	microns
Average paint density:	1400	kg/m3
Coating weight:	196	g/m2
AVERAGE COATING THICKNESS:	129	g/m2
WASTED PAINT:		
Paint usage - paint on product:	14	g/m2
	0.014	kg/m2
	10%	of total paint usage
Based on m2 coverage:	4%	
	6%	
loss to air:	20%	estimate from manager
loss as solidified:	80%	estimate from manager
mass loss to air:	2%	of total
mass loss as solidified:	8%	of total

E.10 Summary Spreadsheet for Calculating the True Cost of Wastes and Emissions

According to the chosen methodology, the true cost of the wastes were determined using a worksheet which allowed for all the costs (raw material value, internal treatment and disposal, external treatment and disposal costs) to be included. A spreadsheet was set up in the same format as the worksheet and the corresponding values were inputted by linking to the relevant working spreadsheets. The resulting summary spreadsheet is included below.



APPENDIX 5.13: WASTE AND EMISSION COST CALCULATIONS
SPREADSHEET FOR WORKSHEET 5

No	Waste/ emission	QUANTITY PER YEAR Figure	Unit	COSTS PER YEAR Internal Costs loss of R/M description		description	Internal treatment	External Costs description	treatment/ disposal cost	TOTAL COSTS PER YEAR
1	[illegible] water	[illegible]	kL							
				[illegible]	R 1,520					
				HNO3	R 1,563					
				[illegible]	R 4,577					
				[illegible]	R [illegible]					
				Total	R 24,220			sewer charges	R 6,044	R 32,322
2	Spent degreasing solution	15	kL	degreaser	R 2,275					
				wetting agent	R 550					
				water	R 15			sewer charges	R 8	
				Total	R 2,840	labour	R 30	(for water use only)		R 2,946
3	Spent [illegible] solution	7	kL	[illegible]	R 198					
				water	R 8			sewer charges	R 4	
				Total	R 206	labour	R 50			R 259
4	Spent passivation solution	126	kL	passivator [illegible]	R 366					
				water	R 215			sewer charges	R 101	
				Total	R 581	labour				R 842
5	Spent chromate conversion bath			chromate [illegible] 1	R 1,452	Na2SO3	R 200			
				chromate [illegible] 2	R 734	lime	R 280			
				water	R 6	labour	R 150	sewer charges	R 4	
				Total	R 1,104	Total	R 590			
5a	solution after treatment	20	kL							
5b	treatment sludge	20	kL					disposal cost	R 7,495	
	Total	40	kL							R 3,784
6	Spent etching bath			[illegible]	R 2,290	labour	R 150			
				water	R 75			sewer charge	R 11	
				Total	R 2,312					
6a	etching solution after treatment	7.5	kL							
6b	etching sludge	1.5	kL					disposal cost	R 1,993	
	Total	9	kL							R 4,596
7	Paint waste									
7a	solidified spent paint (not recovered and not used)	1,200	kg	paint	R 45,343	internal labour		disposal costs	R -	R 45,343
7b	Paint dust emitted to air (overspray, drawing and cyclone exhaust)	315	kg	paint	R 11,330					R 11,336
	Total	1,574	kg	paint	R 56,679					R 56,679
8	Other wastewater (domestic & cleaning)	1,114	kL	water	R 2,596			sewer charges	R 1,260	R 3,856
9	Industrial refuse	25	m3					cost for removal by municipality	R 4,950	R 4,950

E.11 Evaluation Table: Summary of Wastes & Emissions

The summary spreadsheet for evaluating the wastes/emissions from Company 2 is included below:

	COMPANY 1 WASTE SUMMARY FOR EVALUATION								
	Waste/Emission	Quantity	unit	Hazardous component	Hazard Rating	% hazardous component	Cost per yr	WM potential	Other
	Chemical wastes								
2	Spent degreasing solution	6500	L				R 2,948	low	non compliance with oil in effluent and improper treatment
3	Spent desmutting solution	3300	L	HNO3	0	4%	R 256	no idea	non-compliance with no proper pre-treatment before discharge
4	Spent passivation solution	125000	L	Cr(VI)	1	0.03%	R 842	high	non-compliance with Cr(VI) not treated and Cr out of limit
6	Treated spent chromate bath	4500	L	Cr(III)	1	4%	R 5,034	high	
5	Spent etching bath	9050	L	Al	0	1%	R 4,533	no idea	non-compliance as do not follow proper treatment procedure
				NaOH	3	3%			
7	Paint waste	1574	kg				R 58,079	high	airborne is irritation to neighbours and employees & interferes with pre-treatment baths
7a	solidified spent paint	1260	kg				R 45,343	low	
7b	Paint dust emitted to air	315	kg	dust?	fire hazard 10mg/m3		R 11,306	low	
	Wastewater								
1	Dirty rinse water	5316125	L	Cr(VI)	1	0.5%	R 32,522	high	non compliance with Cr(VI) not treated
				Al	0	0.8%			
8	Other wastewater (domestic)	1014464	L				R 3,893	no idea	
	General waste								
9	Industrial refuse	22	units				R 4,950	low	
	Total:						R 112,199		
	Energy usage								
	Electricity	206400	kWh				R 55,000	perhaps	indirect air pollution
	gas	25200	kg				R 37,000	no idea	gas burning?

E.12 Evaluation criteria for Selecting Focus Areas

The evaluation criteria are the same as those set out in the chosen methodology except for two differences. Here, the energy consumption is treated as separate from other wastes/emissions, with a different classification method for its criteria (since it is difficult to compare kWh to kg or L). In addition the hazardous nature is not only rated according to % of hazardous component, but also according to the hazardous rating of the substance of concern. One additional change is the type of the point system. The chosen methodology suggests a point system of ++ for very high, + for high, - for low, -- for very low, and 0 for average. Here these rates are assigned numbers, i.e. ++=5, +=4, 0=3, -=2, --=1. Therefore, each the wastes is given a point value for each criteria. The points are then summed and the wastes with the highest total score are selected as focus areas (up to a maximum of 4).

The point system for all the criteria are noted below:

QUANTITY
The point values for quantity (and cost) are assigned according to the method used by van Beers (1999) in company network mapping, as the data from this assessment is also used for the network project and it is therefore beneficial to use the same basis. There is no change in this criteria from the pre-assessment.

Quantity	Point Value
>100,000 kg or L per year	5 – very high
25,000 – 100,000 kg or L per year	4 = high
5,000 – 25,0000 kg or L per year	3 = average
1,000 to 5,000 kg or L per year	2 – low
0 – 1,000 kg or L per year	1 – very low
0 kg or L per year	0 = none

HAZARDOUS NATURE

In assessing the hazardous nature, consideration should be given to the hazard rating of the substances that make up the waste, as well as to the relative concentration of the hazardous substance. In addition, consideration should be given to the final disposal point of the waste e.g. river vs. sewer.

Point system	Hazardous nature
1	very low
2	low
3	medium
4	high
5	very high

ENERGY CONSUMPTION:

Energy consumption is treated separately and is assigned points as follows:

Quantity	Point Value
Gas:	
0 -10,000 kg	1 = low
10,001 – 20,000 kg	2 – medium
20,001 – 50,000 kg	3 – high
>50,000 kg	4 = very high
Electricity:	
0 – 500,000 kWh	1 = low
500,001 – 1000,000 KWh	2 – medium
1000,001- 1500,000 KWh	3 = high
>1500,000 KWh	4 = very high
Also kVA	Add 1

COST

Cost	Point Value
>R100,000 per year	5 = very high
R25,000 – R100,000 per year	4 = high
R5,000 – R25,0000 per year	3 = average
R1,000 - R5,000 per year	2 – low
R0 – R1,000 per year	1 - very low
R0 per year	0 = none

The waste minimisation potential is assigned points as follows:

WASTE MINIMISATION POTENTIAL

Does the assessment team believe that there is potential for waste minimisation (based on a good knowledge of waste minimisation options for the process)?	No idea = 1 High potential = 3 Low potential = 2

The final criteria takes into account other factors. The final factor takes into account whether the waste is recycled or regenerated already. In other words, the waste is used again and is therefore not as large a problem as if it were left as is.

OTHER

Compliance with present or known future regulations or charges?	Yes = 0 No = 1
Potential environmental liability?	Yes = 1 No = 0
Safety hazards to employees & surrounding areas?	Yes = 1 No = 0
Existing reuse/recycle?	-1

E.13 Evaluation of Wastes and Emissions to Select Focus Areas

The Evaluation Criteria and point system for each of the criteria are set out in Appendix E12. A table was set up listing each of the wastes/emissions and each of the evaluation criteria. The initial tables are included in Appendix E11. Each of the wastes is given a point value for each criterion. The points are then summed and the wastes with the highest total score are selected as focus areas (up to a maximum of 4). The spreadsheet used to calculate the totals for each waste stream and then sort them in descending order is included below.

	COMPANY 1 WASTE EVALUATION						
	SELECTION OF FOCUS AREAS						
	Waste/Emission	**Quantity**	**HN**	**Cost**	**WM poten'**	**Other**	**TOTAL**
1	Dirty rinse water	5	4	4	4	1	18.0
4	Spent passivation solution	5	4	1	4	1	15.0
5	Spent chromate bath treated	2	2	3	4	0	11
7	Total paint waste	2	1	4	3	1	11
2	Spent degreasing solution	3	2	2	2	1	10
6	Spent etching bath	3	3	2	2	0	10
8	Other wastewater (domestic &	5	0	3	2	0	10
7b	*Paint dust emitted to air*	*1*	*1*	*3*	*3*	*1*	9
	Electricity	1	0	4	3	1	9
	gas	3	0	4	2	0	9
7a	*solidified spent paint*	2	*0*	4	3	0	9
3	Spent desmutting solution	2	3	1	2	1	9
9	Industrial refuse	1	0	2	3	0	6

E.14 Activities for generating Waste Minimisation Options

1. A summary list of waste minimisation options was compiled from the available literature (the options relevant to Company 1 were selected from the list in Table 2.3, Chapter 2).
2. Technical reviews were carried out to compile more detailed information on the waste minimisation alternatives and Clean Technologies specific to the processes in Company 1 (through additional literature and specific case study reviews).
3. Various options were discussed with the chemical, paint and equipment suppliers.

4. International experts in the relevant branch (mainly contacts from the European study tour) were also consulted.
5. A brainstorm session was also held within the company to generate ideas (details in Appendix E15).

E.15 Details of Brainstorm Session for Generating Waste minimisation Options

The brainstorm session was the final part of the assessment phase of the waste minimisation assessment at Company 1. The aim was to generate as many ideas for waste minimisation options as possible, whether feasible or not. These, together with all the options formulated from available literature and from discussions with local and international experts in the relevant branch, as well as ideas generated during the assessment, are then evaluated for selection for the feasibility study.

The main aim of the brainstorm was to find possible improvement options that can be further investigated, but there are other advantages, in that it creates awareness amongst all people participating. An important aspect of the brainstorm is the participation of shopfloor employees. It is very important to hear ideas from those directly involved in the activities, as they are often aware of aspects that have previously not been considered.

Participants:

- Industrial Symbiosis Project Leader (UCT)
- Myself (UCT)
- Company manager (Company 1)
- Quality inspection laboratory (Company 1)
- Paint application operator (Company 1)
- 2 Representatives from paint supplier

The session began with a brief description of the problems to be addressed, given by the waste minimisation assessment team leader. The session was held during a single morning, so as not to interfere with production time. There was therefore a strict a time limit to the session and only a few topics could be covered. The main topics covered were as follows:

1. Powder application method
2. Booth and cyclone cleaning
3. Powder recovery (cyclone)
4. Powder dust in pre-treatment area
5. Disposal/selling of used powder

The first aim was to listen to the ideas of those directly involved with these operations (Paint application operator, Paint quality assessor) as to why, in their opinion, these problems arise and how the waste can be minimised. Ideas from those involved with the Waste Minimisation Assessment as well as an outsider to the problem were also put forward. All ideas put forward whether considered feasible or not were noted down. The suggested ideas were not discussed in too much detail during the brainstorm, as the aim was to come up with as many ideas as possible. After the session, these were examined in more detail.

The involvement of the factory personnel in the brainstorm session was a valuable contribution to the assessment in that some valuable ideas were generated through their participation.

E.16 Criteria and Checklists for Evaluation of Waste Minimisation Options

E.16.1 Technical Evaluation

The technical evaluation was carried out to determine whether the proposed options would work in the specific application. It covers installation and processing aspects as well as any possible effects on quality and productivity. The Waste Minimisation Assessment Methodology recommends the use of a checklist of factors to be considered. The following was the broad checklist used in evaluating options. It was adapted according to the degree of complexity of each option. Those options requiring simple changes were not evaluated in as much detail.

Technical Evaluation Checklist

OPTION
Description:
Nature: General specification of equipment:
Rough flow chart:
Availability of equipment:
Successful use elsewhere?
Required change in procedure:
Changes in input materials:
Necessary space needed and location:
Required utilities:
Possible effect on product quality
Effect on production capacity:
Potential risks regarding production output and quality:
Effect on workers:
Extra training required:
Maintenance requirements:
Does it suit the company's working methods:

E.16.2 Economic Evaluation

The economic evaluation establishes the economic consequences for the company from the implementation of an option. Only those options requiring major investment underwent a detailed economic evaluation. It was carried out using the payback period as the measure of profitability. The evaluation is based on estimates of major investments and savings associated with the options. The company's own financial criteria will be used for selecting recommended options for implementation.

The main economic goal of any waste minimisation option is to reduce (or eliminate) the waste discharge or disposal costs and to reduce the cost of raw material and input materials (PREPARE, 1991). Nevertheless, there are many other operating costs (or savings) that may be taken into account. The difference between the estimated operating costs associated with the waste minimisation option and the actual operating costs of the existing system, were used to compare the existing system with the proposed option. For most part, costs that are larger and easier to quantify were taken into consideration first as they have a greater effect on the economics of the option and require less effort to estimate reasonably. The remaining elements usually have a secondary effect and were only considered if it became necessary to make a selection from comparable options.

The assessment team used a brief evaluation method for the simple procedural options not requiring a major investment. The detailed feasibility study is only for those options requiring major investment costs, such as changes or enhancements in the production equipment. Spreadsheets were used to carry out the evaluation. The following checklist was used in the economic evaluation:

1. Investment costs: fixed capital costs for the design, procurement and installation of equipment, additional materials, as well as costs for working capital, training, start-up and financing. (For most options, the cost for procurement & installation was usually included in the cost of the equipment).
2. Operating costs and savings: reduction in waste management costs, savings in the cost of input materials, liability savings, changes in costs associated with quality, changes in facility costs, changes in operating and maintenance costs, changes in revenues from increased production, increase in revenues from by-products. This is expanded below.

ECONOMIC FEASIBILITY STUDY
OPERATING COSTS AND SAVINGS ASSOCIATED WIT WASTE MINIMISATION OPTIONS

A Reduction of waste management costs:
1 Offsite treatment, storage and disposal charges:
2 Transport levies:
3 Onsite treatment, storage and handling:
4 Licenses:
B Savings on the cost of input materials (including electricity)
C Insurance and liability savings:
1 reduced insurance costs
2 remedial clean-up
3 workplace safety
D Changes in costs associated with quality:
1 Rework costs
2 quality control costs:
E Changes in facility costs:
1 electricity:
2 process water:
3 compressed air:
4 gas:
F Changes in operating and maintenance costs:
1 labour costs:
G Changes in operation and maintenance supplies:
H Changes in indirect costs:
I Changes in revenues from production change:
J Increase in revenue from by-products:
TOTAL SAVINGS ASSOCIATED WITH OPERATING NEW OPTION:

Source:

For checklist above - (cited in PREPARE, (1991a) - Adapted from *Perry's Chemical Engineer's Handbook* (1985), and Peters and Timmerhaus, *Plant Design and Economics for Chemical Engineers* (1980)).

For most options, such detail was not available, so only the major costs were taken into account:

ROUGH ECONOMIC EVALUATION
Major Costs:
disposal charges:
transport charges:
pre-disposal treatment costs:
raw material costs:
operating and maintenance costs:
TOTAL SAVINGS:

The estimated investment costs and savings were taken into account in the profitability analysis.

Profitability Analysis:
For those projects where there are no major investments, the projects profitability can be judged on whether there is a saving in operating costs or not. If such a project reduces the overall operating costs it should be implemented as soon as possible. The more detailed profitability analysis is only required for those projects requiring substantial investments.

The method used for measuring profitability for this project is *Payback Period*. The payback period for a project is the amount of time it takes to recoup the initial cash outlay on the project. The formula for calculating payback period before tax is as follows:

Payback period (in years) = capital investment/ annual extra cash flow (savings/yr)

Payback periods in the range of three to four years are usually considered acceptable if there is only a small risk involved on the investment required. This method is only for quick assessments of profitability. If an option is identified as feasible for the company and large investments are involved, a more detailed analysis should be undertaken by the company using their own method of evaluation. This is necessary especially if there are a number of projects competing for funding.

Adjustments for risks and liability:
While profitability is an important factor in deciding whether or not to implement an option, environmental regulations can be even more important, especially those that will be imposed in the future. Possible fines and penalties are an incentive. Site clean-up operations are also an important consideration.

Waste minimisation options can reduce the magnitude of environmental and safety risks for the company. Although it is possible to identify these risks, it is difficult to predict whether the problems will occur, and what will be the nature and magnitude of those problems. One way of taking the reduction of these risks into account is to ease the financial performance requirements of the project. For example, the acceptable payback period may be extended from 4 to 5 years. Such adjustments indicate that certain elements which affect the risks for the company cannot be included directly in the analysis. These adjustments are judgmental and necessarily reflect the individual viewpoints of the people that are required to evaluate the project in terms of performance. It is important that the company's financial experts and decision-makers are aware of the risk reduction and other benefits of prevention options.

For most options the economic evaluation was a simple analysis of the following:

Basic Checklist for Economic Evaluation used in this project

Economic Evaluation
Investment costs
Operating savings/Costs:
Payback Period:

E.16.3 Environmental Evaluation

In many cases the environmental advantage is obvious there is a reduction and/or decrease in the toxicity of the waste stream, without the generation of a new waste stream. Most of the good-housekeeping measures are good examples of this. In such cases the environmental situation in the company improves without shifts occurring in the environmental problems.

Aspects of importance include:

- Changes in the amount and toxicity of wastes and emissions in all phases of the production/consumption chain.
- Changes in energy consumption throughout the entire chain.
- A shift in the environmental effects to other materials
- A shift in the environmental effects to other media
- Changes in degradability of the wastes and emissions
- The extent to which the renewable raw materials are used
- A change in the reusability of waste streams

Owing to the lack of data, a practical approach is to first make a qualitative assessment on the basis of available information. The environmental evaluation quantifies the environmental benefit and ensure that there is no shift of effects (e.g. from water to solid waste) by performing a rough chain analysis (LCA-like).

In cases where the environmental evaluation cannot be established so unequivocally. There is the need for a thorough environmental evaluation of the option, especially where product or process changes or the substitution of raw materials is concerned. In order to make a sound evaluation, information must be gathered on the environmental aspects of the relevant product, raw material or constituent part of the process. This information must relate not only to the environmental aspects during production or use, but also to the raw materials used, the environmental impacts from extracting the raw materials, of the transportation of materials and products, and the environmental effects in the waste treatment phase. Energy consumption should also be included, in other words: an evaluation must be made over the entire life cycle of both the products and the processes in order to make a sound choice (PREPARE, 1991). This was not possible for the majority of selected options and a rough evaluation was performed according to the basic checklist below.

Basic Checklist for Environmental Evaluation used in this project:

What is the expected environmental advantage of the prevention option?
How large is the expected reduction of the wastestream or emission?
Are there any other disadvantageous effects on the environment?
If so, how harmful for the environment are these?

E.17 Summary of Alternatives for Chromate Conversion Coatings

General information on possible alternatives for chromate conversion coatings was compiled from an extensive literature review, and is included below. The commercial availability of alternative products, and potential suppliers in South Africa was researched. An Internet search lead to an inventory of alternative chemical suppliers (www.pfonline.com) who were contacted for more information on any commercially available products. Examples of some of these products are included where significant information on the option has been obtained. The summary is included in Table E17 on the next page. The general advantages and disadvantages give an indication of the likely technical and environmental feasibility and are outlined first below.

Non-chrome systems are generally more paint selective than chrome systems (Sullivan 1993). Chromates are more tolerant of the type and quantity of paint to achieve a given set of requirements for a finished article. Cleaning requirements are usually more stringent with non-chrome. This is because the chrome bath itself is an oxidiser and has the potential of contributing to the surface preparation of articles to be treated prior to the actual conversion coating. This is not true of non-chrome systems, except for permanganates. This therefore places greater demand to present a clean and smut-free surface to the non-chrome bath. Cleaner selection becomes more important and often cleaner must be dumped more often. Rinsing requirements are also often stricter.

Control parameters for non-chrome are more complicated (Ibid.). Controlling the chemistry of a chrome bath is well understood and requires readily available and relatively inexpensive equipment. In a chrome-system, it is possible to monitor for gross problems visually through colour changes. Measuring actual chromate coating is also straightforward. Many non-chrome coatings are colourless or slightly coloured which rules out visual means of monitoring the system in real time. Actual measurement of the non-chrome coating can be complicated.

Industry standards and practices are slow to change. Recognised authorities on standards and practices within the industry are very deliberate in approving or even agreeing to study new procedures. Non-chrome is still new, and many of the quality standards issued specify chrome as required pre-treatment. There is still a widespread perception, accurate or not, that chrome pre-treatment yields the highest quality product.

