

# Valorization of Ferrochrome Slag: Towards increasing the beneficial utilisation of Ferrochrome Slag in South Africa

by

Franz Robert Maria Sprinzl



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# Declaration

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# Abstract

## Valorization of Ferrochrome Slag: Towards increasing the beneficial utilisation of Ferrochrome Slag in South Africa

F.R.M. Sprinzl

*Department of Industrial Engineering,*

*University of Stellenbosch,*

*Private Bag X1, Matieland 7602, South Africa.*

Thesis: MEng (Engineering Management)

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Ferrochrome slag is a leftover of the production process of ferrochrome, a crucial alloying element for the production of stainless steel. The material properties of these slags show excellent properties for reuse in the construction industry. South Africa, the leading producer of ferrochrome does not take advantage of those potential downstream applications, resulting in a concerning and challenging disposal practice, contrary to other international ferrochrome industries that capture value through reuse. The concept of industrial symbiosis can unlock potential material utilization in the South African industry. Despite the opportunities the industry is only making slow progress in implementing successful reuse applications. The legal authorities and industry seem to be misaligned, resulting in sub-optimal waste management practices. Therefore a solution is needed which addresses the problems and opportunities and provides a more efficient method for the reuse of ferrochrome slag. To-

wards arriving at such a solution, this study identifies the primary barriers and opportunities for the reuse of slag through industry surveys and supported by experiences from other industries, such as the ferrochrome industry in Finland and the European steel industry. The outcome from this was the development of a roadmap, which proposes how the utilization of ferrochrome slag might be increased. Innovation platforms are mooted as a suitable approach through which to apply the proposed roadmap in practice. The stakeholders' feedback showed the suitability of the developed roadmap to increase utilization of ferrochrome slag, resulting in economic, environmental and social benefits. The challenge which remains is to motivate the stakeholders to communicate and implement the proposed strategy.

# Uittreksel

## Ferrochroom Slak Waardetoevoeging: 'n Bydrae Tot die Toenemende Voordelige Gebruik van Ferrochroom Slak in Suid-Afrika

F.R.M. Sprinzi

*Departement Bedryfsingenieurswese,  
Universiteit van Stellenbosch,  
Privaatsak X1, Matieland 7602, Suid Afrika.*

Tesis: MEng (Ingenieursbestuur)

September 2016

Ferrochroom slak is 'n oorskiet van die produksie proses van ferrochroom, 'n belangrike legeringselement vir die vervaardiging van vlekvrystaal. Die materialistiese eienskappe van hierdie slakke toon uitstekende eienskappe vir hergebruik in die konstruksiebedryf. Suid-Afrika, die grootste produsent van ferrochroom, maak nie optimale gebruik van die potensiële stroomaf toepassings nie, wat lei tot 'n kommerwekkende en uitdagende beskikbaarheidspraktyk, in teenstelling met ander internasionale ferrochroom nywerhede wat waarde verkry deur hergebruik. Die konsep van industriële simbiose kan potensiële materiaalbenutting in die Suid-Afrikaanse bedryf ontsluit. Ten spyte van die geleenthede, maak die industrie stadige vordering in terme van die implementering van suksesvolle hergebruik toepassings. Die wetlike owerhede en die

industrie blyk nie belyn te wees nie, wat lei tot sub-optimale afvalbestuurspraktyke. 'n Oplossing is dus nodig om die probleme en geleenthede aan te spreek asook 'n meer doeltreffende metode vir die hergebruik van ferrochroom slak te bekom. Om so 'n oplossing te verkry, identifiseer hierdie studie die primêre struikelblokke en geleenthede vir die hergebruik van slak deur gebruik te maak van industrie opnames, en word ondersteun deur ervarings van ander bedrywe, soos die ferrochroom-industrie in Finland en die Europese staalbedryf. Die uitkoms van hierdie studie, was die ontwikkeling van 'n padkaart wat 'n voorstelling bied vir hoe ferrochroom slak gebruik verhoog kan word. Innovasie platforms is voorgestel as 'n geskikte benadering waardeur die voorgestelde padkaart in praktyk toegepas kan word. Die belanghebbendes se terugvoer het 'n geskiktheid getoon ten opsigte van die ontwikkelde padkaart om die benutting van ferrochroom slak te verhoog, wat sal lei tot ekonomiese, omgewings en maatskaplik voordele. Die uitdaging bly egter om die belanghebbendes te motiveer om te kommunikeer en die voorgestelde strategie uit te voer.