Table E17: Summary Table of Conversion Coating Alternatives (compiled from literature and Internet search)

Conversion coating	Brief Description	Advantages/ Disadvantages	Availability
Chromate Hexavalent Cr	A thin protective layer of chromium coating forms on the metal surface. The process is catalysed by fluorides and acids in solution.	- High corrosion resistance - excellent adhesion - contains hazardous hexavalent chrome - cannot withstand very high T's (curing) - catalysed with fluorides	Chemical A from existing supplier (Supplier 1)
Trivalent Cr		- Resulting coating is very similar to Cr (VI) - Offers better colour consistency - Process is more complicated to control - Requires a more residue-free surface - Wastes are considered to be hazardous	Many products are available.
Molybdate Compounds	Metal oxyanion analogue of Cr (NDCEE, 1994)	- non-toxic - not very effective corrosion inhibitor for Al unless other inhibitors like metaborate are present - also improved corrosion resistance if organic emulsion sealing is performed after	
Permanganate	- Conversion coating based on the use of $KMnO_4$ - Chemistries of Mn oxides and Cr oxides are very similar - A simple one-stage treatment in a proprietary permanganate solution at 60°C for approximately 1 minute, followed by rinsing and drying of the processed parts (Bibber, 1998). - Hazard Rating for $KMnO_4$ =2 (DWAF, 1998).	- nearly equal corrosion resistance as chromates (NDCEE, 1994) - wastewater treatment and disposal relatively easy with addition of Fe oxides and lime to remove sulphates and Al salts - can withstand high T's without breaking down - coating is uniform in colour and texture - very little build up of sludge - Drag out is the major source of loss, and its cost is similar to that of chrome-type systems, without the expense of removing toxic waste	Chemical B from Supplier 2 (USA) - Is available commercially in the USA and has been used by US navy and airforce. - will not have representatives in S.A. unless high enough potential sales volume - not prepared to supply product to S.A. until they have representatives to ensure product is being used properly

Conversion coating	Brief Description	Advantages/ Disadvantages	Examples/ suppliers
Rare Earth Metal Salts (REMs)	REM salts such as cerium (nitrate or chloride) form protective REM oxide film on metal surface. Degree of protection strongly depends on immersion time alloys.	- Provides significant protection comparable to that by chromates - Coating also adheres well (NDCEE, 1994)	Patented process has been developed but does not appear to have been developed commercially as yet
Organic Pretreatments	Polymeric system with chelating group (Sullivan, 1995). Molecule can be tailored for a particular application. In case of Cr (VI) replacement organic system needs to be combined with a less toxic heavy metal such as Zr to enhance the base polymer properties. The chelating ability of the polymer takes the heavy metal into solution so it can be introduced to the workpiece Chemical C treatment consists of immersion of substrate in an aqueous solution containing polymeric materials and a soluble salt of Zr. The polymeric material provides a resinous glaze to the metal and the Zr converts to the corresponding oxide, thus providing a protective film. Simpler to operate and with comparable results to chromates. Chemical G conversion coating can be run in a 4 to 8 stage spray or immersion application. According to Supplier F(international) it affords excellent paint adhesion and corrosion protection properties with most paints and meets the needs of the aluminium extrusion market	- excellent paint adhesion and corrosion protection (NDCEE 1994) - is environmentally safe and cost-effective – no sludge is produced in the waste treatment process. - Waste treatment is pH neutralisation and disposal to sewer.	Several products in the U.S.A: Chemical C from supplier 3 (USA) sold worldwide. - Product contains transition metals and approved polymers. They do not have representatives in S.A. Chemical G from supplier 5 (international) for Cr replacement on architectural Al - Suppliers have a representative in South Africa which has been contacted for further information about their product, but as yet (Jan 2000) are still investigating the product for use in South Africa.

Conversion coating	Brief Description	Advnatages/ Disadvantages	Examples/ suppliers
Complexed Transition Metal Salts (CTMs)	CTMs incorporating metals such as Zr, Ti, Ce with other compounds such as fluorine and oxygen – common alternatives to chromates (NDCEE, 1994) Chemical D consists of AlOH, fluorides and a Zr compound. Same operating process as chromates with Chemical D substituted for chromate. (Comparable results to chrome (Pearson, 1999). No chemical information on Product E (Zr-based). Chemical F is based on fluotitanate and process is simpler than chromate	- CTMs offer long term corrosion resistance and excellent organic coating adhesion (Sullivan, 1993) - Very short treatment times required - Effective in providing corrosion protection and improving paint adhesion on architectural Al alloys - Scratches in coat are not self repairing as they are for chromate coatings - Zr salts are generally non-toxic except for those containing fluorides. - Systems are adaptable to almost all existing pre-paint systems - Product D waste treatment method involves using lime only to precipitate the product as Zirconium-oxidehydrate and calcium fluoride. The precipitate is settled and the solution goes to sewer. There is a reduction in the sludge volume but still requires disposal as hazardous waste. Drag-out to rinse may require treatment - Chemical F offers excellent paint adhesion and corrosion resistance. 60% reduction in treatment sludge quantity, but still requires hazardous disposal. Drag-out to rinse may require treatment.	Chemical D from existing Supplier 1 (German) current supplier to co.1 in S.A - Available immediately, but requires 1 year further testing for Qualicoat approval. Chemical E from supplier 4 (Holland) - Has achieved Qualicoat approval but is not available in S.A. Chemical F from supplier 5 (international) - is based on titanium fluoride and has Qualicoat approval. Suppliers do have a representative in South Africa, are still investigating the product for use in South Africa.

Conversion coating	Brief Description	Advantages/ Disadvantages	Examples/ suppliers
Silanes	Silanes possess both organic and inorganic properties and are capable of reacting with inorganic substrates (metals), and interacting with organic polymers (paints). Most useful silanes for metals are ethoxy or methoxy esters which can be hydrolysed by mixing with water (90/10 water/silane volume ratio). Process requires aggressive alkaline degreasing, tap water rinse, silane treatment, drying, painting. Some applications may require double silane treatment (van Ooij and Child, 1998).	- Process is enormously flexible - if properly selected and applied, the silane treatment is superior to chromates - process and materials are environmentally compliant - chemicals are commercially available and relatively inexpensive - cost of silane treatment is of the same order or less than chromates - waste generated is small amounts of mainly condensed silanes and unused fluotitanic acid. The silanes adsorb onto the sludge in conventional treatment and do not interfere with biological processes (Child, 1999)	Chemical H from Supplier 6 (international)
No-rinse Chromate	Conversion coating still contains hexavalent chromium but process has been developed so that conversion coating is the final step and no rinse/final seal is required. Thus eliminating the Cr(VI) in the wastewater.	- Performance as for chromates - Controls on baths is very stringent and requires demineralised water as solvent throughout the pre-treatment system. - Requires separation of painting and pre-treatment sections to prevent paint contamination of bath. - Spent bath still requires special treatment and hazardous waste disposal.	Chemical I from Supplier 7 (International and SA) This Coating has Qualicoat approval is available in South Africa. It is however almost 5 times more expensive than chromates at present, and is used at a higher concentration.

E.18 Feasibility Analysis of Chrome-free Conversion Chemical D

The chrome-free alternative conversion coating chemical supplied by Company 1's existing supplier, is based on Zirconium (complex transition metal) and is considered to have equivalent performance to chromates. Zirconium is known for its excellent corrosion resistance (attributed to its stable cohesive oxide film which is always present in air/water) and is employed as a corrosion resistant metal in the chemical process industry (Kirk & Othmer, 1995).

Testing of the product's performance is mostly complete for Company 1. Sample profiles were obtained from Company 1 for treatment by the process in the supplier's laboratory. These were returned for powder coating and then acetic acid salt spray testing for comparison with their current process. The results were comparable and appear to be good. Initial results in Europe indicate that it will match a chromate process on acetic acid salt spray. The overall performance will be answered as soon as the profiles have completed 3000hrs acetic salt spray. The product has been approved by GSB International, which is a German Organisation of companies who produce coated sheets and profiles for the construction industry.

The suggested process sequence by the supplier is for all other baths to remain the same, and to simply change the chromate for the zirconium-based product. Control of the process baths is not expected to be more stringent than existing control measures at Company 1. Although the price per unit for Chemical D is more expensive, the concentration is 1/10th of the chromate concentration (L/L). The price of the chemical therefore works out 40% cheaper per litre of working solution than the existing chromate. However, it is unclear what the usage will be.

Zr is generally considered non-toxic as an element or in compounds, and is bio-compatible (Yau and Bird, 1995). In Germany (which is generally very stringent regarding environmental regulations – as discussed in Chapter 3) there is no effluent limit for Zirconium. Fluoride is limited to 20mg/L. There does not appear to be any effluent limit for Zr, Al, or Fluoride in the local by-law, or nationally. The existing chromate chemical also contains fluorides. It therefore does not appear that effluent for stage 8 rinse water will require treatment.

The life of the chemical is anticipated to be the same as in the current process. The dumping frequency will be as present. The waste treatment method involves using lime only to precipitate the product as zirconium oxide-hydrate and calcium fluoride. The solution should contain fluoride at 10-12 mg/L and zirconium at 100-200 mg/L and is discharged to sewer. The treatment sludge will be lower in quantity than for chromate. The Department of Water Affairs and Forestry (DWAF) classify Zr (metal) with a Hazard Rating of 3 (moderate hazard). This is the same as for Cr(III), and it is therefore most likely that the sludge will cost the same for disposal as the chromate sludge.

E.19 Results of water quality analysis for Company 1

The mains water at company 1 was tested for conductivity and hardness in order to determine demineralisation requirements. The results are included below:

LABORATORY REPORT

Date: 28/1/99
Company 1 Mains water
This is to confirm that the supplied sample of TOWNS WATER has been tested and the following results obtained:
Sample dated: 99/01/27

TYPE OF TEST	SPECIFICATION	TEST RESULT
Conductivity	N/A	119 µS
Chlorides	N/A	10 ppm
TDS	N/A	59,3 ppm
T.HARDNESS	N/A	60 ppm $CaCO_3$

E.20 Paint Mass balance over painting and recovery system

The company manager estimated the mass of paint that is collected from floor sweepings, and the mass of paint lost through recovered paint that is not reused. Based on these estimates and the results from workings in Appendix 5.9 to determine cyclone efficiency, total paint loss to air and as solid, a mass balance over the system was carried out. The workings are included in the spreadsheet below.

	estimated			estimated		
Source of loss:	**% of loss**	**Mass/yr**		**% of usage**	**Mass/day**	
loss to floor (overspray out of booth):	5%	79	kg/yr	0.5%	0.31	kg/day
loss to floor (booth clean):	5%	79	kg/yr	0.5%	0.31	kg/day
solid lost in unused recovery:	70%	1102	kg/yr	6.9%	4.41	kg/day
total loss as solid:	**80%**	**1260**	**kg/yr**	7.9%	**5.04**	**kg/day**
loss to factory air in overspray (out of l	0.5%	8	kg/yr	0.05%	0.03	kg/day
loss to factory air in booth clean:	0.5%	8	kg/yr	0.05%	0.03	kg/day
loss to outside air from cyclone:	12%	189	kg/yr	1.2%	0.76	kg/day
loss to outside air cyclone clean:	7%	110	kg/yr	0.7%	0.44	kg/day
total loss to air:	**20%**	**315**	**kg/yr**	2.0%	**1.26**	**kg/day**
TOTAL LOSS:		**1574**	**kg/yr**	10%	**6.30**	**kg/day**
mass through to cyclone:	89%	1401	kg/yr	9%	5.60	kg/day
cyclone efficiency:	87%					
% directed at product (usage loss spray out of booth):				99.5%		
transfer efficiency:	91%	mass on product/mass directed at product				
summarise:				**% of usage:**	**Cost:**	
loss from over-spray not contained in booth:		87	kg/yr	0.54%	R 3,117	
loss from cyclone cleaning:		110	kg/yr	0.7%	R 3,967	
loss from cyclone exhaust:		189	kg/yr	1.2%	R 6,801	
loss from booth cleaning:		87	kg/yr	0.54%	R 3,117	
loss from floor sweeps:		157	kg/yr	1.0%	R 5,668	

E.21 Waste Minimisation Options for Powder Delivery System

(Identified through Interactive Training Session)

Identified options by the supplier during the interactive training session were as follows:

1. The mounting position of the gun and shape of the powder cloud both need to be calculated to deliver powder particles close to the part to be coated and at the same time minimise the forward velocity of the powder particle. The present manner in which the spray guns are set-up for painting is to maintain a fast-moving paint cloud, as it is the easiest way to coat a part. However, it is poor in terms of efficiency. The gun settings are set so that the ratio of powder transport air to atomising air is too high at present. This results in a too high a velocity, and the powder 'cloud' is expelled at a tremendous speed past the part. The faster cloud requires many passes at high velocity resulting in much wasted air.

   The desired mode of delivery is a soft powder cloud that gently wraps around the part. To minimise impact fusion, the minimum acceptable delivery air pressure must be used to decrease paint velocity. The solution is to set the powder carrier air at a lower flowrate to slow down the cloud speed, but maintain it sufficiently high to still allow airborne powder to reach the part. The result is a much 'softer' cloud at optimum powder/air ratio. The application method for a 'softer' cloud is different and requires slower spray motion with fewer passes across each part. The applicators were shown the recommended manner in which to set-up the gun for various general paint and part types.

2. Another inefficiency is that the pressure of the atomising air is set too low. It is generally set at 1 bar, but it was discovered that the atomising air has a non-return valve that doesn't start operating until the pressure is >1.8bar. This means that there was no benefit from the atomising air at all for adjusting paint cloud. Dosing air is now always to be set at 2 bar. The overall result is a slower cloud but still carrying enough powder to coat the part, therefore decreasing overspray. Parts painted at varying flowrate and pressure settings, as well as using varying speeds and number of passes, were measured for coating thickness depending on various changes in equipment settings and spray methods. The operators could then observe and the paint effect for the correct air pressure setting.

3. A diffusion cone is installed at the exit end of the gun tip to gain control of the cloud shape. Different cones are designed for different applications. These can be changed as required. It was discovered that the same cone was being used without change and that it was the 'wrong' cone for many applications in that it causes a very direct spray specifically for thin strip parts. Therefore for flat parts, the paint cloud is too fast and too much. The operators have been shown how to determine the optimum deflector selection for varying part-types.

E.22 Feasibility Evaluation of Waste Minimisation Options

This section includes the detailed feasibility evaluations (according to the criteria of Appendix E16) for some of the waste minimisation options identified.

A1. GOOD HOUSEKEEPING MEASURES

3. Implement continuous control programme for ensuring painting and recovery equipment is properly set up at all times

The primary source of paint waste is the paint application process. Paint is lost through overspray.
If gun settings are carefully controlled and adjusted according to the work to be painted, the
overspray can be reduced significantly. At present control is reactive rather than pro-active.
Tests are performed on finished product, and if a fault is found then it is traced back to source
and changes are made. The aim of the control procedure is to implement proactive control to prevent
problems before they occur, as well as to reduce overspray waste.

Technical Evaluation:

Procedural change.
Control procedures are already outlined in operation manuals.
This option requires time from manager to compile control programs to be implemented as part of work procedure.
Particularly aimed at spray-gun settings.
Format will be procedure checks to follow with forms to sign-off when in order.
Any problems reported before processing begins.

Time for manager: approximately 1 hour
Manager time is an important consideration, as his time is limited. This is the main barrier which has prevented the option from being implemented already.
Training of operators has already begun, but the training needs control program to maintain.

Economic Evaluation:

Investment costs:

Manager time:	R 500 difficult to estimate value
Instruction forms:	R 100
Total:	R 600

Operating Costs:
Form processing: R 1,000 /yr

Savings:
Paint savings through improved first transfer efficiency.
This can only be estimated, but manager believes that
proper control of equipment settings can save up to: 15.0% of paint loss
or R 8.502 /yr
1.5% of total paint usage.

If defective work through painting problems is eliminated,
manager estimates savings of: R 10.000 /yr in total
of which: 20% may be due to incorrect paint equipment setting
R 2.000 /yr

Savings less costs: R 9.502

Profitability analysis:
Payback period: 0.06 years
1 month

Environmental Evaluation:

Saves rework of defective work - saves both additional coating as well as additional metal.
Saved oversprayed paint - improves working environment as well as atmospheric emissions from cyclone
Since less oversprayed paint will mean less paint enters cyclone for recovery.
Especially beneficial for colour painting where most of the oversprayed paint is wasted (very little recovered).

A1 - 4. Implement continuous maintenance programme for all equipment

Some paint is lost directly through leaks in painting and recovery equipment, as well as indirectly
where leaks may cause a decrease in equipment efficiency (such as cyclone recovery efficiency)
Maintenance on guns, hopper, connecting pipes, and cyclones, is reactive at present.
At present, leaks or other fault are only fixed after they occur instead of being prevented.

Technical Evaluation:
Procedural change.
Option would be to perform regular preventive maintenance, by incorporating it in weekly work procedure.
Should form part of control program, as would require similar procedure of following checklist and sign-off of forms.
Maintenance checks should be on pre-treatment equipment as well as on paint application and recovery equipment.
Option requires time from manager to set it up of approximately 1 hour.
Would like some form of monitoring equipment on cyclone e.g. to measure pressure drop?
Training of operators will be merely to follow checklist and increase awareness regarding equipment operation.

Economic Evaluation:

Investment costs:

Manager time:	R 500 difficult to estimate value.
Instruction forms:	R 100
training:	R 500
cyclone monitoring equipment:	R 2,000 depends on option - may not be necessary
Total:	R 3,100

Operating costs:

Form processing:	R 1,000 /yr

Savings:
Chemical and water savings in pre-treatment area from pipe and tank leak prevention,
as well as downtime savings through preventive maintenance of crane and pumps.

Estimated savings:	R 2,000 /yr

Paint savings through leak prevention and improved efficiency of application and recovery equipment.
This can only be estimated, but manager believes that

preventive maintenance of equipment can save another		0.5% of total paint usage
or	R	2,880 /yr
Also savings in downtime through preventive maintenance.	R	1,000 /yr

Savings less costs:	R	4,880 /yr

Profitability analysis:

Payback period:	0.6 years
	8 months

Only estimate, but basically, minimal investment costs with good potential savings.

Environmental Evaluation:
Prevent chemical spills through leaks.
Prevent paint waste from leaks as well as through inefficiencies as a result of leaks.
Especially beneficial for colour painting where most of the oversprayed paint is wasted (very little recovered).

A1 - 5 Improve painting operator skill through a continuous interactive training programme

The paint application process is the primary source of wasted paint. Inefficient paint application is through
both faulty equipment as well as inefficient application process.
Training of operators can include how to ensure equipment is set up and operating at optimum efficiency,
as well as optimum application to maintain production and minimise paint wastes.
Training needs to be interactive to include operator input regarding specific problems,
and should be repeated on a regular (4x/year) basis to maintain operator skill.

Technical Evaluation:
Paint equipment supplier offers free training for paint-spray equipment which includes set-up as well as spray method training
The trainer observes paint operators and points out faults and methods of improvement.
A training session has already been undertaken, during a low production period.
The trainer identified a number of common problems in application:
1. Incorrect cone deflectors in place
2. Incorrect air-to-paint ratio and air pressure settings for certain applications
3. Speed of application and number of passes can be reduced for better quality result in same time
Solutions merely required equipment checks as well as improved awareness and skills.

The manager believes that the control program needs to be implemented to ensure the lessons learned are implemented.
In addition, he believes that this training should be repeated annually.

Economic Evaluation:

Investment costs:

trainer	R 0 at present
downtime	R 0 during low production period.
Operating costs	R 0 negligible?

Savings:
It is difficult to determine the possible savings from saved paint
Saved paint in reduced overspray
Saved paint in reduced overlap of paint on parts

Combined with control programme - the two can save up to 3% - On its own - save 1/2 of this
1.5% of total paint usage can be saved through improved awareness and application skill of operator
R 8,502 /yr

Profitability analysis
Payback period: immediate

Environmental Evaluation:
Saved paint both solid and air emissions
Especially beneficial for colour painting where most of the oversprayed paint is wasted (very little recovered)

B1. Drag-out reduction
B1.1 Minimising drag-out

1. Longer dwelling time for parts over process baths

Not much attention is payed to drag-out reduction at present. The method to keep drag-out to a minimum is not properly employed. Instead of attaching the one end of the basket to the bath and raising the crane, the end of the basket is hand-held by the operator, and drag-out off-flow is usually rushed.
Increased awareness of operators of drag-out reduction is necessary, and can be helped by re-introducing the proper method of drag-out reduction as process regulation.

Drag-out results in loss of chemicals as well as increased contamination of dirty rinsewater.
Rinse-water quality falls below specified limits within a week, and baths require weekly dumping, which is an additional water wastage.

Technical Evaluation:
Procedural change.
See Figure 5.5 for diagram of proposed method of minimising drag-out.

After withdrawal of basket from process solution, chain must be attached to bar extension, and crane raised until the majority of drag-out is reduced. Process of doing this by hand must be eliminated.
Requires manger discussion with operators to raise awareness of need for drag-out reduction, and to impress the need for following proper procedure.
Increase in production time is not a concern at present, due to low production.
However, during high production periods, the problem can be solved by using an additional basket.
At present only 3 baskets are used at a time. It is possible to process up to 9 at a time.
There is already one additional basket.

Economic Evaluation:

Investment costs:

Training:	will form part of general awareness training
Equipment:	Chains and bars are already in place may require additional basket, but not at present.

Operating costs:
Increased production time not a concern at present

Savings:
Loss of chemicals through drag-out in the rinsewater was estimated during pre-assessment:
Total loss of chemicals through drag-out: R 8,358 /yr estimated
Also loss of passivation chemicals through drips to floor - but <R100/yr
If assumes can save: 70% of this drag-out through proposed method
R 5,851 /yr savings in chemicals

Water savings may be through decreased flowrate of rinsewater, or reduced dumping frequency.
Assume estimated saving of: 25% of rinse water usage
(conservative) R 5,991 /yr

Total savings: R 11,842 /yr

Also future savings in sewage fees due to reduced contamination of wastewater,
reduce Cr(VI) and other contaminants in water by 70% without water decrease, or
60% with water decrease
At present not a problem, but may become a problem if Cr limit is decreased

Payback period: Payback is immediate and can amount to around R10,000 /yr or more.

Environmental Evaluation:

Major benefit is reduction of Cr(VI) and Al in dirty rinsewater
Also reduction of NaOH and Nitric acid d-, therefore extending rinse quality, or allowing for water use reduction.

B2. Rinse water use reduction
B2.4 Controlling flow rate of rinse water use

1. Adjust incoming tap to limit the volume of rinse water flowing through at the optimal flowrate

Once drag-out reduction option has been implemented, tests may be performed to determine optimum reduction in flowrate.
Flow restrictors are inexpensive, but are not as effective for rinse water control lines where the production rate is inconsistent.

3. Install automatic rinsewater flow control device

Conductivity Control of rinsewater flowrate:

Technical Evaluation
Equipment requirement:

Conductivity controllers are expensive, require frequent preventive maintenance;
and do not sense non-ionic contaminants like oil and paint dust.
Paint dust and oil may also interfere with sesors.
This option is not technically feasible with 4 different rinse baths and only 1 entrance of fresh water.

4. Install flowmeters to monitor rinse flowrate and water use (raise awareness)

These do not reduce water use by themselves but make the operator aware of use rates
and help identify specific locations of excessive water use.

Investment costs depends on type	R 2,000 to install one for each bath?
Savings depend on findings	

This would help in determining optimum flowrate with reduced drag-out.
However, if water reduction methods are implemented based on rough measurements, there is no need.

B4. Reduced energy usage
1. Repair/improve methods of tank and surface insulation to minimise heat losses

Reubber mats on bath surface are deteriorating and should be replaced.
In addition, the rubber pieces break up and contaminate the heated baths.
The tank insulation can be repaired in some places.

Economic Evaluation:
Investment costs:

Replace insulation	R 1,000 maximum

Savings:

Electricity costs to maintain bath heat at present	R	9,540 /yr
Estimated savings from improved insulation		5%
	R	477 /yr

Payback period	2.1 years
but minimal investment	

Environmental Evaluation:
Minimal energy savings

B5. IMPROVED CLEAN-UP

1. Use vacuum suction instead of compressed air blow-out for cyclone and booth cleaning

Technical Evaluation:

Not as effective because it is easier to blow-out dust from corners than to access with vacuum
It may be difficult to find a vacuum for the application
The air emissions will however be substantially reduced, but the waste will be transferred into solidified wastes

Economic Evaluation:

Investment costs:

Cost of vacuum equipment	unknown

Operating costs:

Electricity to operate:	lower/higher than compressed air?
Increased downtime?	

Savings:
Same paint loss but contained rather than emitted into working environmental and atmosphere.
Possible savings in future air emission regulations, or liability for contamination of external environmental with paint dust.

Environmental Evaluation:
Waste contained in smaller area - solidified and properly disposed rather than emitted to air hap-hazardly

B5- 2. improve booth design to minimise spraying outside of booths

Much paint overspray goes past side of booths which could be reduced if booth-sides increased in width?

Technical Evaluation:

Requires extended side-panels on paint spray booth, or equivalent.
May not be necessary with improved operator skill, but will help with dust in working area
and more oversprayed paint may be captured in cyclone for recovery.
may slow down production by restricting painting area - depends on how additional panels are attached.

Economic Evaluation:

Investment costs:
Equipment:

Steel/plastic? to extend side panels:	R	800	per booth depending on option?
4 booths:	R	3,200	for all
installation:	R	1,500	
	R	5,500	total
Decrease in production time:	R	5,000	/yr estimated

Savings:
Some paint recovered instead of lost to atmosphere:

Savings:		5%	of paint loss
	R	2,834	/yr

Not all this paint will be reused - some will still be wasted.

Assume that of the recovered paint:		50%	is reused
Savings:	R	1,417	/yr

Loss in production time outweighs savings in paint.
Investment not woth the savings in economic terms.

Environmental Evaluation:

Savings in paint dust to atmosphere:	0.5% of loss of paint to air
	80 kg/yr

Improved working environment

B5-3. Optimise position parts are placed for spraying in spray booth to minimise spraying outside of booths

Much paint overspray goes past side of booths which could be reduced if
did not allow spray-gun to aim outside of booth area

Technical Evaluation:
Markers could be placed in the booth to ensure that operators only spray within a certain area.
This would slow painting rate down, and decrease production rate

Economic Evaluation:
negligible investment costs
Savings:
Savings in overspray: 0.5% of paint usage R 3 117 /yr

Operating costs:
Loss in production : Manager estimates: >R1000 /month
>R11,000 /yr
Therefore costs outweigh savings - not economically feasible

Environmental Evaluation:
As for improved booth design
Savings in paint dust to atmosphere: 0.5% of paint usage
Improved working environment

B5- 4. Install covers over baths at night to prevent paint from settling in baths during night shift (also insulating)

The covers would need to be easily movable - can be louver
These for the acid and caustic baths would have to be corrosion resistant
They could be stored against the factory wall during operation and moved over covers at night.
Would only prevent dust settling at night and not the dust from day painting which is still a problem

Technical Evaluation
9x covers of 9.1x0.76m
or double size for 2 baths etc
Manufactured from strong, resistant plastic?

Economic Evaluation:
Investment costs:
cost per cover R 1,500
9 covers R 13 500 total
Operating costs:
minimal

Savings:
Energy savings for heated baths: R 500 /yr
Savings through decreased contamination of rinse baths:
Baths will probably be dumped at same frequency in any case.
Payback: 27 years

Environmental Evaluation:
Effluent that leaves the plant will not contain any paint
NOT FEASIBLE

B5- 5. Separate paint area from pretreatment area

This would prevent contamination of baths with paint dust both in day-shift and night-shift
It would also improve working environment
This is normal practice for most powder paint operations

Technical Evaluation:
Would require re-arranging factory outlay and installing a partition with area for moving pre-treated parts into paint and cure area.
Paint & cure area may become very warm due to oven heat in smaller area?
Partitions may be simple or complex

Economic Evaluation:
Investment costs: would be substantial R 40,000 ?
Operating costs would be possible decrease in production
Savings: would be twice as much as for covers at night: R 1,000 /yr Rough estimate
Payback: 40 years for large investment

Environmental Evaluation:
Effluent that leaves the plant will not contain any paint.
NOT FEASIBLE FOR COMPANY

B6 Improved Process Efficiency

1. HEATED PASSIVATION DRYING TANK

Technical Evaluation:

An additional tank is installed after passivation with folding/sliding lid, and
heated using electric elements and fans
The tank would also capture drag-out drips which normally fall to floor.
Drying time is reduced from 2hrs to 5 mins per load and space for drying area is reduced substantially
Working area will be cleaner, and space will be available for installing other equipment such as
demineralisation unit or dust filtration unit
Will be required if passivation rinse is changed to demineralised water rinse

Equipment requirements:

Additional tank required with cut-out on side to allow for elements and fans to be installed
the following is a very rough estimate - as option still requires proper design
2 * 0.5m fans (1.0 kW) installed on one side
4*3 kW (0.5m) electric elements (2 infront of each fan)
Electrical cabling and control instruments
Mechanical sliding/folding lid to cover

Elements take 1hr to reach 60degC operating temperature,
but once temperature is reached heating may be switched off between loads
Parts can be sourced from local suppliers with installation performed by company staff

Economic Evaluation:

Investment costs

additional modified tank:	R	12,000
mechanical lid:	R	2,000
insulation installed:	R	1,000
electrical cabling/control:	R	1,500
fans installed:	R	1,200
elements installed:	R	1,800
training costs:	R	500
TOTAL Investment:	R	20,000

Operating Costs:

Electricity cost/unit:	R 0.07 /kWh	
Electricity for fan:	11070 kWh/yr	estimate
Electricity for elements:	66420 kWh/yr	estimate
Total electricity costs:	R 5,750 /yr	

Savings:
Increased production: if fast can then improvement, but if slow as at present than no benefit (can clean faster than staff)
improved quality due to decrease in handling while wet
improved working efficiency
Total savings:
Savings less costs:
Passivation heating not required: R 1,860 /yr

Operating costs greater than savings, but need to take into account future savings due to chrome-free

Environmental Evaluation:
Savings in rework due to improved quality
Increased energy usage
Allows for demineralised water rinse to replace Cr(VI) passivation rinse

BB. Improved Process Efficiency

<u>2. Modify old paint application equipment over a period of time</u>

Spray-gun equipment is old and therefore losing efficiency
Gun supplier recommends modification of guns.
There are 5 guns, 1 has been upgraded already.

Technical Evaluation:
Upgrade of gun so that carrier-flow can be adjusted and controlled more easily
(involves installing an additional air line)
This allows for savings in wasted paint of 25%
Can upgrade one gun at a time so that will not interfere with production.

Economic Evaluation:

Investment costs:			Cost of complete renewal of gun with 15% improvement in efficiency
cost to upgrade 1 gun	R	2,000	R 15,000 per gun
cost for 4 other guns	R	8,000	5 guns: R 75,000 total
Operating costs:			
compressed air usage increase		R 1,000 /yr	R 1,500 /yr
Savings:			
Paint savings in application		20% of paint losses	30% of paint wastage
	R	11,336 /yr	R 17,004 /yr
Savings less costs:	R	10,336 /yr	R 15,504
Payback period:		0.9 years	5 years

Rough estimate but payback of about 1 year for small investment

Payback of 5 years for large investment
not within company's financial ability
May be possible to replace 1 gun every few yrs?

Environmental Evaluation:
Savings in paint at source
Reduced air emissions as well as reduced solid paint waste
Improved working environment

<u>BB-3. Install a continuous feeding device for parts in spray booths to ensure minimum overlap of paint on parts</u>

Technical Evaluation:
Some paint is wasted through overlap of paint on part
A feeding device can be designed which may be foot-activated so that parts move through booth
at a continuous steady rate. Overspray could also be reduced.
Would require design and construction and training of operators.
Adjustment in spray application method as well.

Probably involve motor and method of activation and release.

Economic Evaluation:

Investment costs:			
Device for each booth:	R	2,000	each for design, construction and installation
Total:	R	10,000	
Operating costs:			
Electricity:	R	2,000 /yr	
Savings:			
In overlap and overspray		1.3% of total usage	50% of overspray that is contained and recovered will not be reused - therefore only 50% savings in this overspray, but an additional 1% saving through overlap reduction.
	R	7,319 /yr	
Savings less cost:	R	5,319	
Payback:		2 years for medium investment	

Environmental Evaluation:
Savings in paint
Reduced emissions to air and improved working environment

B6 - 4. Improve cyclone efficiency through modifications

Cyclones have been tested and found to be only 90% efficient
They are old and require either upgrading or good maintenance to fix leaks etc
A device could be installed for monitoring operation efficiency of cyclone to indicate problems.
Requires input from cyclone manufacturers
One manufacturer when contacted was not interested in helping, but this should be pursued
It is not considered good practice for powder coating operations to use cyclone on its own
It is common practice to include filters after cyclone to capture dust fines.

Rough calculations were performed to determine possible efficiency improvement options.
However, no conclusive findings.
It is unclear what improvement in efficiency may be achievable for a specific option
However, this option is preferred over installing expensive filtration equipment which merely transfers air emissions to solid waste.

It can improve efficiency to:		95%	(maximum)
will imply saving of:		0.9%	of paint used (no longer going to air, but now recovered)
Expect that some is saved through reuse: assume		30%	of this recovered paint is reused
	R	150	/yr
Therefore, any change would have to be less than	R	748	in total for all cyclones
To allow for a payback period of under		5	years

In other words - savings in economic terms are negligible whatever the investment

Environmental evaluation:

Savings in powder loss to air:	128 kg/yr less going to atmosphere
	0.512 kg/day less going to air outside factory
	0.8% of usage
	41% less air emissions

B6 -5. Install filters after cyclone to capture paint dust fines that are not collected

Pollution control rather than waste minimisation
(however waste is contained vs spread out over area - also less hazardous as solid than in air)
It is possible to combine the exhaust air from each cyclone via ductwork to a central filtration unit.
A supplier has been contacted and has quoted a technically feasible unit.

Technical Evaluation:
After-filter system
Filtration unit supplied by vendor
Space for unit needed
Ductwork may be complicated as cyclones are spaced relatively far apart
Filters will require cleaning on a regular basis and replacement over time
Collected powder is too fine for reuse and will have to be solidified and disposed - additional gas usage

Economic Evaluation:
Investment Costs:

Filtration unit:		R 36,000
ductwork: mains cables: compressed air lines:		R 10,000 combined
Installation:	R	2,000
		R 48,000

Operating costs:

Electricity:	R	2,000	/yr
labour for cleaning:	R	1,000	/yr
filter replacement:	R	2,000	/yr
gas usage:	R	2,000	/yr
Total:	**R**	**7,000**	/yr

Savings:
Collected paint in filter cartridges is still wasted
Savings are potential liability savings if paint dust in atmosphere and landing on cars & buildings in the area is regulated
Also expected more stringent air pollution regulations in future

Payback period: difficult to determine due to unknown future liability
Investment is also substantial, but may be within company's financial capacity
This will have to compete with other options
Good to be aware of option if needed in the future

Environmental Evaluation:
Solidified contained powder is less hazardous and safer for workers in area than airborne dust
No longer this amount lost to air: 128 kg/yr

B8.2 Advanced corrective maintenance methods

1. Microfiltration for continuous oil removal from degreaser

Expensive unit Estimated cost: R 40,000
Recovered oil may be recycled, but most likely to require special disposal
Operating costs for diposal, electricity, filter cleaning and replacement: R 6,000 /yr
Has to compete with free dumping at present.
However will extend bath life indefinitely, thereby saving: R 2,948 /yr

Environmental benefit includes no oil to sewer, but will still be disposed to land
Not feasible unless regulations on oil more stringent, and unless can recycle oil

C3. Process material/chemical substitution

1. Substitute the chromate conversion chemical with a chrome-free alternative

Many chrome-free chemicals have been developed
Some are becoming available commercially in South Africa
Requires approval from paint supplier before can change
therefore require a Qualicoat approved alternative

Technical Evaluation:
The option that is available as a drop-in replacement and easily supplied still requires another year of testing before it gains Qualicoat approval

Qualicoat approved options will be available in South Africa in near future.
1 of these options is silane-based which appears to be cost-effective on initial investigation.

2 option for which a quote has been obtained is expensive and requires much more stringent control of pre-treatment operating conditions.
It is infact not Chrome-free, but the conversion coating is the final step and therefore rinse and passivation treatment are eliminated
It will also require a substantial change in process
Spent conversion bath will still require expensive treatment and disposal

Economic Evaluation:
Depends on the alternative - ranges from cheaper overall for option still requiring approval to much more expensive for other 2 options
Possible savings in the future if regulations for Chrome become more stringent.
Main investment is the requirement for demin water final rinse and drying oven

Environmental Evaluation:
Will eliminate Cr(VI) in rinsewater
Chrome-free options allow for less expensive treatment and disposal of spent bath

Best to be aware of options now and to test various alternatives, so that when changes become necessary will be ready.

C3 - 2. Substitute final passivation rinse with demineralised water rinse (only in conjunction with heated drying tank).

Demineralised water as final passivation rinse is commonly used in Europe
One large powder coater in South Africa uses this option.
It cannot be heated, and can only be used in conjunction with heated drying
The demin water is one of the requirements for extending quality guarantee from 15 to 25 years
Quote for possible demin water unit has been obtained.

Technical Evaluation:
Equipment:
Existing tank needs to be lined (glass fibre)
Demin water unit that has been quoted can treat 1500L/hr of water
For 3,000L bath, requires at least 2 turnovers per day
It involves 1 cation and 1 anion resin
The water to be treated requires reduction in conductivity from 120microS to <5microS
drag-out from previous rinse will contaminate bath over time, thereby increasing conductivity
Water drip-off from parts is tested for conductivity, and when reaches 20microS, resins will require regeneration
Conductivity meter is included in the equipment.
3hrs required for automatic regeneration of resins
18L of 30% NaOH solution, and 16L of 32% HCl required for each regeneration.
However, frequency of regeneration is unknown at present - requires testing.
Resins will require replacement after certain operating time dependent on load over time

Economic Evaluation:

Investment costs:

Tests:	R 1,000	
Unit:	R 30,000	
Tank lining:	R 3,000	
Installation:	R 4,000	(includes piping, pumps, electrical cabling, etc.)
	R 38,000	
Drying oven	R 20,000	additional requirement

Operating costs:

Electricity:			
Resin regeneration:	R	530.00	per regeneration
		80000	L treated before regeneration
		3000	L/day required
		1500	L/hr
	every	27	days
		9	times per year
	R	4,969	/yr
resin replacement:		R 4,500	/10 years
		R 450	/yr
water:	estimate same volume as for passivation terefore do not include		
dumping frequency:	weekly but only demin water at >20microS of chrome-free conversion coating		
Total:		R 5,419	

Savings:

Passivation chemical:	R	368	/yr
Saved heating for bath:	R	1,860	/yr
Total savings:	R	2,228	

Costs less savings: R 3,191 /yr
Also possible future increased sewer charges or treatment requirements
The bath is dumped weekly (3,000L) with Cr content 30ppm over limit
This is not legal and treatment requirements are a potential high cost for company
savings in treatment cannot be estimated

At present, operating costs outweigh savings.
Investment costs is high and may not be within financial ability of the company

Environmental Evaluation:
No more Cr(VI) to sewer
The regeneration of resins will result in additional effluent of NaOH and HCl which may neutralise each other.
Spent resins will also require disposal after 10 years
Slight increase in energy requirements?

E.23 Method for Rating Feasibility and Selecting Waste Minimisation Options

A summary list of identified options is compiled for rating. The technical, economic and environmental feasibility of each option is then rated according to the following point system. In each case, the rating is subjective, based on the results of the feasibility evaluation and the opinion of the assessment team. Details of the feasibility Evaluation are outlined in Appendix E16.

Technical Feasibility Points for Option Rating:
0- not feasible
1- very low feasibility/complex/not available/disruptive
2- low feasibility
3- average
4- high
5- very high/simple procedure change

Points for Rating Economic Feasibility:
1- very low economic feasibility/ payback period very high, etc.
2- low economic feasibility
3- medium
4- high economic feasibility
5- immediate savings

Points for Rating Environmental effect:
1 – neglibible environmental improvement/remains the same/no change
2- Small environmental improvement
3 – medium environmental improvement
4 – high environmental improvement
5 – very high environmental improvement
5- large improvement in environmental effect

The scores are summed for each option, and those options with the highest total score should be considered first for implementation.

E.24 Summary Table of Rated Options for Company 1

Table E24: Summary table of rated waste minimisation options for Company 1

Waste Minimisation Option	Technical Evaluation	Economic Evaluation	Environmental Effect	Other	TOTAL
I. SOURCE REDUCTION					
A. General Waste Reduction Practices					
A1. Good Housekeeping practices					
1. Maintain improved chemical tracking & record keeping	3	4	3		10
2. Employee awareness and education regarding waste minimisation	3	4	3		10
3. Implement continuous control programme for ensuring equipment is properly set up at all times	4	3	3		10
4. Implement continuous maintenance programme for ensuring leaks from all equipment (guns, hopper, connecting pipes, and cyclones) are minimised	4	3	3		10
5. Improve painting operator skill through a continuous interactive and motivational training programme	4	4	3		11
B. Improved Operations/Process Modifications					0
B1. Drag-out reduction					0
B1.1 Minimising drag-out					0
1. Improved method to ensure longer dwelling time for parts over process baths	4	3	4	1	12
B2. Rinse water use reduction					0
B2.3 Optimise Rinse tank design					0
1. Use flow distributor to feed the rinse water evenly	4	2	2		8
2. The incoming water may enter along the length of the rinse baths instead of on one end to increase the rinsing efficiency.	0				0
B2.4 Controlling flow rate of rinse water use					0
1. Adjust incoming tap to limit the volume of rinse water flowing through at the optimal flowrate.	2	3	3		8

Waste Minimisation Option	Technical Evaluation	Economic Evaluation	Environmental Effect	Other	TOTAL
2. Manual control of water flow to reduce when production is low (dependent on operator adjusting flow with taps/valves).	4	3	3	with drag-out reduction	10
3. Install automatic rinsewater flow control device	0				0
4. Install flowmeters to monitor rinse flowrate and water use (raise awareness)	3	2	2		7
B2.5 Alternative rinsing configurations					0
1. Use a combination of spray rinsing and dip rinsing	evaporation rates not high enough to make this feasible				0
B4. Reduced energy usage					
1. Repair/improve methods of tank and surface insulation (e.g replace existing low efficiency mats) to minimise heat losses.	3	2	2		7
B5. Reduce/ eliminate the need for cleanup or improve cleanup methods					
1. Use vacuum suction instead of compressed air blow-out for cyclone and booth cleaning	1	1	2		4
2. Improve booth design to minimise spraying outside of booths	3	0	1		4
3. Optimise position parts are placed for spraying in spray booth to minimise spraying outside of booths	3	0	1		4
4. Install covers over baths at night to prevent paint from settling in baths during night shift (also insulating)	2	0	1		3
5. Separate paint area from pretreatment area	1	0	2	1	4
B6. Improved Process Efficiency					0
1. Install heated drying tank after passivation step to decrease drying time	3	2	3		8
2. Modify old paint application equipment over a period of time	4	5	3		12
3. Install a continuous feeding device for parts in spray booths to ensure minimum overlap of paint on parts	3	2	2		7
4. Improve cyclone efficiency through modifications	unknown	unknown	1		1
5. Install filters after cyclone to capture paint dust fines that are not collected	3	0	3		6

Waste Minimisation Option	Technical Evaluation	Economic Evaluation	Environmental Effect	Other	TOTAL
B7. Extending Bath Life					
B8.2 Advanced corrective maintenance methods					
1. Microfiltration for continuous oil removal from degreaser	2	1	1		4
C. Substitute Techniques/ Technologies					
C3. Process material/chemical substitution					
1. Substitute the chromate conversion chemical with a chrome-free alternative	2	2	4	1	9
2. Substitute final passivation rinse with demineralised water rinse (only in conjunction with heated drying tank)	3	1	3	1	8
II. RECYCLING AND RESOURCE RECOVERY					
D. On-site Recovery and Recycling					
D3. Wastewater recycling and chemical/metal recovery					
1. Collect and treat wastewater prior to discharge to sewer	2	1	2		5
2. Treat wastewater and reuse (closed water system)	1	0	3	1	5
E. Off-site Recycling and reuse					
E1. Off-site Recycling					
1. Centralised waste treatment for wastes of similar type from different shops (e.g. recover Cr from chromate sludge?).					0
E2. Off-site reuse of waste material					0
1. Recover valuable materials from a waste stream before disposal Recovered metals may be used as feed material for manufacturing processes, e.g. Chromium for stainless steel manufacturing.					0

F APPENDICES FOR CHAPTER 6

F.1 The Need for Quenching and Passivation after Galvanizing

In some shops in some countries, quenching is done in pure water and in others it is not performed at all. Quenching after galvanizing is very much normal practice in South Africa (Barnett, 1999b). There are a number of reasons for this. Firstly, quenching enables galvanized components to be handled immediately after galvanizing, and secondly, the rinsing effect removes oxides which may have been dragged out from the zinc surface in the bath.