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# Dedications

*I would like to dedicate this thesis to my family for their unconditional love  
and support.*



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# Nomenclature

$\text{Al}_2\text{O}_3$  ..... Aluminium oxide

$\text{CaO}$  ..... Calcium oxide

$\text{MgO}$  ..... Magnesium oxide

AC ..... Alternating current

ChCr ..... Charged chrome

Cr(II) ..... Chromium(II) chlorid

Cr(III) ..... Chromium(III) oxide

Cr(VI) ..... Hexavalent chromium

DC ..... Direct current

DEA ..... Department of Environmental Affairs, South Africa

ISO ..... International Organization for Standardization

LCFeCr ..... Low carbon ferrochrome

MINTEK .... Council for Mineral Technology, South Africa

PAIA ..... Public Access to Information Act

SAWIC ..... The South African Waste Information Centre

US EPA ..... United States Environmental Protection Agency

# Chapter 1

## Introduction

### 1.1 Motivation

The mining and mineral processing industry plays an important role in the South African economy. In 2013, the mining industry contributed 8.3% to South Africa's gross domestic product, reaching sales of R384.9 billion and presenting a total primary mineral sales export of R279.5 billion in the same year (Chamber of Mines South Africa, 2014).

This study sought to evaluate the ferrochrome industry in South Africa with particular focus on reuse opportunities for ferrochrome slag. Ferrochrome is an alloy of iron and chrome and is the most important alloy for the production of stainless steel.

The only natural form of chrome that can be used economically is chromite. The world's largest deposits of chromite can be found in the Bushveld Complex in South Africa. In 2013, the South African mining industry produced 13.6 megatons of chromite while in the same year, the domestic sales value presented a figure of R5.9 billion.



After chromite is mined, the mineral needs to be processed to create a more concentrated ferroalloy. This takes place either in alternating current (AC) arc furnaces or direct current (DC) arc furnaces and includes the smelting of the chromite. The International Organization for Standardization (ISO) classified ferrochrome according to its carbon content, classifying the alloy as either low-, medium- or high-carbon ferrochrome. Additionally, it is also classified in relation to its percentage of chrome content. The five groups of classification are 50%, 60%, 70%, 80%.

This slag can have various compositions, depending on the original ore utilised and the processing technology employed to extract the mineral. Separated from the production of the primary mineral, slag can be utilised in various ways. In some instances, it can be reused in civil engineering and road construction. It can also be used for producing refractory materials (Niemelä and Kauppi, 2007).

In Finland, ferrochrome slag is predominately used as a filler material to replace natural soil materials such as moraines, sand and gravel. However, in many countries, including South Africa, slag is primarily discarded in slag dumps. These can pose environmental hazards if handled incorrectly as toxic elements, especially Cr(VI), may leach into the ground. Furthermore, slag dumps can degrade useful land and the aesthetics of an area where there may be high levels of groundwater (Hattingh and Friend, 2003).

Environmental legislation plays a crucial role in ensuring the management of slag in the most effective manner. While it is technically possible to reuse mineral waste, the national legislation and economic policy in South Africa make reuse difficult in certain cases. As a large amount of mineral waste is produced in South Africa, there is great potential to significantly improve the environmental situation in specific cases (Godfrey *et al.*, 2007). In the last few

years, South Africa has made significant progress in addressing waste streams and supporting reuse. For example, the National Waste Management Strategy promotes waste minimisation, reuse, recycling and recovery of waste (Department of Environmental Affairs, 2011). This research evaluated opportunities to add more value to the slag produced by the ferrochrome industry.

## 1.2 The challenge

The identification of barriers and opportunities for reuse of ferrochrome slag is a complex system. Proposed reuse scenarios involve a number of stakeholders. In the first place the situation of the producer needs to be addressed. The producer is mainly responsible for the waste streams and is the only stakeholder who has influence on the production of ferrochrome slag. The second stakeholder, the proposed buyer, is responsible for the proposed material specification. The government as third stakeholder aims to regulate waste streams to protect the environment and human beings from potential negative impacts. All of the mentioned stakeholder have therefore different drivers for reuse. For the producer it might be the minimization of waste streams due to high costs for landfill. The proposed buyer is looking for an economical alternative for raw materials. The government driver is to protect the eco-system. The different standpoints of the stakeholders lead to a situation where it is very difficult to find a consensus. The challenge was therefore to understand the producer point of view, which required understanding of the production process, technology used and the effect on slags, while considering waste management and legal aspects and how sustainable development can increase motivation for utilization of ferrochrome slag.