Another reason for quenching is as follows. Different steels react differently in the presence of molten zinc with mainly the silicon content but also the phosphorous level playing the major roles. In the case of reactive steels, the formation of Fe/Zn alloy layers at the interface between the steel substrate and the coating can be extremely severe. The diffusion process results in coatings which are thick while, due to the extremely hard properties of the Fe/Zn alloys they can also be brittle, hence, susceptible to mechanical damage. Quenching after galvanizing of this material is essential since the diffusion process continues down to a temperature well below the melting point of zinc (418.5°C). (Barnett, 1999b).

The reactive steels are generally referred to as silicon killed as opposed to aluminium killed steel, with either silicon or aluminium used as a deoxidisng agent during the steel manufacturing process. Probably some 70% of the structural steel currently galvanized in South Africa is reactive silicon killed material for which quenching after galvanizing is essential.

Water quenching can be carried out without water which does not contain a passivating chemical. The presence of the passivating chemical tends to prevent the formation of wet storage stain. The need for the passivation chemical is discussed below.

The presence of the passivating chemical is to prevent the formation of white rust or wet storage stain. White rust or wet storage stain is the voluminous white or grey deposit formed by accelerated corrosion of the zinc coating when closely-packed, newly galvanized articles are stored or shipped under damp and poorly ventilated conditions. It is found most often on stacked and bundled items such as galvanized sheets, plates, angles, bars, and pipe. Weathered zinc surfaces that already have formed their normal protective layer of corrosion products are seldom attacked.

Whenever galvanized articles are packed together closely for appreciable periods of time, adequate precautions should be taken against white rust. It can be minimised by maintaining a low humidity environment around the material and by providing adequate ventilation between the stacked pieces.

- the galvanized steel should be clean and free from flux residues
- the material should be stored under cover in dry, well-ventilated conditions

- if outdoor stacking is unavoidable the articles should be raised from the ground and separated as well as inclined to give maximum drainage.
- Small items that are quenched and stored in containers should be thoroughly dried before packing.
- Seawater is especially corrosive under conditions conducive to wet storage stain. When shipping by sea, galvanized steel should not be consigned as deck cargo or stowed where contact with bilge water is likely. The high humidity at sea, makes the provision of dry, well-ventilated facilities particularly important (www.EGGA.org).

Various surface treatments are available to reduce the possibility of white rust. Conduits are often coated with a clear film after galvanizing. Waxes and oils are commonly used on wire, sheet steel, and fencing. For after fabrication hot dip galvanizing, chromate dip treatments, or other proprietary solutions, are sometimes utilised. Most products are however shipped without treatment (note this is a European document). The need for treatment largely depends on the configuration of the product and the anticipated storage conditions. Fabricated assemblies that fully expose the galvanized surfaces typically do not need a post treatment.

White rust results from exposure conditions and is not indicative of inferior or poor quality coating. Despite the presence of a bulky corrosion product, medium or heavy layers of white rust, although unsightly, represents the loss of very little zinc from the base coating. In most cases it should have little or no significant effect on the durability and intended service life of the coating. When it has occurred, the objects should be arranged so that their surfaces dry rapidly. For medium and heavy build-up, the corrosion product must be removed by brushing with a stiff bristle (not wire) brush, otherwise the essential protective film cannot form in affected areas.

From this information it therefore appears that as long as parts are shipped and stored correctly, the passivation/quench step can be eliminated. This would result in water savings, chemical savings, elimination of the use of a hazardous substance, as well as a reduction in the amount of zinc-containing sludge that collects on the floor of the passivation bath and needs to be treated/disposed. This seems like a very beneficial waste minimisation step. However, the Hot Dip Galvanizers Association South Africa recommend that it is necessary, because of the South African climate. In some climates the white rust problem is more significant than in others. For example, in South Africa, and particularly in Cape Town, the frequent extremes in maximum and minimum temperature result in condensation even in dry weather, making the need for passivation more critical. It is therefore not recommended to eliminate this step.

The chairman of the Hot Dip Galvanizers Association South Africa does however state that the concept of offering a passivating process which is claimed to provide a galvanized surface ready for painting is in his view, "irresponsible, particularly if chromates are involved". "Chromate passivation should never be applied if the coating requires subsequent painting". There are apparently a "host of reasons" why this will not yield consistent results in a general galvanizing plant. When painting is required after galvanizing, the Hot Dip Galvanizers Association South Africa recommends that products should be quenched in clear water or alternatively a phosphate based passivating chemical should be used. A further option is to air cool.

Sodium dichromate passivation of a galvanized coating is a "major cause of poor paint adhesion". (Barnett, 1999b).

In the future it may be possible to substitute the existing method used for another, e.g. to use a chrome-free passivation treatment. Research is already underway internationally to develop a commercial satisfactory substitute (e.g. chromium (III) or silanes). According to a representative from the Hot Dip Galvanizers Association South Africa, there are no substitute chemicals available at present that work as effectively as chromium as a passivation agent and that can withstand the high temperatures. In many applications in the metal finishing industry, chromium is beginning to be replaced with less toxic chemicals, and it is likely that it will be replaced in this application as well eventually. Phosphate based chemicals are available but they tend to discolour the coating surface, although very effective in preventing white rust formation. Research with silanes is well advanced and this could well provide a substitute for chromates (Barnett, 1999b).

F.2 Hazardous nature of input materials

The Department of Water Affairs and Forestry's (DWAF, 1998) definition of a substance as *hazardous* is based on the chemical reactivity or toxic, explosive, corrosive or other characteristics which cause, or are likely to cause, danger to health or to the environment, whether alone or when in contact with other waste.

The Hazard Rating is a system of classifying and ranking hazardous waste according to the degree of hazard they present. This is based on Mammalian Acute and Chronic Toxicity, Ecotoxicity, and Environmental Fate. Hazardous rating classification is:
Hazard rating 1 = Extreme hazard
Hazard rating 2 = High hazard
Hazard rating 3 = Moderate hazard
Hazard rating 4 = Low hazard

The hazardous nature of some of the materials used in Company 2 are described in some more detail below:

SODIUM HYDROXIDE -NaOH
Hazard rating = 3 (Severe-Poison)
Excessive inhalation of dust is irritating and may be severely damaging to respiratory passages and/or lungs. Contact with skin or eyes may cause severe irritation or burns. Ingestion is harmful; may be fatal or cause severe burning of mouth and stomach or cause nausea and vomiting. Acute toxic effects may include the death of animals, birds, or fish, and death or low growth rate in plants. NaOH has high acute toxicity to aquatic life. Chronic toxic effects may include shortened life span, reproductive problems, lower fertility, and changes in appearance or behaviour.

HYDROCHLORIC ACID - HCl
Hazard Rating = 3 (Severe Poison)
Inhalation of vapours may cause coughing and difficult breathing, pulmonary edema, circulatory system collapse, damage to upper respiratory system, collapse. Liquid may cause severe burns to skin and eyes. Ingestion is harmful and may be fatal; may cause

sever burning of mouth and stomach and may cause nausea and vomiting. Releases of hydrochloric acid to soil or water will be neutralised to a certain extent by the buffering capacities of both systems. Spills to waterways of high concentrations may adversely affect aquatic life. Acute toxic effects may include the death of animals, birds, or fish, and death or low growth rate in [plants. It has slight acute toxicity to aquatic life. Chronic toxic effects may include shortened life span, reproductive problems, lower fertility, and changes in appearance or behaviour. It has slight chronic toxicity to aquatic life. It does not tend to bio-accumulate.

HCl fumes are transparent and, while not toxic, excessive inhalation can be dangerous and harmful particularly in the case of an individual suffering from a chest complaint. These acid fumes are rapidly diffused in the atmosphere and thus a significant fume level is confined to the close proximity of acid tanks (Barnett, 1998).

HCl fumes are extremely corrosive and will attack unprotected structures e.g. steel buildings, in which the acid containing tanks are housed. Fume extraction is not commonly applied in most countries since installations are extremely costly and interfere with the workflow. One plant in RSA uses lip extraction on the tanks which seems to be effective (Barnett, 1998). However, it is generally believed that good practice in a plant ensures that excessive fuming does not occur.

This includes:

- Maintaining acid concentration at about 15%. At concentrations above 20% fuming can be excessive. In any case, increase in cleaning rate at higher concentrations is not significant.
- The acid must not be artificially heated above a temperature of 25 °C.
- Sludge accumulates at the bottom of acid tanks and should be cleaned out each time that spent acid is replaced. Excessive sludge increases fuming substantially.
- Soapy deposits are available which can be deposited on the acid surface. This reduces fuming substantially. Additives (inhibitors) can also be used to reduce the vapour escape.

HEXAVALENT CHROME – Cr^{6+} or Cr(VI)
Hazard Rating = 1 (Extreme)
Hexavalent chromium is a recognised toxic material with carcinogenic properties. Hexavalent chromium compounds are corrosive and cause chronic ulceration and perforation of the nasal septum when inhaled. They also cause chronic ulceration of other skin surfaces. Chromium (VI) has high acute toxicity to aquatic life.

SODIUM DICHROMATE – $Na_2Cr_2O_7$
Hazard Rating – 2 (high hazard)
High hazard owing to hexavalent chromium content.

CHROMIC ACID – $HCrO_4$
Hazard Rating = 1 (extreme hazard)
Extreme hazard owing to hexavalent chromium content and acidic nature.

AMMONIUM CHLORIDE – NH_4Cl
Hazard Rating = 4 (low hazard)

ZINC CHLORIDE – $ZnCl_2$
Hazard Rating = 3 (moderate hazard)
Inhalation of zinc chloride can result in coughing, chest pain, and respiratory tract irritation. Death can result from acute high dose inhalation.

ZINC – Zn – heavy metal
Hazard Rating = 2 (high hazard)
Inhalation of zinc oxide is common in occupational exposures and can produce serious injury to the respiratory system upon direct contact.
Significant zinc contamination of soil is only seen in the vicinity of industrial point sources. Zinc is a relatively stable soft metal, though burns in air. The two factors that influence zinc toxicity are water hardness and pH. Acute toxic effects may include the death of animals, birds, fish, and death or low growth rate of plants. Zinc and its salts have high acute toxicity to aquatic life. Chronic toxic effects may include shortened life-span, reproductive problems, lower fertility, and changes in appearance or behaviour. Zinc and its salts have high chronic toxicity to aquatic life. Zinc and its salts are highly persistent in water, with half-lives greater than 200 days. Zinc bio-accumulates and the concentration of zinc found in fish tissues is typically considerably higher than the average concentration of zinc in the water from which the fish was taken.

IRON – Fe – heavy metal
Hazard Rating = 3 (moderate hazard)
Same Hazard Rating when in Ferric or Ferrous ion form.

Sources:
http://www.epa.gov/chemfact/ - U.S. EPA OPPT Chemical Fact Sheets
http://www.nsc.org/EHC/ew/chems – Environment Writer *Chemical Backgrounders*, Chemical Information Environmental Health Center, A division of the National Safety Council, USA
Prager, J. (ed.) - Dangerous Property of Industrial Materials Report, as cited in UNEP WG, 1998.

F.3 Water Consumption Measurements and Calculations

The water meter for the company is not working accurately, and water usage is not measured internally by the Company. It was, however, possible to measure the rinsewater flowrate into each bath directly. Owing to lack of more accurate measuring equipment, the "bucket and stopwatch" method was used to determine the actual water flowrate. A measuring cylinder and stopwatch were used to determine the time taken for the flowing rinsewater to reach a certain volume. The measurements were done for each bath separately and repeated a number of times each and the average was taken. The accuracy of this method depends on reaction time of person and accuracy of stopwatch, as well as on accuracy of volume reading. (One can in fact do experiments to determine effect of reaction time and test the stopwatch, etc. but this did not seem to be necessary owing to the fact that this kind of accuracy is not important for the kinds of calculations performed here). The results were calculated in a Spreadsheet presented below.

COMPANY 2 RINSE WATER USAGE							
Water usage:							
Rinsewater flowrate measurements:							
Determined using bucket and stopwatch method:							
Degreaser rinse			Acid rinse				
Amount (L	time (s)	L/s	Amount (L)	time (s)	L/s		
		0.48			0.46		
		0.39			0.49		
		0.47			0.49		
		0.41			0.42		
		0.43			0.51		
		0.53			0.42		
		0.45			0.41		
		0.46			0.41		
		0.43			0.41		
		0.42			0.41		
		0.47			**0.44**	L/s	
		0.47			1589	L/hr	
		0.50			3425970	L/year	
		0.44			3426	kL/year	
		0.43					
		0.45					
		0.45	L/s	sum of the two is =		**0.9**	L/s
		1625	L/hr			3214	L/hr
		3503101	L/year			6929071	L/year
		3503	kL/year			6929	kL/year

The average flowrate for each bath was calculated to be 0.45 and 0.45 L/s. It appears therefore that the flowrates into the baths are approximately equal as expected. The total flowrate for each both baths is approximately 1L/second, which converts to 6900kL/annum (assuming 245days/yr operation @ 8.8hrs/day).

Although the capacity of each of the baths is 30,375L, the solution volume in each bath is assumed to be 30,000L and all additions are made based on this (chemical supplier recommendation). The rinse baths are therefore assumed to contain about 30,000L water each on dumping. The acid rinse bath is drained, usually by half, 1x/week on average. The degreaser rinse bath is only drained in this way, 1x/month on average. The number of rinse bath drains was estimated at 55x/yr (44x/yr for acid rinse and 11x/yr for degreaser rinse, based on operating weeks/yr and log records of draining frequency). The total volume of water dumped per year was therefore calculated to be 825kL/yr. Therefore, total rinsewater usage is 7800kL/yr.

Additional water is used as solvent, for evaporation replacement, floorwash, tank cleaning, domestic and general usage.

Solvent usage was calculated as follows:
The chemical baths need to be maintained in a given concentration range (chemical supplier specifications). Thus since chemicals and water are lost through usage, drag-out and evaporation, regular additions of chemicals and water are made to each bath. The chemical additions are recorded, but the water additions are not. However, the water additions may be roughly estimated based on calculations that take the total chemical additions made per bath for the year and divide these by the initial bath concentrations. Although there is room for error, the result at least will indicate order

of magnitude of solvent water use. The calculations used to determine solvent water use in this way were carried out in spreadsheet 'solvent water'.

Calculations for determining water usage as solvent in process baths:							
PROCESS BATHS	content	concentratic	unit	additions per annum	unit	equivalent water (kL)	
Degreaser	NaOH	0.07	kg/L	3688	kg	49	evap+drag-out
Pickle	HCl (33%)	0.5		10000	L	10	drag-out
Flux	2NH4Cl.ZnCL2	0.12	kg/L	5200	kg	38	evap+drag-out
Passivation 1	H2CrO4	0.001	L/L	40	L	40	evap+drag-out
Passivation 2	Na2Cr2O7	0.001	L/L	40	L	40	evap+drag-out
TOTAL WATER for additions			(loss through drag-out and evaporatio			177	kL/yr
TOTAL WATER for initial bath make-up						162	kL/yr
SUBTOTAL						339	kL/yr

Total solvent water usage (initial + additions) was calculated to be 340kL/yr.

Evaporation loss:

Evaporation loss is based on total water additions to each bath less additions for solvent requirements. Total water additions to each bath were calculated using very rough estimate of flowrate into bath and time taken to add the water to each bath.

WATER ADDITIONS:				
to replace evaporation, drag-out and usage				
		Total added	**Evaporation:**	**drag-out and usage:**
Degreaser:	kL/yr	89	29	60
Flux:	kL/yr	117	78	38
chromic acid:	kL/yr	177	137	40
sodium dichromate:	kL/yr	177	137	40
TOTAL	**kL/yr**	**559**	**381**	**179**
			68%	**32%**

Evaporation replacement is calculated as roughly 380kL/yr or 4% of total usage.

Floorwashing:

For floorwashing, the entire floor area is washed with water (~3.2kL/hr) for a 2 hr period on Friday afternoons. This amounts to 300kL/yr (3% of total).

Total

It is assumed that water used for rinsing is approximately 85% of the total water usage. This is based on an estimate from the Operations Manager. This is in-line with the findings from the National Industrial Water and Waste-Water Survey (NATSURV2, 1987), that approximately 80% of the annual water intake of the metal finishing industry is used for rinsing. Total water usage is therefore estimated at 9,100kL/yr.

A mass balance therefore yields the remaining water for 'other' usages as 340kL/yr or 1.4kL/day. Water costs for the factory should therefore amount to about R23,000/year. Effluent charges are based on 75% of incoming water volume, and a charge of R1.70/kL – R12,000/yr. Total water bills should amount to R35,000/yr. Actual water bills at present only amount to R12,000/yr or 35% of the calculated usage.

F.4 Measurement and calculation of heavy metal and chemical content of dirty rinsewater

The heavy metal content was measured directly through samples taken from the rinse baths. Samples were taken from inside as well as the exit pipes of the baths. These were analysed for Fe and Zn content using AA spectrometry, by the UCT Department of Chemical Engineering main laboratory personnel. Results are assumed to be within 95% confidence. However, the representative nature of the sample needs to be taken into account. These samples were taken at the end of the week during a relatively high production period, and are therefore expected to be on the high end of the range. The results from the 3 samples and the average are set out in the table below.

Table F4: Results of measurements of heavy metal contents of dirty rinsewater for Company 2

Rinse bath	Sample	Fe content (ppm)	Zn content (ppm)
Degreaser rinse:	Sample 1	5.4	0.83
	Sample 2	2.4	0.76
	Sample 3	3.2	0.75
	Average	**4**	**0.8**
Acid rinse:	Sample 1	25.5	10.9
	Sample 2	14.4	5.4
	Sample 3	18.7	3.0
	Average	**20**	**19**
Combined		**12**	**10**
	LIMIT	**50**	**30**

The rinses have approximately equal flowrates, therefore combining the two rinses as they exit to sewer; the resulting content in wastewater would be around 12ppm Fe and 10ppm Zn. In any case, both are well within the specified limits.

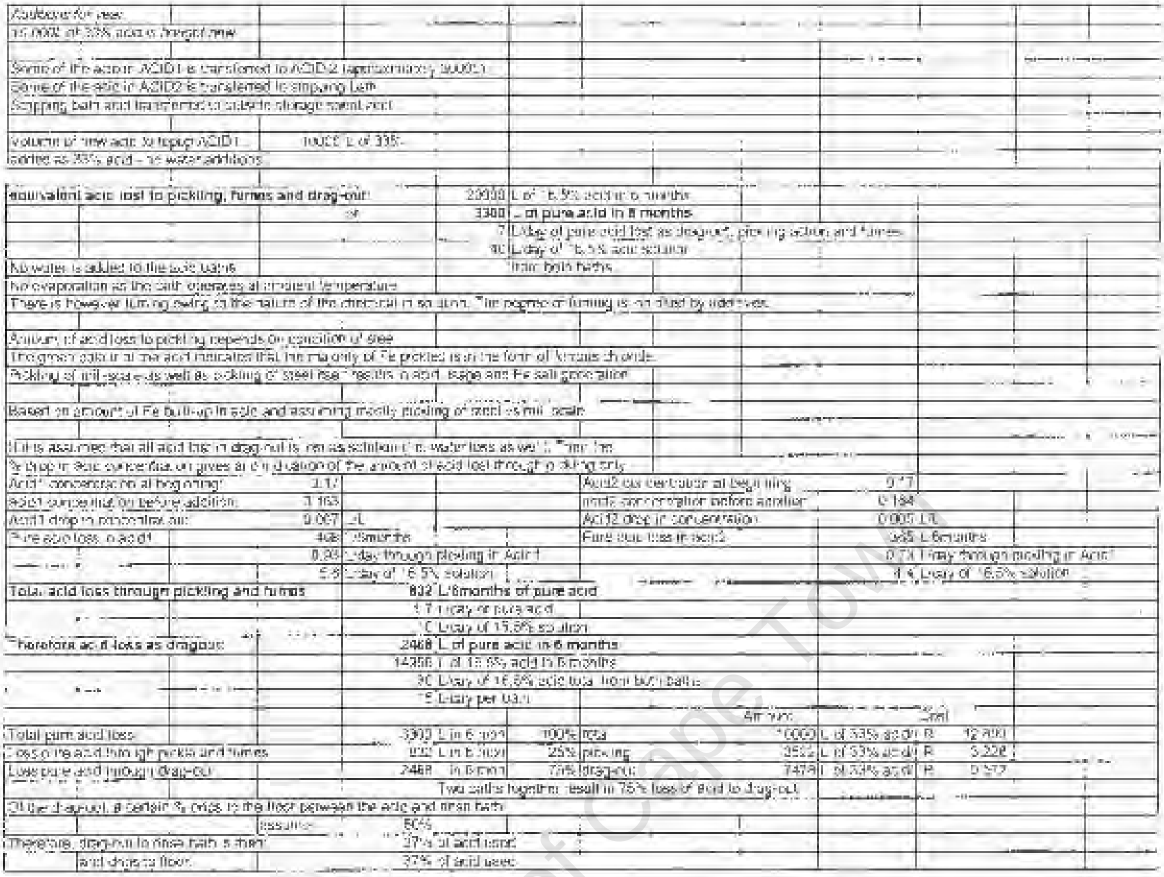
Drag-out volumes to rinse baths:

It is difficult to measure the actual drag-out from the baths owing to considerable variation in type and rate of production which means that it is unclear how representative any drag-out measurements are. Mass balances based on certain assumptions were therefore used to calculate the effective loss through drag-out. Some of the data for the mass balances could not be measured and had to be estimated.

The total solution volume loss/yr for each bath has been calculated based on chemical additions for the year and bath concentrations. This solution is lost through use on product or through drag-out (either to rinse bath or as drips to floor). To determine the drag-out loss, an estimate of the % usage vs. % loss to drag-out needed to be made.

It is difficult to determine actual usage of chemicals on products accurately. However, an average usage for the acid could be roughly calculated. This is because acid additions are only made after 6 months and the drop in concentration over this time is measured – this gives a longer time period for a known drop and therefore a more reliable calculation than for degreaser for example (where additions are made weekly, and drop in concentration is not recorded).

If it is assumed that all acid lost in drag-out is lost as solution (i.e. water loss as well). Then the % drop in acid concentration gives and indication of the amount of acid lost through pickling only. Calculations were performed using the following spreadsheet:



[illegible] for year:					
15 000L of 33% acid is bought new					
Some of the acid in ACID1 is transferred to ACID2 (approximately 3000L)					
Some of the acid in ACID2 is transferred to stripping bath					
Stripping bath acid transferred to outside storage spent acid					
Volume of new acid to top up ACID1	10000 L of 33%				
added as 33% acid – no water additions					
equivalent acid lost to pickling, fumes and drag-out	20000	L of 16.5% acid in 6 months			
or	3300	L of pure acid in 6 months			
	7	L/day of pure acid lost as dragout, pickling action and fumes			
	40	L/day of 16.5% acid solution			
No water is added to the acid baths		from both baths			
No evaporation as the bath operates at ambient temperature					
There is however fuming owing to the nature of the chemical in solution. The degree of fuming is controlled by additives.					
Amount of acid loss to pickling depends on condition of steel					
The green colour of the acid indicates that the majority of Fe pickled is in the form of ferrous chloride					
Pickling of mill-scale as well as pickling of steel itself results in acid usage and Fe salt generation					
Based on amount of Fe built-up in acid and assuming mostly pickling of steel vs mill scale					
If it is assumed that all acid lost in drag-out is lost as solution (i.e. water loss as well). Then the					
% drop in acid concentration gives an indication of the amount of acid lost through pickling only					
Acid1 concentration at beginning	0.17		Acid2 concentration at beginning	0.17	
Acid1 concentration before addition	0.163		Acid2 concentration before addition	0.164	
Acid1 drop in concentration	0.007	L/L	Acid2 drop in concentration	0.006	L/L
Pure acid loss in acid1	408	L/6months	Pure acid loss in acid2	[illegible]	L/6months
	0.96	L/day through pickling in Acid1		0.73	L/day through pickling in Acid1
	5.8	L/day of 16.5% solution		4.4	L/day of 16.5% solution
Total acid loss through pickling and fumes	832	L/6months of pure acid			
	1.7	L/day of pure acid			
	10	L/day of 16.5% solution			
Therefore acid loss as dragout	2468	L of pure acid in 6 months			
	14958	L of 16.5% acid in 6 months			
	30	L/day of 16.5% acid loss from both baths			
	15	L/day per bath			
			Amount		Cost
Total pure acid loss	3300	L in 6 mon 100% total	10000	L of 33% acid	R 12 800
Loss pure acid through pickle and fumes	832	L in 6 mon 25% pickling	2522	L of 33% acid	R 3 228
Loss pure acid through drag-out	2468	L in 6 mon 75% dragout	7478	L of 33% acid	R 9 572
		Two baths together result in 75% loss of acid to drag-out			
Of the drag-out, a certain % drips to the floor between the acid and rinse bath					
assume	50%				
Therefore, drag-out to rinse bath is then	37%	of acid used			
and drips to floor	37%	of acid used			

Results were that 25% of the acid is used through pickling operation, while 75% of the totals acid used is lost as drag-out. This is for both acid baths combined. The rapid decrease in acid rinse quality over time, indicates that this result is possible.

A better understanding of the pickling operation was obtained from the literature (CAMEX, 1995).

The conventional pickling method is totally chemical and the various processes can be described as follows:

For removing mill scale & derusting with HCl:

$FeO + Fe_3O_4 + Fe_2O_3 + 16HCl \rightarrow 2FeCl_2 + 4FeCl_3 + H_2O$ (a)

For acid dissolution of steel:

$Fe + 2HCl \rightarrow FeCl_2 + H_2$ (b)

For conversion & reversion to $FeCL_3$ & $FeCL_2$:

$Fe + FeCl_3 \leftrightarrow 3FeCl_2$ (c)

$2FeCl_3 + H_2 \leftrightarrow 2FeCl_2 + 2HCl$ (d)

The majority of the acid is used up in reactions (a) and (b), and the relative amount of acid formed in reaction (d) is assumed to be small to negligible, for the purposes of this calculation.

A significant proportion of this drag-out acid is lost as drips to floor. However, a significant amount still remains on the parts and jigs that requires rinsing in the rinse bath. It is therefore assumed that the percentage that drips to floor versus dragged-in to rinse water is 50%:50%. Therefore, 37% of acid used is lost as drag-out drips to floor, and 37% is carried over as drag-in to rinsewater. It is important to bear in mind that this is merely a rough calculation, and represents the average loss over time. For 10,000L of 33% acid additions per year, loss as drips to floor is 3700L/yr and as drag-out to rinsewater is 3700L/yr or R5,000/yr loss for each.

Once the acid loss as drag-out versus usage was known, then based on rough indications of comparative viscosity, the ratio for the other baths was estimated. There is no indication as to how accurate these figures are, and they can only be considered very rough estimates. However the estimates were discussed with the Operations Manager and considered sufficiently representative for the purpose of these calculations.

Degreasing solution is heated and less than 50% concentration of acid. Therefore, drag-out is assumed to be 30% of total chemical additions to the bath. Information on the chemical reaction to remove grease was not obtained, due to lack of knowledge of the chemical additive constituents and type of grease. The aim was also to keep these calculations simple. Of this drag-out volume, drips to floor are assumed negligible, so the total amount of 1100kg/yr is assumed to be carried to drain (wasted R10,700/yr). Calculations were carried out using the following spreadsheet:

Additions for year			
chemical usage per year:	5600	kg/year	(1998 usage given by manager)
Subtract mass for bath make-up:	4550	kg/year	(balance added over the year)
	18	kg/day	R 175 /day to remove oil and drag-out
Cost for additions:	R 43,862	/year	
Additions to maintain concentration at:	7%		
Therefore replacing equivalent solution volume:	65000	L/year	7% solution
	259	L/day	total solution loss through degreasing action and drag-out
Drag-out loss for acid is about	75%		
but degreaser is heated and less than 50% concentration of acid			
assume that drag-out from degreaser is:	30%	(only rough estimate for waste cost calculations)	
	77	L/day loss through drag-out?	
	5	kg of NaOH into rinse/day	
and water volume required to replace is	60450	L/year	water
	60	kL/year	In evaporation, drag-out and used to remove grease
	242	L/day	water loss through d/o and evaporation

Drag-out volumes from flux and passivation baths:

The drag-out volumes from these baths is not carried to rinsewater but drips to floor, and is washed to trench system. The % drag-out for these baths was estimated as for the degreaser bath (above).

Flux drag-out calculation was carried out using the following spreadsheet:

Flux additions for year			
chemical usage per year	5200	kg/year	(balance added over the year)
	21	kg/day	R 177 /day
	or product (1/2 after use as fumes) and drag-out		
Cost for additions	R 44,460	/year	
Additions to maintain concentration at	12.0%		
Therefore replacing equivalent solution volume	43333	L/year	of solution
	173	L/day	total solution loss through pick-up and drag-out
Drag-out loss for acid is about	75%		
but flux is heated and concentration is 4% lower than acid			
assume that drag-out from flux is	40%	(best estimate assumption for waste cost calculations)	
	70	L/day loss through drag-out?	
	8	kg/day of flux chem. drips to floor	
and water volume required to replace is	38133	L/year	water
	38	kL/year	This is replacing losses from drag-out and usage
	152	L/day	water loss through d/o

Flux solution is heated, but concentration is only 4% lower than acid, therefore assume 40% of chemical additions are to replace drag-out losses. This amounts to 2000kg/yr or R17,800/yr loss as drips to floor washed to trench system.

For the passivation/quench baths, drag-out is observed to be very high and pools of solution fall to floor from are drag-out drips. Therefore it is assumed that 75% of additions is to replace drag-out losses. This amounts to 16L/yr of each passivation chemical or R600/yr chromic acid, and R130/yr sodium dichromate lost as drips to floor washed to trench system.

Passivation drag-out losses were calculated using the following spreadsheets:

Chromic acid additions for year:							
chemical usage per year:							
		40	L/year				
		0.159	L/day	R	3	/day	loss per day
Cost for additions:	R	756	/year				
Additions to maintain concentration at:		0.1%					
Therefore replacing equivalent solution:		40000	L/year				
		159	L/day				total solution loss through drag-out and usage
drag-out volume is observed to be high							
assume:		75%	loss as drag-out				
drag-out volume:		120	L/day				drag-out only
and water volume required to replace is:		39960	L/year				water
		39.96	kL/year				This is replacing losses from drag-out and usage
		159	L/day				water loss through d/o

Sodium dichromate additions for year:							
chemical usage per year:							
		40	L/year				
		0.159	L/day	R	1	/day	loss per day
Cost for additions:	R	320	/year				
Additions to maintain concentration at:		0.1%					
Therefore replacing equivalent solution:		40000	L/year				
		159	L/day				total solution loss through drag-out and usage
		155	L/day				drag-out only assuming 3% pick-up
drag-out volume is observed to be high							
assume:		75%	loss as drag-out				
drag-out volume:		120	L/day				drag-out only
and water volume required to replace is:		39960	L/year				water
		39.96	kL/year				This is replacing losses from drag-out and usage
		159	L/day				water loss through d/o

Drag-out depends significantly on the type and number of products. These values therefore are only indicative of the magnitude of the average drag-out volumes over the year. It is important to realise that drag-out will vary considerably and may range from very much lower volumes to higher volumes during the course of a year's production.

Oil skimming:

1cm skimmed off surface of bath every other day.

This is 0.01mx7.5mx1.5m =112L/day for 123 days/year (245days/2) = 13,800L/yr.

The majority of this is oil, but there is some degreasing solution.

F.5 True Costs of All Wastes

According to the chosen methodology, the true cost of the wastes were determined using a worksheet which allowed for all the costs (raw material value, internal treatment and disposal, external treatment and disposal costs) to be included. A spreadsheet was set up in the same format as the worksheet and the corresponding values were inputted by linking to the relevant working spreadsheets. The resulting summary spreadsheet is included below.

APPENDIX F6 WASTE AND EMISSION COST CALCULATIONS AND ASSUMPTIONS

No.	Waste/ emission	QUANTITY PER YEAR		COSTS PER YEAR						TOTAL COSTS PER YEAR
				Internal Costs				External Costs		
		Figure	Unit	description	loss of RM	description	internal treatment	description	treatment/ disposal cost	
1	Dip rinse water	7776	kL	H2O (actual)	R 19441					
	(to sewer)			NaOH	R 10532					
				HCl	R 4785					
				H2O (charged)	R 7947					
				Total actual	R 34 853			sewer charges actual	R 10 513	R 45 377
				Total charged	R 21 386			sewer charges paid	R 4,053	R 27 419
2	Spent acid (HCl 12%)	134	L	HCl (33%)	R 20,227					
	(taken away for regeneration)			water	R 54			regeneration	R -	
				Total	R 20,281	labour	R 100			R 20,381
3	Sludge from degreaser (B.5, and pre	11	kL	NaOH	R 1,938					
				NH4Cl ZnCl2	R 2,448					
				[illegible]	R 51					
				Na2Cr2O7	R 21					
				water	R [illegible]			sewer charges actual	R 13	
				Total	R 4,653	labour	R 400	sewer charges paid	R -	R 5,053
4	French drain waste	389	kL	water	R 771					
	(spills and floorwashing to French drain)			HCl (33%)	R 4,785					
				flux chemical	R 17,863					
				passiv. 1 chem	R 557					
				passiv. 2 chem	R 240					
				Zn (metal)	R 3,180					
				Total	R 27,396	Floor washing	R 50			R 27,446
5	ash	105	tons	Zn	R 576,363	labour	R 300			
								ash sales	R -156,707	
										R 419,956
6	Dross	22	tons	Zn	R 127,924	labour	R 500			
								dross sales	R -104,025	
										R 24,399
7	Fumes above galvanising bath			NH4Cl	R 17,160					
	(dust & flux carry-off)									R 17,160
	Roller (tangeroller)	25.9	tons	Zn						
8	Wire	2200	kg	wire	R 7,482					
				Zn (17% pickup)	R 1,549			wire sales	R -441	R 8,590
				Total	R 9,031					
9	Industrial refuse	53800	L					cost for removal	R 3,025	R 3,025
										R 552,411

F.6 Evaluation table: Summary of Wastes & Emissions

The summary spreadsheet for evaluating the wastes/emissions from Company 2 is included below.

COMPANY 2 WASTE SUMMARY FOR EVALUATION

	Waste/Emission	Quantity	unit	Hazardous component	HR	%w.v or w.w hazardous	Cost per yr	WM potential	Other
	Chemical wastes								
2	Spent acid (HCl 12%)	43413	L	HCl	3	12%	R 25,361	no idea	existing regeneration
				FeCl2/FeCl3	3	10%			
3	Sludges from degreaser, flux	10214	L	NaOH	4	2%	R 5,060	no idea	
				NH4Cl	2	1.3%			
				ZnCl2	3	1.7%			
				chromic acid	1	0.08%			
				sodium dichro	2	0.05%			
5	ash	135350	kg	Zn	2	85%	R 418,966	definite	existing zinc recovery
6	Dross	20000	kg	Zn	2	91%	R 24,399	perhaps	existing zinc recovery
7	Fumes above galvanising ba	6600	kg*	NH4Cl	4	80%	R 27,100	definite	safety complaints from
				ZnCl2	3	20%			workers & neighbours
	Wastewater								
1	Dirty rinse water	7776227	L	NaOH	3	0.02%	R 77,419	definite	NaOH and HCl
				HCl	5	0.036%			combined neutralisation
				Zn	2	0.001%			
				Fe	3	0.0016%			
4	French drain waste	349444	L	HCl	3	0.2%	R 27,445	definite	non-compliance and
				NH4Cl	4	0.2%			potential environmental
				ZnCl2	3	0.3%			liability
				chromic acid	1	0.01%			
				sodium dichro	2	0.01%			
				Zn (metal)	2	0.06%			
				Fe2+3+	3	0.01%			
	General waste								
8	Wire	2200	kg	Zn	2	10%	R 8,580	no idea	sold as scrap - existing reuse
9	industrial refuse	32800	L				R 3,025	no idea	
	Total:								
	Energy usage								
	Electricity	1760000	KWh				R 131,400		indirect air pollution
		8000	kvA				R 233,600		
	Total						R 365,000		

F.7 Evaluation of Wastes and Emissions to Select Focus Areas

The Evaluation Criteria and point system are the same as for Company 1 in Chapter 5, and are set out in Appendix E12. Each of the wastes/emissions in the evaluation table (Appendix F6) is given a point value for each criterion. The points are then summed and the wastes with the highest total score are selected as focus areas (up to a maximum of 4). The spreadsheet used to calculate the totals for each waste stream and then sort them in descending order is included below.

COMPANY 2 WASTE EVALUATION
RESULTING POINTS FOR EACH WASTE FROM RATING

	Waste/Emission	Quantity	HN	Cost	WM poter	Other	TOTAL
4	French drain waste	5	5.0	4	2	2	18.0
5	ash	5	2.0	5	2	-1	13.0
7	Fumes above galvanising bath	3	5.0	1	2	1	12.0
1	Dirty rinse water	5	3.0	3	2	-1	12.0
3	Sludges from degreaser, flux, and passivation baths	3	4.0	3	0	1	11.0
10	Electricity	4	1	5	0	0	10.0
6	Dross	4	2.0	3	1	-1	9.0
2	Spent acid (HCl 12%)	4	3.0	3	0	-1	9.0
9	Industrial refuse	4	0.0	2	0	0	6.0
8	Wire	2	1.0	3	0	-1	5.0

F.8 Activities for generating Waste Minimisation Options

1. A list of WM options was formulated from the available literature (the options relevant to Company 2 were selected from the list in Table 2.3, Chapter 2).
2. In addition to these, a large amount of information regarding Best Practice for hot dip galvanizing in other countries was obtained through the overseas study tour and meetings/ correspondence with Hot Dip Galvanizers Associations from South Africa, the U.K. and the Netherlands. A detailed report for presentation to the Hot Dip Galvanizers Association South Africa, was in fact written on waste minimisation options for the hot dip galvanizing industry (Janisch, 1999). From this report, the options applicable to Company 2 were extracted.
3. A brainstorm session involving all company staff was organised to generate further options. The details of the brainstorm session are discussed in Appendix F9.
4. Technical reviews were carried out to compile more detailed information on the waste minimisation alternatives and Clean Technologies specific to the processes in Company 2 (through additional literature and specific case study reviews).
5. The various options were discussed with chemical and equipment suppliers.
6. Local (mainly industry association representatives) and international (mainly contacts from the European study tour) experts in the relevant branch were contacted regarding certain options.

F.9 Details of Brainstorm Session for Generating Waste minimisation Options

As the final part of the assessment phase of the Waste Minimisation Assessment before option selection, a brainstorm session was held. The aim of brainstorming is to generate as many ideas for waste minimisation options as possible, whether feasible or not. These, together with all the options formulated from available literature and from discussions with local and international experts in the relevant branch, as well as ideas generated during the assessment, are then evaluated for selection for the feasibility study.

The main aim of the brainstorm was to find possible improvement options that can be further investigated, but there are other advantages, in that it creates awareness amongst all people participating. An important aspect of the brainstorm is the participation of shopfloor employees. It is very important to hear ideas from those directly involved in the activities as they are often aware of aspects that have previously not been considered.

The following people took part in the brainstorm session:

UCT - Industrial Symbiosis Project leader
UCT - myself
UCT – external party
UCT - interpreter
Company 2 - Operations manager
Company 2 +/-35 (all) shopfloor workers

A Xhosa-English interpreter from UCT was necessary to ensure that all workers had a clear understanding of all discussions. The session began with a brief description of the problems to be addressed, given by the waste minimisation assessment team leader. The session was held during the ½ hour lunch-break at Company 2 and for a further ½ hour into production time. There was therefore a strict a time limit to the session and only a few topics could be covered. The main topics covered were as follows:

1. Drag out reduction
2. Rinse water use reduction
3. Floor wash method

The first aim was to listen to the ideas of those directly involved with these operations (drag-out, rinsing, floor wash) as to why, in their opinion, these problems arise and how the waste can be minimised. Ideas from those involved with the Waste Minimisation Assessment as well as an outsider to the problem were also put forward. All ideas put forward whether considered feasible or not were noted down. The suggested ideas were not discussed in too much detail during the brainstorm, as the aim was to come up with as many ideas as possible. After the session, these were examined in more detail.

The involvement of the workers in the brainstorm session was a valuable contribution to the assessment in that it was discovered that the workers were in fact not aware of all the wastes which arise from drag-out, or of actual water usage. In addition some valuable ideas were generated through their participation. Their interest and participation was very encouraging. The open-minded approach to the brainstorm session and the involvement of management was also encouraging and expected to have beneficial effects.

F.10 Geological and hydrogeological conditions in the vicinity of Company 2.

Previous work (Kniel, 1999) has shown that 2 aquifers occur within the thick sand succession beneath the site. These aquifers consist of a shallow primary sand aquifer (which is known to be heavily contaminated in many areas) underlain by a semi-confined aquifer which is a major regional groundwater resource. The two aquifers are separated by calcretised layers and clayey silts which tend to represent aquitards. The groundwater flow direction is expected to be towards the south. The surface soils on site are sandy and relatively permeable and potential contaminants can thus enter the shallow aquifer very easily. It is considered possible that in this area pollution from surrounding industries may have already impacted the groundwater system. The fairly level topography and permeable substrate suggest that migration of contaminants is likely to have occurred vertically rather than laterally. Concentrations of contaminants may have reduced over time due to dilution from rainwater penetration.

F.11 Implications of French drain wastes

The Cape Metropolitan Council (CMC) have made it clear that the use of French drains by industry for this purpose is not acceptable (CMC, 1999). Under the new National Water Bill 1998 (act 34 of 1998), it is an offence to wilfully or negligently pollute surface water or groundwater In addition, the person who owns, controls, occupies or uses the land in question is responsible for taking measures to prevent pollution of water resources. The regulatory authority can recover the costs of clean-up from the polluter For the remediation of soil the Department of Water Affairs has accepted the use of risk assessments as the basis for establishing remediation criteria. It is recommended that the environmental effects of and remediation requirements for the French drain be investigated as a separate project.

F.12 Measurement of heavy metal content of process baths to determine relative contribution of each to trench system wastewater.

The heavy metal content of each of the baths was measured in order to determine the heavy metal content of the drag-out drips to floor (assuming drag-out content is same as in the bath). Samples were taken for each bath at the end of the week during a relatively high production period, in the middle of the year (i.e. ½ bath life). The samples were analysed for heavy metal content using AA spectrometry, by UCT Department of Chemical Engineering main laboratory personnel.

The measurements were also compared to company data in cases where the iron content was measured on a regular basis. The results for each bath are presented below.

Table F12: Results from measurements of heavy metal content of each of the process baths at Company 2

BATH	Zn content (ppm)	Fe content (ppm)	Cr content (ppm)
Acid 1	4666	61500	38.99
Acid 2	16739	139500	54.17
	12984	207220	40.4
	14862	**173350**	**47**
Flux	32418	675	0.3
Chromic acid	1665	0.95	29.69
Sodium dichromate	1591	0.93	56.80

The heavy metal content of each bath will change over time. However, these values serve merely as a means to determine the relative content of each source, and are not intended as representative of the average content. The results serve as an initial investigation, in order to determine where to focus a more detailed investigation.

Using the volume of drag-out drip waste from each bath, the total contribution of each waste to total heavy metal content of the French drain were calculated using the spreadsheet below.

Heavy metal content of wastes to French drain:										
Source:	Volume	Total Zn	Total Zn	Contribution	Total Fe	Total Fe	Contribution	Total Cr	Total Cr	Contribution
	(L/yr)	(mg/L)	(kg)	%	(mg/L)	(kg)	%	(mg/L)	(kg)	%
Acid 1	3700	4666	17	1.6%	61500	228	26%	39	0.14	8%
Acid 2	3700	14862	55	5.2%	173350	641	73%	47	0.17	10%
Flux	16700	32418	541	50.8%	675	11	1%	0.3	0.01	0%
Chromic acid	16000	1665	27	2.5%	0.90	0.02	0.002%	30	0.48	28%
Sodium dichroma	16000	1591	25	2.4%	0.93	0.01	0.002%	57	0.91	53%
Zn spatter			400	37.5%						
Oil skim	14000									
Floorwash	300000									
TOTAL	370100		**1066**	**100.0%**		**880**	**100%**		**1.72**	**100%**
expected ppm		**2880**			**2378**			**5**		
There is much room for error										

The estimated content in total waste to French drain is not considered accurate by any means. However, the % contribution to heavy metal content from each waste stream may be considered sufficiently representative.

F.13 Analysis of samples of wastewater to French drain for heavy metal content

Two samples were taken from the overflow wastewater in the French drain (point FD in Figure 6.4). The samples from point A in Figure 6.4 were taken at the end of the week, during the floorwash process. These were analysed for the Zn, Fe, and Cr content using AA spectrometry by the UCT Department of Chemical Engineering main laboratory personnel. For all samples, a test sample was also provided to check the accuracy of the results. In some cases analysis was repeated if necessary as a double check on results. The accuracy of the analysis (generally 95% confidence) far exceeds the accuracy of the samples representative nature in any case. The results are presented in the table below:

Table F13a: Results from analysis of samples taken from French drain overflow (point FD in Figure 6.4)

Heavy metal	Sample	Content (ppm)
Zn (ppm)	1	437
	2	388.5
	average	**413**
Fe (ppm)	1	143
	2	169
	average	**156**
Cr (ppm)	1	0.129
	2	0.24
	average	**0.2**

Table F13b: Results from analysis of samples taken from trench system (point A in Figure 6.4)

Heavy metal	Sample	Content (ppm)
Zn (ppm)	1 (beginning of floorwash)	756.4
	2 (after 45 minutes of floorwash)	517.6
	3 (after 1.5 hrs of floorwaash)	460.5
	Average	**580**
Fe (ppm)	1	118
	2	95.2
	3	83.69
	Average	**100**
Cr (ppm)	1	0.08
	2	0.04
	3	0.03
	Average	**0.15**

F.14 Measurement of heavy metal content and pH of combined wastewaters to sewer

Samples were taken from point E Figure 6.7 over a period of 4 weeks, during a period of relatively high production throughput period. This set of samples were analysed using AA spectrometry for Zn, Fe and Cr content. Measurements of pH using litmus paper were also taken using simple litmus paper tests on samples. The results are summarised below.

Table F14: Results from measurements of heavy metal content and pH of combined wastewaters at Company 2

Sample	Zn (ppm)	Fe (ppm)	Cr (ppm)	pH
Week 1:				
Friday sample	4.67	2.28	0	-
Week 2:				
Monday sample;	82.44	56.69	0	7
Wednesday sample:	6.22	10.79	0	4
Week 3;				
Tuesday sample:	20.3	1.35	0.04	6
Wednesday sample:	31.8	41.35	0.07	8.5
Thursday sample:	31.2	7.93	0.08	10
Friday sample:	30.6	5.53	0.07	8
Week4:				
Tuesday sample	57.7	1.61	0.04	7
Wednesday sample:	79.1	1.56	0.05	11
Thursday sample:	80	0.53	0.04	6
Friday sample:	113	0.19	0.06	6
AVERAGE:	**49**	**12**	**0.05**	**7.3**
Range:	**4.7 - 113**	**0.19 - 56.7**	**0 - 0.08**	**4 - 11**
Std. Deviation:	**35.7**	**19.0**	**0.03**	**2**

F.15 Alternative degreasing chemical for Company 2

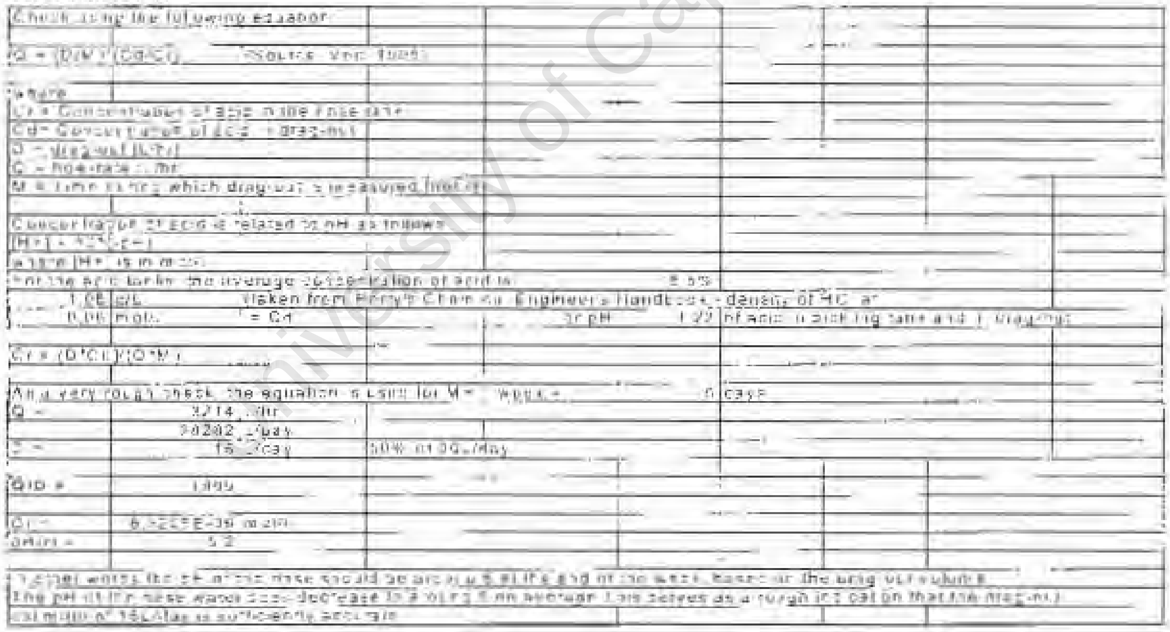
The new degreasing chemical is an alkaline degreaser effective for low-temperature cleaning operations. The chemical composition is a blend of inorganic salts (including phosphates), chelating agents and biodegradable surfactants. Operating concentration is 5% mass/volume. Therefore 1500kg in 30000L is required for charge-up. Cost is R7/kg (Existing degreasing chemical is at higher concentration 7% and higher price of R9.64/kg). The chemical is compatible with the existing alkaline degreaser and can therefore be added to existing solution without dumping it. The product dissolves easily, features a long solution life and rinses freely for complete cleaning.

The temperature can be operated at anywhere between 27°C and 82°C. Minimum temperature for efficient operation can be determined by pre-testing the solution's cleaning ability at different levels, starting at 27°C. However, decreased temperature results in increased drag-out an the recommendation is to maintain the temperature at 60°C as before.

Recommended disposal is to neutralise with a suitable material, dilute and discharge in accordance with local regulations.

F.16 Calculation to check estimate of drag-in to rinse water

Using Equation 6.1 in Section 6.7.2. The following Spreadsheet was used for the calculations.



Check using the following equation

Q = (D*V)/(Cd/Cr) (Source: [illegible])

where

Cr = Concentration of acid in the rinse tank

Cd = Concentration of acid in drag-out

D = drag-out (L/hr)

Q = flowrate L/hr

M = time in hrs which drag-out is measured (hours)

Concentration of acid is related to pH as follows

[H+] = 10^(-pH)

where [H+] is in mol/L

For the acid tank the average concentration of acid is 5.5%

1.06 g/L taken from Perry's Chemical Engineers Handbook - density of HCl at

0.06 mol/L = Cd or pH 1.22 of acid in pickling tank and in drag-out

Cr = (D*Cd)/(Q*M)

As a very rough check, the equation is used for M = 1 week = 6 days

Q = 3214 L/hr

90202 L/day

D = 15 L/day 50% of DO/day

Q/D = 1399

Cr = 6.522E-08 mol/L

pH = 5.2

In other words the pH of the rinse should be around 5.2 at the end of the week, based on the drag-out volume.

The pH of the rinse water does decrease to [illegible] on average. This serves as a rough indication that the drag-out

estimation of 15L/day is sufficiently accurate

F.17 pH measurements for acid and degreaser rinses at Company 2

The rinse baths are monitored for pH, mainly for quality reasons. Measurements of pH for both rinse baths are taken on a regular basis when all baths are checked by the Operations Manager. The pH measurements and each time the bath is drained, are recorded in company on log sheets which are then filed for later analysis by chemical supplier. This data was entered into spreadsheets for easy of analysis. The measurements are usually carried out every second operating day, but this depends on production. The data for the degreasing and acid rinses is presented below. It is assumed that the pH in the rinse baths as measured for logsheets is correct, and that the pH in the bath is equal to the pH of the wastewater leaving the baths. This implies well-mixed rinse water. The upper and lower limits of pH for rinse quality and for discharge to sewer are included in the data. Further data is included for the combined acid and degreaser rinses. The average pH for these has been calculated by assuming equal mixing, except when bath drains are recorded, in which case the pH of the bath that is drained, is included twice in the calculation of average. This in effect takes an average based on twice the volume of the bath that is drained. Although this is not exactly correct, it serves merely as a representation of the draining effect.

DEGREASER RINSE
Contains : Water

Date	Measured pH	Average pH	MAX quality limit	Sewer Limit	Action / Remark
01/14/99	6	8	9.5	12	
01/16/99	7	8	9.5	12	
01/21/99	8	8	9.5	12	
01/23/99	9.5	8	9.5	12	drain
01/26/99	7	8	9.5	12	
01/30/99	7	8	9.5	12	
02/04/99	8	8	9.5	12	
02/06/99	8	8	9.5	12	
02/08/99	7	8	9.5	12	
02/10/99	8	8	9.5	12	
02/15/99	8	8	9.5	12	
02/18/99	9	8	9.5	12	
02/25/99	5	8	9.5	12	
02/26/99	9	8	9.5	12	
03/02/99	10	8	9.5	12	drain
03/05/99	8	8	9.5	12	
03/09/99	9	8	9.5	12	
03/11/99	7	8	9.5	12	
03/23/99	8	8	9.5	12	
03/25/99	8	8	9.5	12	
04/05/99	8	8	9.5	12	
04/08/99	9	8	9.5	12	
04/12/99		8	9.5	12	
04/16/99		8	9.5	12	
04/20/99	9	8	9.5	12	drain
04/22/99	6	8	9.5	12	
04/26/99	7	8	9.5	12	
04/29/99	8	8	9.5	12	
05/03/99	6	8	9.5	12	
05/05/99	9	8	9.5	12	
05/10/99	7	8	9.5	12	
05/12/99	8	8	9.5	12	
05/18/99	7	8	9.5	12	
05/22/99	6	8	9.5	12	
05/24/99	8	8	9.5	12	
05/27/99	9.5	8	9.5	12	drain
05/31/99	7	8	9.5	12	
06/03/99	7	8	9.5	12	
06/14/99	8	8	9.5	12	
06/17/99	8	8	9.5	12	
06/21/99	8	8	9.5	12	
06/23/99	9.5	8	9.5	12	
06/26/99	6	8	9.5	12	
06/28/99	9.5	8	9.5	12	
07/05/99	8	8	9.5	12	
07/07/99	9.5	8	9.5	12	
07/12/99	8	8	9.5	12	
07/16/99	9	8	9.5	12	
07/19/99	8	8	9.5	12	
07/22/99	7	8	9.5	12	
07/26/99	8	8	9.5	12	
07/28/99	9.5	8	9.5	12	
08/09/99	9	8	9.5	12	
08/11/99	9	8	9.5	12	
08/16/99	9.1	8	9.5	12	
08/19/99	9.5	8	9.5	12	
08/23/99	7	8	9.5	12	
08/25/99	9.5	8	9.5	12	
08/30/99	7	8	9.5	12	
09/01/99	9.5	8	9.5	12	
09/13/99	8	8	9.5	12	
09/16/99	9.5	8	9.5	12	
09/28/99	9.5	8	9.5	12	
09/30/99		8	9.5	12	
10/04/99	9.4	8	9.5	12	
10/06/99	9.5	8	9.5	12	
AVERAGE	8	8	9.5	12	

PICKLING RINSE

Contains : Water

Date	Sewer Limit	MIN quality limit	Average pH	Measured pH	Action/ Remark
1/14/99	5.5	4.5	4.4	5	
1/18/99	5.5	4.5	4.4	4	Drain
1/21/99	5.5	4.5	4.4	5	
1/23/99	5.5	4.5	4.4	5	
1/25/99	5.5	4.5	4.4	3	Drain
1/30/99	5.5	4.5	4.4	4.8	
2/4/99	5.5	4.5	4.4	5	
2/6/99	5.5	4.5	4.4	4	Drain
2/8/99	5.5	4.5	4.4	3	Drain
2/10/99	5.5	4.5	4.4	4	
2/15/99	5.5	4.5	4.4	4	
2/18/99	5.5	4.5	4.4	3	Drain
2/23/99	5.5	4.5	4.4	3	Drain
2/26/99	5.5	4.5	4.4	4	
3/2/99	5.5	4.5	4.4	3	Drain
3/5/99	5.5	4.5	4.4	5	
3/9/99	5.5	4.5	4.4	3	Drain
3/11/99	5.5	4.5	4.4	5	
3/23/99	5.5	4.5	4.4	5	
3/25/99	5.5	4.5	4.4	4	Drain
4/5/99	5.5	4.5	4.4	4	
4/8/99	5.5	4.5	4.4	3	Drain
4/12/99	5.5	4.5	4.4	5	
4/15/99	5.5	4.5	4.4	4	
4/20/99	5.5	4.5	4.4	5	
4/22/99	5.5	4.5	4.4	4	Drain
4/26/99	5.5	4.5	4.4	5	
4/29/99	5.5	4.5	4.4	4	Drain
5/3/99	5.5	4.5	4.4	5	
5/5/99	5.5	4.5	4.4	5	
5/10/99	5.5	4.5	4.4	5	
5/12/99	5.5	4.5	4.4	4.5	
5/18/99	5.5	4.5	4.4	4	
5/20/99	5.5	4.5	4.4	3	empty
5/24/99	5.5	4.5	4.4	3	Drain
5/27/99	5.5	4.5	4.4	4	
5/31/99	5.5	4.5	4.4	6	
6/3/99	5.5	4.5	4.4	3	Drain
6/14/99	5.5	4.5	4.4	4	
6/17/99	5.5	4.5	4.4	5	
6/21/99	5.5	4.5	4.4	5	
6/23/99	5.5	4.5	4.4	4	
6/25/99	5.5	4.5	4.4	5	
6/28/99	5.5	4.5	4.4	4.5	
7/6/99	5.5	4.5	4.4	4	
7/7/99	5.5	4.5	4.4	3	Drain
7/12/99	5.5	4.5	4.4	5	
7/16/99	5.5	4.5	4.4	5	
7/19/99	5.5	4.5	4.4	5	
7/22/99	5.5	4.5	4.4	5	
7/26/99	5.5	4.5	4.4	5	
7/28/99	5.5	4.5	4.4	4	Drain
8/6/99	5.5	4.5	4.4	4.8	
8/11/99	5.5	4.5	4.4	5	
8/16/99	5.5	4.5	4.4	6	
8/19/99	5.5	4.5	4.4	5	
8/23/99	5.5	4.5	4.4	5	
8/25/99	5.5	4.5	4.4	4.5	Drain
8/30/99	5.5	4.5	4.4	5	
9/1/99	5.5	4.5	4.4	5	
9/13/99	5.5	4.5	4.4	4	Drain
9/15/99	5.5	4.5	4.4	5	
9/28/99	5.5	4.5	4.4	5	
9/30/99	5.5	4.5	4.4	4	Drain
10/4/99	5.5	4.5	4.4	5	
10/6/99	5.5	4.5	4.4	5	
AVERAGE	**5.5**	**4.5**	**4.4**	**4.4**	

COMBINED RINSE WATER TO SEWER

The average pH is determined by assuming equal mixing of each rinse, except when drains, in which case the pH of the drained bath is included twice in the calculation of average

Date	Ave pH	Action acid rinse	Action deg rinse	MAX pH	MIN pH
01/14/99	5.5			9.5	5.5
01/18/99	5	Drain		9.5	5.5
01/21/99	5.5			9.5	5.5
01/23/99	6.0		drain	9.5	5.5
01/26/99	4	Drain		9.5	5.5
01/30/99	5.9			9.5	5.5
02/04/99	6.5			9.5	5.5
02/06/99	6	Drain		9.5	5.5
02/08/99	4	Drain		9.5	5.5
02/10/99	5			9.5	5.5
02/15/99	5			9.5	5.5
02/18/99	5	Drain		9.5	5.5
02/23/99	5	Drain		9.5	5.5
02/26/99	6.5			9.5	5.5
03/02/99	6.5	Drain	drain	9.5	5.5
03/05/99	6.5			9.5	5.5
03/09/99	5	Drain		9.5	5.5
03/11/99	6			9.5	5.5
03/23/99	5.5			9.5	5.5
03/25/99	6	Drain		9.5	5.5
04/05/99	6			9.5	5.5
04/08/99	5	Drain		9.5	5.5
04/12/99	5			9.5	5.5
04/15/99	4			9.5	5.5
04/20/99	7.7		drain	9.5	5.5
04/22/99	5	Drain		9.5	5.5
04/26/99	6			9.5	5.5
04/29/99	6			9.5	5.5
05/03/99	6.5			9.5	5.5
05/05/99	7			9.5	5.5
05/10/99	6			9.5	5.5
05/12/99	6.25			9.5	5.5
05/18/99	5.5			9.5	5.5
05/20/99	5	empty		9.5	5.5
05/24/99	5	Drain		9.5	5.5
05/27/99	7.7		drain	9.5	5.5
05/31/99	6.5			9.5	5.5
06/03/99	4	Drain		9.5	5.5
06/14/99	5			9.5	5.5
06/17/99	5.5			9.5	5.5
06/21/99	6.5			9.5	5.5
06/23/99	7.7		drain	9.5	5.5
06/25/99	6.5			9.5	5.5
06/28/99	7.5		drain	9.5	5.5
07/05/99	5			9.5	5.5
07/07/99	6.25	Drain	drain	9.5	5.5
07/12/99	6.5			9.5	5.5
07/16/99	7			9.5	5.5
07/19/99	6.5			9.5	5.5
07/22/99	6			9.5	5.5
07/26/99	6.5			9.5	5.5
07/28/99	6.75	Drain	drain	9.5	5.5
08/06/99	6.9			9.5	5.5
08/11/99	7			9.5	5.5
08/16/99	7.55			9.5	5.5
08/19/99	8.0		drain	9.5	5.5
08/23/99	6			9.5	5.5
08/25/99	7	Drain	drain	9.5	5.5
08/30/99	6			9.5	5.5
09/01/99	8.0		drain	9.5	5.5
09/13/99	5	Drain		9.5	5.5
09/15/99	8.0		drain	9.5	5.5
09/28/99	8.0		drain	9.5	5.5
09/30/99	5	Drain		9.5	5.5
10/04/99	7.2			9.5	5.5
10/06/99	8.0		drain	9.5	5.5
Average	6.2				

F.18 Analysis of Ash samples before change in collection method

Prior to change:

Two samples of ash of were taken from different sections of the collected ash. The first sample was taken from month 1, and the remaining three were taken from the ash collected in month 2. The aim was to obtain sufficiently representative samples for the rough analysis of zinc content. The samples were weighed and total mass noted. The samples were then crumbled inside plastic container-bags in order to loosen the grey pieces of metal zinc from the powdery red zinc-oxide. Each sample was then mechanically sieved using various mesh sizes, until the larger Zn metal pieces were effectively separated from the powdery ash. The metal and ash were then weighed separately. The results are as follows:

Table F18a: Results of analysis of original ash samples for ZnO and Zn metal content

Sample	Mass ZnO	Mass Zn	Mass total	% ZnO (g/g)	% Zn (g/g)
Sample 1	153.9g	361.8g	515.7g	29.8	70.2
Sample 2	202.6g	450.5g	653.1g	31.1	68.9
AVERAGE				30%	70%

The ash was analysed by the UCT main laboratory for zinc content using AA spectrometry. The results are as follows:

Table F18b: Results of analysis of ZnO for Zn content

Sample	% Zn (kg/kg)
Sample 1	84.1
	81.6
Sample 2	82.1
	80.1
AVERAGE	**82%**

Zinc content in zinc oxide can also be determined through calculations based on molar mass percentages.

Molar mass of zinc = 65g/mol
Molar mass of oxygen = 16g/mol
Molar mass of ZnO = 80g/mol
% Zn (g/g) =80.2% which is comparable to the results from direct measurement.

Combining the % Zn in ZnO with the % ZnO, determines the overall zinc as zinc-oxide, versus Zn as Zn metal. Using the average figures from above, the result is as follows:

% zinc oxide:	30%
% zinc metal:	70%
Zn in ZnO:	82.0%
Therefore Total Zn:	95%

F.19 Zinc Balance

The total use of Zn is 380tons/year. The Zn used on product is estimated at 8% of mass of steel galvanized per year. The remaining Zinc is lost in ash, dross, and as spatter to floor.

Zinc lost as spatter is assumed to be 7%of the total Zinc usage. This estimate is the general estimate for the industry which the Operations Manager believes to be representative. The zinc content of the ash was determined in Appendix F18. In order to complete the zinc balance the, Zn content of the dross was measured. Samples of dross collected were also analysed for zinc content in order to complete the Zn balance. Two samples were taken and were analysed by the UCT main laboratory personnel for Zn content. The analysis was repeated twice for the first sample and three times for the second. The results are as follows:

DROSS Samples								
taken twice to determine %Zn, %Fe and other components								
Use this to determine ratio of Fe:Zn in Dross								
	Zn (mg/L)		Fe (mg/L)		(g)	%Zn	%Fe	%other
sample 1	4512.53		143.89		0.5	90.2506	2.88	6.87
	4712.2		152.97		0.5	94.244	3.06	2.70
	4612.37		**148.43**		**0.5**	**92.2473**	**2.97**	**4.78**
test	50	45.5785	30	29.393				
	50	46.185						
	Zn(ppm)		Fe (ppm)			%Zn	%Fe	%other
sample 2	904150		31752			90.42	3.176	6.41
	902190		31397			90.22	3.140	6.64
	908700		31023			90.87	3.102	6.03
	905017		**31394**			**90.50**	**3.139**	**6.36**
AVERAGE of 2 SAMPLES						91.37	3.05	5.57
						91.37%	3.05%	5.57%

ZINC BALANCE				
IN				
	amount/annum	unit	% Zinc	
Zinc	270	tons	100%	
[illegible]	1.68	tons	20%	
% new Zn recycled				
ON PRODUCT				
Zn (8.5% pick-up)	281	tons		
Zn less use on product	91	tons		
OUT	amount/annum	unit	% Zinc	Zn t/an
Ash	105	tons	34.5%	36
Dross	20	tons	91.4%	18
un recovered spatter	26	tons	100%	26
TOTAL				80
Balance	-11	tons		
This is acceptable, since there is room for error in the above estimates.				

F.20 Analysis of Ash samples After Change in collection method

Samples of the ash taken after the change were analysed in the same way as above, and the results are as follows:

Table F20a: Results of analysis of new ash for ZnO and Zn metal content

Sample	Mass ZnO	Mass Zn	Mass total	% ZnO (g/g)	% Zn (g/g)
Sample 1	233.8g	121.9g	355.6g	65.7	34.2
Sample 2	312.5g	155.3g	467.8g	66.8	33.2
AVERAGE				66%	34%

The ash was analysed by the UCT main laboratory for zinc content using AA spectrometry. The results are as follows:

Table F20b: Results of analysis of new ZnO for Zn content

Sample	% Zn (kg/kg)
Sample 1	80.6
	80.1
Sample 2	80.0
	80.4
AVERAGE	**80.3%**

Combining the % Zn in ZnO with the % ZnO, determines the overall zinc as zinc-oxide, versus Zn as Zn metal. Using the average figures from above, the result is as follows:

% zinc oxide:	**66%**
% zinc metal:	**34%**
Zn in ZnO:	**80.3%**
Therefore Total Zn:	**87%**

F.21 Analysis of savings from change in ash collection method

The analysis was carried out using the following spreadsheet.

ASH CALCULATIONS								
Savings in amount of ash after change in collection method.								
Before:					After:			
Ash mass/drum:		420	kg/drum			394	kg/drum	
drums collected/day:		1	drums			0.5	drum	
volume of drum:			m3				m3	
mass ash per day:		420	kg/day			197	kg/day	
						47%	of before amount	
						53%	less ash collected	
working days/yr:		250	days					
Mass ash/year:		105.0	tons/yr			49.3	tons/yr	
Zinc price:	R	7,000	/ton					
Cost of selling ash:	R	2,635	/ton					
Sale of Ash:	R	276,707	/year		R	129,789	/year	
Actual savings in Zinc consumption:								
BEFORE:					AFTER:			
% total Zn in ash:		**95%**				**87%**		
% zinc metal in ash:								
% zinc oxide in ash:								
Zn loss in ash:		99	tons/year	35%		43	tons/year	13%
Cost of Zinc loss:	R	695,523	/year	26%	R	300,107	/year	11%
Minus sale of ash:	R	418,816	loss/year		R	170,319	loss/year	
loss/ton ash:	R	3,989			R	3,458		
Overall saving:					R	**248,497**	/year	
						59%	savings	

F.22 Feasibility Analysis of Identified Waste Minimisation Options

This section includes the detailed feasibility evaluations (according to the criteria of Appendix E16) for some of the waste minimisation options identified.

B1. Drag-out reduction
B1.1 Minimising drag-out

<u>1. Vibration mechanism on crane to speed up run-off (less drag-out in shorter dwelling time)</u>

Crane supplier has investigated this option
Mechanism is not available locally but in Germany
Can import it and this is being investigated

Mechanism involves an off-centre motion device.
As the crane raises the jig, it automatically vibrates and shakes off drag-out

Cost may be quite high?

drag-out losses at present:	R 38,965	/yr
Savings in drag-out reduction:	70%	possible?
	R 27,276	/yr

Also savings from decreased contamination of wastewater to sewer and extended bath lives
As well as improved quality from decreased cross-contamination of baths, especially decreased fe carry-over to galvanising bath

Payback period should therefore be cost-effective

B1.2 Direct drag-out return
<u>1. Jolt jig above bath after withdrawal for quicker and greater run-off of drag-out</u>

After withdrawing load from process bath, it is held above bath and
manual control button for crane is pressed and released (3x) which causes jolting
This causes the majority of dripping to run back into process bath
No cost - except might damage crane in long term, therefore vibrating mechanism is long-term option

Possible decrease in drag-out:	70%	
	R 27,276	/yr
Loss in production time:	minimal	

This has been implemented already
Result is observable in minimum dripping and floor area where drips used to fall is much dryer

B1.2 Direct drag-out return

3. Tilted drip tray to capture drag-out from flux bath to return to bath.

Technical Evaluation:

Equipment requirement.
Drip tray 7.8m x 3.2 m installed in flux drying area.
Depth = 200mm
Raised at flux bath end to tilt, so that run-off can be captured
5mm mild steel tray with 10mm polypropylene coating

Economic Evaluation:

Assuming downtime negligible since will be performed during shut-down

Investment Capital:

Cost of installed tray:	R	16 000	
Drum for capture:	R		
labour for instalation:	R	500	
in-house engineering:	negligible		
Total investment:	R	16,500	

Operating Costs:

Labour to return captured drips:	R	–	

Savings:

Loss of flux chemical to floor:	R	17,953	/yr

Calculated in waste summary based on assumption of 40% of total chemical loss is due to drag-out

Estimate of recoverd flux chemical:		85%		some loss (dry-up on tray) in drying process
Estimated savings in chemicals:	R	15,260	/yr	

Other savings:

Reduced need for clean-up:				difficult to estimate bu cannot be ignored
Reduce floorwash water:	R	255	/yr	assuming 1/3 of floorwash water to wash flux
Total savings:	R	15,515		

Profitability Analysis:

Payback period:	1.06 year

If drag-out is reduced, then payback period will be much shorter

For example:	50%	reduction in drag-out	
Then savings: R	7,757	/yr	not including floorwash cost
Payback peri	2.1	years	
For example:	70%	reduction in drag-out	
Then savings: R	4,654	/yr	not including floorwash cost
Payback peri	3.5	years	

Without drag-out reduction, the installation of drip tray in flux drying area has a payback period of about a year.
Assuming drag-out reduction is implemented, then payback period is about 4 years.
However, this should be adjusted for intangible savings due to reduced need for clean-up.

Environmental Evaluation:

Reduced contamination of working area
Eliminates need for wet floorwashing and hence reduces contaminants to wastewater
A significant proportion of Zn (and Fe) in wastewater is from flux drips

Recommendations:

The first priority is to reduce drag-out from the baths.
If this is done significantly then the recovery of chemicals with drip-tray is minimal.
However, the requirements for cleaning the accumulated spills has associated costs.
Drip tray is recommended mainly for spill containment and reduction in wastewater contamination.

It must be kept in mind that the profitability analysis depends significantly on the estimated volume of drag-out from the flux bath.

B1.2 -4. Tilted drip tray to capture drag-out from passivation baths to return to bath

A similar drip-tray to capture passivation drips is not as simple, as both the drips will be a combination of chemicals from each bath. There would have to be 2 separate trays to keep the chemicals segregated.
In addition, the total loss of chemicals amounts to under R800/yr, so payback period would be minimal.
However, the drips to floor need to be prevented by making every effort to minimise drag-out from these baths.

B1.3 Drag-out recovery and return

1. Place spare tank after acid bath to captue drips to floor and recover acid for stripping bath

Technical Evaluation:
Equipment requirement:
Move spare tank into space to capture drips
Modify tank (piping and pumps) to allow captured acid to be pumped to either pickling/stripping tanks

Economic Evaluation:
Assuming downtime negligible since will be performed during shut-down period/weekend

Investment Capital

Modified and installed tank:	R 500
Labour:	R 250
Total Investment:	R 750

Operating costs:

electricity for pump:	R 1,000 /yr

Savings

Total acid lost to floor:	R	1,780	/yr

Calculated in waste summary based on assumption of 70% of total chemical loss is due to drag-out and 50% of drag-out drips to floor. This value is therefore dependent on the drag-out assumption

Estimate of recovered acid:	Assume negligible loss			
Estimated savings in chemicals:	R	4,786	/yr	at current drag-out rate.
If drag-out is reduced by 70%, then savings will be lower at:	R	1,436	/yr	
Other savings:				
Reduced need for clean-up:				
Reduce floorwash water:	R	255	/yr	assuming 1/3 of floorwash water to wash acid drips
Total savings without drag-out reduction:	R	5,040	/yr	
Total savings with drag-out reduction:	R	1,690	/yr	
Savings less operating costs:	R	4,040	/yr without drag-out reduction	
	R	690	/yr with drag-out reduction	
Payback period:		0.2	years without drag-out reduction	
		1.1	years with drag-out reduction	

Owing to the low initial investment, this option is economically feasible even with drag-out reduction.
Other savings include reduced contamination of wastewater from clean-up
This is the main reason for installing the spare tank in any case.

Environmental Evaluation:
The acid drips to floor require cleaning and were washed to sewer.
The acid is a source of Fe in the wastewater, it also causes Zn metal in the trench system to go into solution
Acid spills which contribute to concrete floor corrosion and are a danger to workers will be reduced

Recommendations:
First priority is to reduce drag out at source
The spare tank is not being used at present, and the cost of using it to capture spill acid is low
Another option may be to use the spare tank to re-install the double rinse
This option is not possible if the spare tank is repaired and the double rinse is re-installed (Option B2.5 - 1)
However, in this case, the problem of acid drips to floor will be solved.

Option B1.3 –2: Degreaser rinse additions for evaporation replacement

Rough calculations can be performed by assuming the degreasing chemical to be mostly NaOH, and the molar concentration of the NaOH is assumed to be equivalent to the concentration of hydroxide ions. The average pH of the degreaser rinse is 8.5.
Therefore
$[OH] = e^{pH-14} = e^{8.5-14} = 0.0040867$ mol/L (adaption of equation 6.3)
where $[OH^-]$ = concentration of hydroxide ions = NaOH concentration in mol/L
Since the molar mass of NaOH is 20g/mol, the concentration of NaOH in degreaser solution is therefore = 0.0817 g/L

For 60kL of rinse solution added to the degreaser bath, this would mean a saving of
0.0817g/L* 60000L/1000g/kg = 5kg/yr of NaOH or R50/annum.

<u>B1.3-2. Use degreaser rinse water instead of freshwater for evaporation replacement for degreaser bath</u>
(save water and chemicals)

Technical Evaluation
Requires hose connection and pump between rinse bath and degreasin tank

Economic Evaluation

Investment costs:

Equipment C	R 1,000	
Labour for ins	R 100	
Operating costs:		
Electricity cos	R 2,000 /yr	estimate
Savings		
Water use:	29 kL/yr	
R:	72 /yr	
Degreaser Ch	R 50 /yr	
Total savings	R 122	
Savings-cost:	R -1,878 /yr	

Profitability Analysis:
Cost to install and operate this option outweighs minimal savings

Environmental Evaluation:
Savings in water and chemicals are negligible.
This is mostly due to the fact that the oil layer on the surface of the degreaser bath
lowers the evaporation rate significantly

B2.1 Avoid the need to rinse
<u>ELIMINATE ACID RINSE IF USE FLUX PURIFICATION</u>

This will have to be tested once purification system is in place.
For advanced purification technologies this option has been proven to be feasible.
In effect the Fe carry-over is removed so this problem is eliminated
Secondly, the acid carry-over to the flux is a benefit and not a problem (since the acid forms for flux chemical)

Technical Evaluation:
Requires testing after flux purification is installed before rinse can be removed.
Only possible once flux purification is in place, and is therefore dependent on technical feasibility of purification technology.
Also depends on the degree of purification obtained.
If an advanced purification method is used, such as the commercially available filtration options, this option is
feasible without testing.
However, the proposed option for Fe content reduction in the flux is simple settling of the precipitated Fe-salts
which may not be as effective. In which case, testing is necessary once the option is in place.
The elimination of the bath itself is simple technically.

Economic Evaluation:
This will have to be performed in conjunction with the flux purification technology evaluation,
as it is not an option on its own.

Environmental Evaluation:
Water saving and effluent halved.
However, alkaline nature of effluent acts as a neutralising agent for acidic rinsewater from other rinse.
The acid rinsewater will therefore require treating before discharge if this bath is eliminated

B2.4 Controlling flow rate of rinse water use

RINSE WATER FLOW REDUCTION/CONTROL

1. Adjust incoming tap to optimal flowrate.

Optimum flowrate depends on the degree of drag-out.
The drag-out varies substantially with product type and production rate at present.
In addition, even with the flowrate at it's maximum, the rinse quality drops very fast.
The acid and degreaser rinses requires weekly dumping at present flowrate.
If drag-out is minimised with the implementation of Option B1.2 – 1,
Then the time between rinse dumps will be extended, or the rinse flowrate may be reduced.
Since rinse flow uses far more water per annum than the rinse dumps, decreasing flowrate is a better saving option.
However, optimum option will determine flowrate for minimal rinseflow in conjunction with minimum rinse dumping.

Existing loss of acid and degreasing chemical to water through drag-out is:

Degreaser:	R	10,633
Acid:	R	4,786

If drag-out is reduced by 75%, then loss of Acid and degreasing chemicals to rinsewater is reduced by 75%.
For a single rinse bath, the concentration in the rinse is proportional to the drag-out.
Therefore, if drag-out is decreased by 75%, then concentration in the rinsebath will decrease by 75%.

Degreasor savings:	R	7,975
Acid savings:	R	3,589
Sum:	**R**	**11,564**

The concentration is also inversely proportional to the rinse flowrate.
Therefore if the rinse flowrate is decreased by 40%, the concentration in the rinse bath will increase by 2.5
Combining the reduced drag-out effect and flowrate decrease, the resulting concentration will be effectively reduced by 30%.
This would have a positive effect on draining frequency of both baths.

Possible rinsewater flow reduction:	40%
Potential savings in water use:	3110 kL/yr
In effect this should save up to:	**R 11,478 /yr**

However, the company is undercharged for water at present, and the savings in water use may not be observed.
If the double rinse after pickling is reinstalled, then the optimum flowrate calculations will be affected differently.

Once the drag-out reduction has been implemented, tests may now be performed to determine optimum reduction in flowrate.
Flow restrictors are inexpensive, but are not as effective for rinse water control lines where the production rate is inconsistent as at Company 2.
Tests for optimum flowrate will have to be determined for minimum drag-out reduction.

If the double rinse after pickling is reinstalled, then the optimum flowrate calculations will be affected differently.
Q= (D/M)*(Co/C2)^1/2
where C2 is the concentration in the 2nd counter-flow rinsebath, see Option B2.5-1.

B2.4 -3. Install automatic rinsewater flow control device

Conductivity Control of rinsewater flowrate:

Technical Evaluation
Equipment requirement:
Conductivity meter with control solenoid valve

Conductivity controllers are expensive, require frequent preventive maintenance
and do not sense non-ionic contaminants like oil and dirt.
Oil may also interfere with sensors.

Economic Evaluation: based only on rough estimates.
Investment costs:
conductivity control meter: R 5.000 ?
external engineering & design costs:
installation costs:

Training for control

Operating costs:
Electricity: R 2.000 /yr estimate
maintenance: R 500 /yr estimate

Savings:
Water: depends on % reduction in water use achievable.
Cost of water at present is low, therefore with 20% reduction savings would by:
R 2 400 /yr

Savings less cost: R -100 /yr

At present cost of water, payback period is not cost-effective.
If water costs increase substantially, may be more feasible

Environmental Effect:
Decreased water usage
Increased concentration in wastewater - but can be set at optimum.
With reduced drag-out it has better environmental effect.

B2.4- 4. Install flowmeters to monitor rinse flowrate and water use (raise awareness)

These do not reduce water use by themselves but make the operator aware of use rates
and help identify specific locations of excessive water use

Investment costs depends on type: R 2.000 to install one for each bath?
Savings depend on findings:

Since municipal water meter is broken, it may be useful to rais awareness to encourage water savings.
However, if water reduction methods are implemented based on rough measurements, there is no need.

B2.5 Alternative rinsing configurations

<u>1. Re-install double counterflow rinse for acid rinse (can reduce rinsewater use here by up to 50%)</u>

Technical Evaluation:

Equipment requirements:
Repaired/replacement tank, pipes, pump
Has been used succesfully before
Will increase production time for additional rinse by 5mins extra per load.

Economic Evaluation:

Total investment costs:	R 22,000 to install additional tank and connections		
Operating costs:			
Electricity:	R	2,000	/yr?
production time loss:	R		/yr
Savings:			
With drag-out reduction:	R	1,436	
Can decrease water flow by:		50%	
Cost of water should be reduced by:	R	6,539	/yr
Actual water costs 35% of this:	R	1,962	/yr - if any savings are observed at all as long as watermeter is broken

Reduced need for dumping will be more of effect of drag-out reduction
Savings through improved rinsing efficiency include:
Improved quality through less Fe carry-over to flux
Decrease in amount of Fe sludge for removal from flux?
Or decrease in dross formation (minimal)

combined saving estimate:	R 2,000 /yr	
Savings less costs:	R 3,398	not including loss in production which could be significant
Payback period:	6.5 years	

I.e. payback period is in the vicinity of 5 years not even taking the loss in production time into account.
However, increase in water costs and/or greater decrease in water flowrate may lead to this being more economically feasible

Environmental Evaluation

Decrease in water usage

B5 Reduce/ eliminate the need for cleanup or improve cleanup methods

<u>1. Use less water for floorwash by installing a trigger mechanism on the hose used</u>

This allows for more efficent floorwashing and uses less water

Trigger mechanism is relatively cheap:			R 200
Savings in water use:	50%?	R	396 /yr

Payback period of < 1 year

However, if less water is used for floorwashing, then the contaminant concentration in wastewater increases, since dilution effect is reduced.
Unless the drips to be washed are reduced themselves.

However, then a better option would be to eliminate floorwashing altogether.

B.5- 2. Close up trench system Use dry-sweeping instead of wet washing for floor cleaning if chemical drips are eliminated/prevented

Technical Evaluation

Pre-requisite is that drag-out is reduced substantially and all chemical spills to floor are eliminated.
If so, then floorwashing with water may be stopped, and floor may be dry-swept.
The Zinc metal spatter on floor may be more easily recovered since the wet chemicals do not intefere.
The dry sweepings may be melted for zinc recovery simply bo returning togalvanisnig bath.

Economic Evaluation:

Investment costs:

drag-out reduction through jolting;	R	-	
drip trays	R	16,000	installed
drip tank:	R	750	installed
	R	16,750	

Operating Costs:

no change in labour requirements
melting costs negligible

Savings:

floorwash water:	R	771	/yr
total saved chemicals:	R	23,546	/yr
Zn metal recovery:			
10kg per week loss before, now saved			
0.44 tons/yr		R 0	/yr
wastewater charges:			
eliminate labour for trench sludge removal:	R	440	/yr
Savings less Costs:	R	24,758	

Profitability Analysis:

Payback period: 0.68
8.1 months

Environmental Evaluation:

Eliminate chemical loss through spills
Save zinc metal
Reduce heavy metal load in wastewater substantially
Eliminate trench sludge disposal
improved working environment

B5-3. Install anti-splash cover/hood over zinc bath

Technical Evaluation:
This is common practice in Europe as it is air emission regulations require fume control
Hood is expensive and difficult to install with work flow at 90degrees to bath layout as in Company 2
It is more for air emission control than waste minimisation
However, it has advantages in eliminating zinc spatter losses in workarea, as all are captured within hood
It also reduces ash formation by minimising the return of collected spatter which causes further zinc oxidation
Hood equipment is not easily available locally, those companies in South Africa who have installed
have sourced design from Europe
It is technically difficult to install such a hood system where the workflow is perpendicular to the baths, as in Company 2
Effect on production is minimal since loss through lowering and raising hood is matched by gain in ability to
continue other operations during galvanising (normally have to move away from bath during galvanising)
Usually combined with fume extraction equipment

Economic Evaluation:

Investment cost is considerable:		R 100,000 rough estimate
Operating costs:		
Electricity		R 8,000 /yr
Savings mainly in Zn spatter:	R	171,500 /yr
Savings less costs:	R	163,500 /yr
Payback period		0.6 years

Although the payback period is within a year, the investment is considerable and is inhibited by the availability of finances at the company

Environmental Evaluation:
Savings in Zn metal loss
Fume extraction is merely control and either transports fumes externally or scrubs fumes
Scrubbing fumes merely transfers waste from air-emissions to solid and liquid waste.

Better option to reduce fumes and spatter by installing heated flux drying

OPTION B6- ELIMINATE UNECESSARY FLUX DUSTING

Savings due to change in amount used:

Cost/kg dust		R 2.60 /kg		
Dust amount				
before	=12*50kg bags/month	600 kg/month	6600 kg/year	
Cost per month		R 1,560 /month		
Annual cost:		R 17,160 /year		
after	=1*50kg bag per mon	50 kg/month	550 kg/year	8%
Cost per month:		R 130 /month		
Annual cost:		R 1,430 /year		
Annual savings:		**R 15,730 /year**	6050 kg/yr	92%

When mas of flux dust used was decrease, the flux solution concentration was increased:

previous flux bath concentration:	8%
new flux bath concentration:	12%
% increase in concentration:	4%

Cost of flux chemical/kg:	R 8.55	/kg
previous usage of flux chemical:	8150	kg/year
previous cost for flux chemical:	R 69,683	/year
new usage of flux chemical:	8476	kg/year
	R 72,470	/year
Increased annual cost:	**R 2,787**	**/year**
Overall savings:	**R 12,943**	**/year**

B6. Improved Process Efficiency

2. Ensure optimum drying of flux (heated drying) to avoid unnecessary fuming from wet flux volatilisation and to minimise spatter.

Technical Evaluation:

The flux drying area is closed off and heated using electric elements and fans.
The drip tray to capture drag-out drips is installed as part of this system.
Drying time is extended from 5mins to 15 mins per jig, but the effect on production time is avoided by implementing staggered start.
With improved flux drying, dusting can be completely eliminated.

Equipment requirements:
Refer to diagram - Figure 6.8
Tilted drip tray is installed as base 7.8m x 3.2m and depth of 200mm
Cross beams and panels are installed on sides
Panels and tray manufactured from 5mm mild steel lined with 10mm polypropylene.
Insulation on panels
2 * 1.2m fans (1.5 kW) are installed on flux-tank side
8*7.5kW (1.5m) electric elements (4 infront of each fan)
Electrical cabling and control instruments
Mechanical sliding/folding lid to cover

Elements take 1hr to reach 70degC operating temperature,
but once temperature is reached heating may be switched off between loads.
System was designed by Industrelek consultants for free
Parts will be sourced from local suppliers with installation perofrmed by company staff

Economic Evaluation:

Investment costs:

installed tilted drip tray:	R	16,000
installed side panels:	R	20,000
lid installed:	R	7,000
insulation installed:	R	2,000
electrical cabling/control:	R	3,000
fans installed:	R	3,000
elements installed:	R	5,000
training costs:	R	1,000
TOTAL investment:	R	57,000

Operating Costs:

Electricity cost/unit:	R 0.07 /kWh
Electricity for fan:	16635 kWh/yr
Electricity for elements:	324723 kWh/yr
Total electricity costs:	R 25,258 /yr

Savings:
Spatter reduction: 2% of total Zn usage saved (still 5% lost)
R 56,130 /yr
Ash amount decreased: 7% decrease in amount of ash formed
R 11,913 /yr saved
Energy savings from saved Zn losses:
3% of bath energy requirements R 6,570 /yr
Dusting eliminated: R 1,430 /yr
Saved flux chemicals: R 7,767 /yr R 1,939
Improved quality --> eliminate rework
Rework costs: 1.1% of total production @ R 7.00 /kg
R 231,000 cost for Redo
Depends on production
Total savings: R 314,810 /yr

Savings less costs: R 289,552 /yr
Payback period: 0.20 years
2 months
Rough estimate: <6months

Environmental Evaluation:

Reduction in Zn loss and ash formation
Reduction in fuming - not only from dusting elimination, but wet, cold flux is main cause of flux fumes
No flux drips to floor - reduced wastewater contamination from clean-up
Will help with expected more stringent air pollution regulations in near future
Disadvantage: small increase in energy usage

B8.1 Common corrective maintenance methods

2. Fe removal from flux using settling

Technical Evaluation:

Flux heating tank requires replacement as rubber lining is dissolving and causing oily contamination of flux
Fe-chloride salts precipitate in flux solution and build-up as sludge in the bath
The Fe affects the quality of the coating by increasing Zn pick-up
Fe carry-over to Zn bath also results in dross formation
To replace heating tank, decided to allow for sludge collection by special design of new tank.
Flux is continuously circulated through heating tank, therefore can collect precipitated Fe rich sludge in heating tank, and remove on a regular basis.
Expected 75% Fe removal.
Construction material is 5mm steel with 10mm polyproylene lining
Base has 8mm perforation and tapered base with tap-valve to allow for sludge collection
New tank design is shown in Figure 6.12

Economic Evaluation:

Investment Costs:

Tank:	R	12,000
Lining:	R	3,500
Installation:	R	3,000
TOTAL	R	18,500

Operating Costs:

electricity:	as before		
sludge collection:		R	488 /yr
(1/day for month, then 1/week)			

Savings:

Decrease in Zn pick-up on parts leads to improved quality of coating
Expected decrease in Zn usage: 0.5%
R 14,032 /yr
Energy savings for less Zn heating R 1,643 /yr
Decrease in dross amount.
expect to dross less frequently - collect after 8weeks vs after 4 weeks
Decrease in dross amount: 35% R 8,540 /yr

Decrease in ash formation: 2% estimate
R 3,406 /yr
Possible sale of sludge: ?
Total savings: R 27,621

Savings less costs: R 27,134 /yr

Profitability Analysis:

Payback period: 0.7 years
8 months <1year

Environmental Evaluation:

Reduction in fuming, Lower Zn usage,
Savings in energy, Less dross formation,
Decreased ash formation

C2. Cleaning material/chemical substitution

1. Alternative (emulsifying) degreasing chemical which allows for elimination of surface skimming

Regular skimming of oil from degreaser flows via lip around tank through pipes and into trench system
Oil is messy to clean up and contaminates the wastewater flowing to sewer
Also forms a sludge as it cools, and lies stagnant in the trenches.

Technical Evaluation
Alternative emulsifying chemical has been identified which simply may be added to existing bath over time
until the entire bath is effectively replaced. The concentration can then be decreased to specified 5%.
The chemical is an emulsifying degreaser that also causes the saponifiable grease to be converted into 'soap'
The oil content is therefore kept to a minimum and there is no oil layer on the surface

Economic Evalution
The chemical is about R3/kg less expensive than the existing degreasing chemical.
It will be used at a lower concentration
The costs associated with proper oil disposal have been eliminated

Environmental Evaluation
Elimination of oil waste
Bath operates so that it has exended life, and only requires sludge removal every 2nd year according to supplier
(versus once/year for existing chemical)
The oil content of the sludge will be substantially reduced

C2 -3. Bacteriological degreasing to replace aqueous degreaser

Technical Evaluation:
This involves a major investment in technology that is not available in South Africa
The technology is still new and until it becomes widely used it cannot be evaluated for its feasibility.

The technology was observed in process in Denmark during European study tour.
It appears to work well and eliminates water rinse requirement, acid can operate at lower concentration,
and the bath life is extended indefinitely through continuous oil/grease removal (biological process)
The oil is consumed by the bacteria and does not require disposal
Although the time for degreasing is longer, the pickling time is shortened
From case-studies it appears this option has a payback period of <3yrs.

This option requires more than simple degreasing chemical changes, but is in effect a complete change in technology
This option should be kept in mind in future when the technology becomes available.

F.23 Fume extraction and control equipment for galvanizing kettle

Equipment necessary to capture fumes is expensive and may retard the production flow through a plant. Various methods of fume extraction have been developed. The most important aspect is the need to ensure that these installations do not interfere with the production flow through the plant. The most modern concept is to provide a total enclosure over the galvanizing bath which encapsulates all fumes generated during immersion and withdrawal. These units are very effective but also extremely expensive. Lip extraction is another option but this requires a positive flow of air across the bath surface and the absence of any through draft in the plant area. It can be effective in the case of narrow galvanizing baths (Barnett, 1998).

One galvanizing company (the largest in the country, but still an SME) has installed a hood over the galvanizing bath as well as recovery system for the iron in a pre-treatment bath. Though the purpose of these installations was mainly for efficiency and quality improvements, international experience has shown that these have resulted in significant waste minimisation.

A further consideration is the need to consider what to do with the fumes once they have been captured. A common practice in most countries is to exhaust the fumes to the atmosphere through a chimneystack extending about 10m above the factory building. The ultimate solution is to install a scrubber that encapsulates all emissions.

F.24 Biological degreasing

A biological degreasing system has recently been introduced to the market (Northern Europe only as of 1999). This degreasing method is in use in Scandinavia and it can be directly connected to the acid pickle (no rinse between) to provide a long life pre-treatment system at low temperature. The biological degreasing process reduces the cost by 60-80% compared with conventional degreasing. It has energy saving implications in that the bath does not require heating. No rinse is needed after the degreaser. The degreasing process can withstand a high oil and impurity load. As it is closed, the process has a maximum length of life through continuous biological decomposition of oil and impurities. The system enables the oil and grease content to be kept as low as 20-200 mg/L. This means that the bath is continuously kept active and lasts a very long time. The chemicals do not contain any substances dangerous to health.

The one disadvantage could be the time it takes to effectively degrease. Though when used in conjunction with activated pickling (takes a shorter time than ordinary pickling), the combined time is no longer.

Activated pickling baths consists of a great volume of iron salt (up to 30%) and mill scale dissolution starts immediately without dissolving the pure iron. The process works with low acid emissions and rapid oxide-scale dissolution. Using biological degreasing prior to activated pickling will ensure that no oil is carried along to the pickling bath. Chemicals transferred from the degreasing bath function as inhibitors in the pickling bath so that acid emissions are blocked. This activated pickling results in less etching of the parts and depth of pickling can be reduced from 10-15 microns to just 5 microns. As a result the acid consumption in most cases will be halved as will the quantity of spent pickle to be dumped. Spent pickling baths have a low acid and high iron-chloride content, and can be used as a reagent in municipal sewage treatment plants.

To avoid too large amount of ferric chloride salt to be taken to the flux bath after the activated pickling, the goods are then dipped into a light-pickling bath before taken to the flux bath. The light-pickling bath has a low content of ferric chloride and acid. This bath is also used as a refill bath for the other pickling baths.

If biological cleaning is used, the dead bacteria could be collected, settled and sold as a slow release protein additive for fertilizers (Reeve, 1998).

F.25 Flux Purification Equipment

Fe in the flux bath:

The flux bath becomes contaminated by a build-up of iron until it must be replaced by a new solution. Once the concentration of iron exceeds 20g/L, dross formation increases substantially. These problems can be eliminated by continuous purification of the flux bath. A regeneration unit can be installed that keeps the iron concentration of the flux bath at a minimum.

Benefits of Fe separation from a flux bath:

- Less iron carried-over to the Zn bath results in less dross formation and an improvement in product quality, with a decrease in need for afterworking.
- Less dross formation means lower labour costs required to remove it. The size of the savings is strongly dependent on the depth of the zinc bath, the workload, and the sort of products. Since dross removal is not pleasant work, the less dross, the better the working conditions.
- The surface of the product will have a much smoother appearance and requires less afterwork.
- Lower zinc use (iron particles in the flux layer on components become entrained in the zinc coating as it is forming and tend to trap some zinc that would normally drain away on withdrawal)
- Which means less heating is required for melting new zinc.
- The temperature of the flux bath and the drying time can, in principle, be reduced, as there will be less chemically-bound water.
- A lower flux concentration implies less flux chemical which leads to less fuming and less zinc ash.

It is important not to transfer iron from the flux bath to the molten zinc, since 1 part of iron reacts with 25 parts of Zn to form dross, which will increase the zinc usage. The change in components of the flux salt make it possible to obtain a slow reaction between iron and zinc (a low content of ammonium chloride and a high content of neutral salts). This gives a low loss of iron to the molten zinc (CAMEX, 1995).

Of considerable importance is that a filter not only removes iron but also cleans the flux of other impurities (dust and oil, etc.). Dirty flux is a major cause of poor quality (bare spots) and excess splashing during zinc immersion. The rinse water that is carried over to the flux not only contains iron salts but also free acid. This carry over of acid can be exploited by adding zinc ash to the flux and creating zinc chloride which is flux. Alternatively, ammonium hydroxide can be added to produce zinc chloride which is the other flux ingredient. It is for this reason that the purification of flux solution may be favoured over purification of the rinse water (Barnett, 1999).

The core of a flux regeneration unit is the reactor. A small amount of flux solution is continuously pumped to the reactor (at around 900L/hour). Chemicals oxidise the iron in the solution and form iron hydroxide. Filtration and a filterpress reduce the water content to 60%. The filtercake requires removal and disposal. These regeneration-units were first used in the industry in the beginning of 1997. Such installations have an estimated payback period of between 2 and 2,5 years (Reimerink, 1999).

Fe removal from pickling rinse

There is another type of Fe removal installation which has been developed for the hot dip galvanizing industry by the Dutch Bammensgroep. The difference between this Fe removal installation and others is that it is installed on the rinse bath prior to the flux bath instead of the flux bath itself. This is simply because it is easier to get Fe out of a bath with nothing in it than out of the flux bath with many other components.

This process known as the ReFe process was developed as an economical way of reducing zinc consumption in the hot dip galvanizing industry. It is based on preventing iron from being picked up and carried over to the flux bath. Consequently there is a dramatic reduction in the production of dross and zinc ash, resulting in enormous savings. Iron is separated from rinse bath solutions in a continuous process. The ion-exchange material is regenerated with an HCl solution, which can later be used to adjust the composition of pickling baths.

The unit consists of three different sections: neutralisation, ion exchange and regeneration. First, solid particles are filtered out from the feed solution with a standard plate-filter. Then the rinse solution is pumped into a neutralisation unit, where the pH value of the fluid is adjusted to the required level. This is done by adding concentrated NaOH. The neutralisation unit is stirred continuously to ensure that a homogeneous solution is formed. Afterwards the solution is pumped through the ion-exchange column where the Fe is absorbed by a resin developed specially for the purpose. The liquid is then returned to the rinse bath. When the resin becomes Fe saturated it is regenerated. The stripping/regeneration solution is pumped through the column and into a storage vessel. In the column, an exchange of Fe and acid takes place. The Fe dissolves in the HCl, while the acid is absorbed by the resin. Rinsing is not necessary. Even when all the Fe is separated from a rinse bath, proper flushing is still of vital importance. If not done properly, Fe will still be picked up and will contaminate the flux.

It is possible to dispense of the acid rinse water altogether and merely to use an efficient purification process. Apparently this is done in Japan where water is in short supply. New process technology in flux purification allows the acid rinsing stage to be eliminated and the zinc ammonium chloride preflux to be regenerated. This type of technology is being adopted worldwide.

F.26 Fe Content in the Flux Bath

The analysis of the iron (Fe) content in the flux bath indicates a very low content of less than 1g/L of Fe. This analysis is from samples taken from the surface of the bath after bath agitation and analysed using AA analysis for total Fe content. In addition samples are taken by the operations manager on a regular basis (after bath agitation) and a titration is performed to test for Fe content. The supplier has provided the conversion formula for mL titrated to Fe content in g/L. The results of these two sets of analysis are similar at around 0.68 g/L and 0.62 g/L for AA analysis and titration analysis respectively (there is room for error in both methods). Closer analysis of the bath has indicated that there is a large amount of precipitated iron chloride salts that settle to the bottom of the bath.

F.27 Summary Table of Rated Options

Table F24: Summary table of rated waste minimisation options for Company 2

Waste Minimisation Option	Technical Evaluation	Economic Evaluation	Environmental Effect	Other	TOTAL
I. SOURCE REDUCTION					
A. General Waste Reduction Practices					
A1. Good Housekeeping practices					
1. Maintain improved chemical tracking & record keeping	3	4	3		10
2. Employee awareness and education	4	4	3		11
B. Improved Operations/Process Modifications					0
B1. Drag out reduction					0
B1.1 Minimising drag-out					0
1. Vibration mechanism on crane to speed up run-off (less drag-out in shorter dwelling time)	3	2	4		9
B1.2 Direct drag-out return					0
1. Jolt jig above bath after withdrawal for quicker and greater run-off of drag-out	5	5	4		14
2. Install rack over process bath to hang jig while crane moves elsewhere (must not interfere with double dipping)	2	3	3		8
3. Tilted drip tray to capture drag-out from flux bath to return to bath.	4	3	3		10
4. Tilted drip tray to capture drag-out from passivation baths to return to bath.	2	1	2		5
B1.3 Drag-out recovery and return					0
1. Place spare tank after acid bath to capture drips to floor and recover acid for stripping bath	4	2	3		9
2. Use degreaser rinse water instead of freshwater for evaporation replacement for degreaser bath (save water and chemicals)	4	1	0		5
B2. Rinse water use reduction					0
B2.1 Avoid the need to rinse					0
Considered with bacteriological degreasing and flux purification.					0
B2.3 Optimise Rinse tank design					0
1. Locate water inlet & discharge points at opposite positions in the tank to avoid short-circuiting.	5	3	2		10

Waste Minimisation Option	Technical Evaluation	Economic Evaluation	Environmental Effect	Other	TOTAL
2. Use flow distributor to feed the rinse water evenly.	4	2	2		8
3. The incoming water may enter along the length of the rinse bath instead of on one end to increase the rinsing efficiency	3	3	2		8
B2.4 Controlling flow rate of rinse water use					0
1. Adjust incoming tap to limit the volume of rinse water flowing through by maintaining a constant flow at the optimal flowrate.	2	3	3		8
2. Manual control of water flow to reduce when production is low (dependent on operator adjusting flow with taps/valves).	4	3	3		10
3. Install automatic rinsewater flow control device	3	2	3		8
4. Install flowmeters to monitor rinse flowrate and water use (raise awareness)	3	2	2		7
B2.5 Alternative rinsing configurations					0
1. Re-install double counterflow rinse for acid rinse (can reduce rinsewater use here by up to 50%)	3	2	3		8
2. Use the same rinse water for both the acid and degreaser rinsing with neutralisation reaction.	Soap formation interferes negatively with fluxing				0
3. Use a combination of spray rinsing and dip rinsing	spray rinsing only effective for flat parts or variable settings				0
B5. Reduce/ eliminate the need for cleanup or improve cleanup methods					0
1. Use less water for floorwash by installing a trigger mechanism on the hose used	3	2	2		7
2. Close up trench system Use dry-sweeping instead of wet washing for floor cleaning if chemical drips are eliminated/prevented	4	4	4		12
3. Install anti-splash cover/hood over zinc bath	2	3	2		7
4. Place a cover over trenches where spatter may fall to prevent Zn from flowing to wastewater	2	2	2		6

Waste Minimisation Option	Technical Evaluation	Economic Evaluation	Environmental Effect	Other	TOTAL
B6. Improved Process Efficiency					0
1. Eliminate unnecessary NH4Cl dusting to reduce amount of fuming above galvanising bath.	5	5	3		13
2. Ensure optimum drying of flux (heated drying) to avoid unnecessary fuming from wet flux volatilisation and to minimise spatter.	3	4	5		12
3. Improve Ash collection method to minimise Zn metal entrainment	4	5	3		12
B7. Extending Bath Life					
B8. Corrective Bath Maintenance					
B8.1 Common corrective maintenance methods					
1. Fe removal from flux using filtration	3	3	2	supplier r	8
2. Fe removal from flux using settling	4	3	2	1	10
B8.2 Advanced corrective maintenance methods					
1. Microfiltration applied to the degreasing bath for the removal of emulsified oil and grease. Also applicable to the recovery of degreasing solution drag-out from rinse water.	2	1	3		6
2. Fe recovery from flux bath using commercially available electrolytic flux recovery system.	2	3	2	can eliminate acid rinse	7
C. Substitute Techniques/ Technologies					
C2. Cleaning material/chemical substitution					
1. Alternative (emulsifying) degreasing chemical which allows for elimination of surface skimming	5	5	4	implemented	14
2. Use acidic degreasing which may allow for elimination of rinse before pickling.	2	2	3		7
3. Bacteriological degreasing to replace aqueous degreaser	0	0	4	not available	4
C3. Process material/chemical substitution					
1. Chrome-free alternatives to Passivation Chemical - may use phosphate-based chemical, or possibility of using silanes in the near future when commercially available.	2	2	2		6
2. Use light pickle instead of freshwater for acid rinse only if use flux purification	2	2	1		5

Waste Minimisation Option	Technical Evaluation	Economic Evaluation	Environmental Effect	Other	TOTAL
3. Activated pickling (low Acid, high Fe salts pickle) only in conjunction with flux purification	2	2	2		6
II. RECYCLING AND RESOURCE RECOVERY					
D. On-site Recovery and Recycling					
D1. Waste segregation					
1. Segregate sludges from spent acid	2	1	2		5
D3. Wastewater recycling and chemical/metal recovery					
1. Collect and treat wastewater prior to discharge to sewer	2	2	2		6
2. Collect, treat and reuse treated wastewater	2	1	3		6
3. Recover Zn on used wire through melting	2	1	1		4
E. Off-site Recycling and reuse					
E1. Off-site Recycling					
1. Recovery of Zn from spent wire.					0