In addition, the information available in the public domain regarding utilization of ferrochrome slag in South Africa is very limited. The large industry which consists out of plenty ferrochrome operations makes it very difficult to

address a solution which can be applied in general. The ferrochrome industry is convinced that ferrochrome slag is a suitable material for reuse, blaming the environmental authorities to be overprotective and therefore a barrier for reuse. The environmental authorities on the other side do not see themselves as barrier, stating they want to support reuse. The key point to overcome barriers is to find a solution which involves all stakeholders and enables an effective way for communication.

### 1.3 Significance of research

The South African economy is growing, resulting in an increasing demand of construction materials. Ferrochrome slag shows excellent properties to replace those materials, resulting in a more sustainable economy. Furthermore the increasing production of ferrochrome slag will be a future challenge for the ferrochrome industry and government. The industry faces a massive problem to handle those waste streams. Sustainability will define the environment of future generations. The ferrochrome industry need to adapt the vision of sustainable development to keep the status as the leading ferrochrome producer in the world. The utilization of ferrochrome slag can increase the competitiveness of the industry and lead to new job opportunities. The whole eco-system will earn the benefits of ferrochrome slag reuse, by saving natural raw materials and reducing waste streams.

### 1.4 Research design and methods

At the beginning of every research project, the question of an appropriate research methodology needs to be answered. Methodology can be described as the theory of the organisation of an activity (Novikov and Novikov, 2013). In this case, the activity was the identification of a research gap followed by

the formulation of a research question with the goal to solve a specific problem with suitable research techniques. The reasons for this research activity and the organisation thereof are described in the following chapter (Novikov and Novikov, 2013).

The first step in the organisation of this research was of a conceptual nature. The goal was to identify contradictions in practice or a scientific knowledge system. This led to the formulation of an appropriate problem statement. The formulated problem could then be used to formulate the goal of research.

The general research approach and the identification of research fields will also be discussed. The research design and the research techniques used are described and justified at the end of the chapter.

#### **1.4.1 Problem statement and research question**

Solid residues from the mineral processing industry are viewed worldwide as suitable materials for different reuse purposes. In Western countries, especially in Finland, the reuse of ferrochrome slag has reached high levels. This is the result of intensive research and waste management policy to minimise waste streams and to conserve natural resources.

In South Africa, the largest ferrochrome producer in the world, ferrochrome slag is mainly sent to landfills. Some authors state the reason for this as an obscure and misleading waste management system. Other authors share the opinion that the reuse of ferrochrome slag has too much negative impact on the environment because of possible leakage of toxic elements such as Cr(VI) into the environment. The research that is available in the public domain, focusing on South Africa, is very limited.

The resulting problem statement therefore primarily concerned the barriers to and opportunities for an increased beneficial utilisation of ferrochrome slag. Due to the large volumes of ferrochrome slag, it is impossible to aim for a zero-waste industry, as is the case with some other countries. However, it is specifically because of these large volumes that it is important to find more efficient ways of handling ferrochrome slag. This therefore led to the primary research question:

What prevents the South African ferrochrome industry of increasing the beneficial utilization of ferrochrome slag?

The research objectives included the evaluation of current waste management practices in South Africa and the resulting problems that are faced by the industry in comparison to international practices/industries. The research aimed to give an overview of the current state of research regarding the recovery of metals from slag, recycling and reuse, and the role of the mineral processing industry regarding sustainable development. Furthermore, public interaction that had an influence on the decision-making process was investigated. The following subobjectives helped to achieve the desired outcome of the study: the identification of barriers to and opportunities for the reuse of ferrochrome slag in South Africa:

- Evaluate the South African waste management system and legislation regarding reuse of 'waste' material
- Compare the Finnish ferrochrome industry to the South African industry
- Evaluate technological challenges and innovations
- Evaluate opportunities for industrial symbioses
- Roadmap development to overcome barriers

## 1.4.2 Paradigm

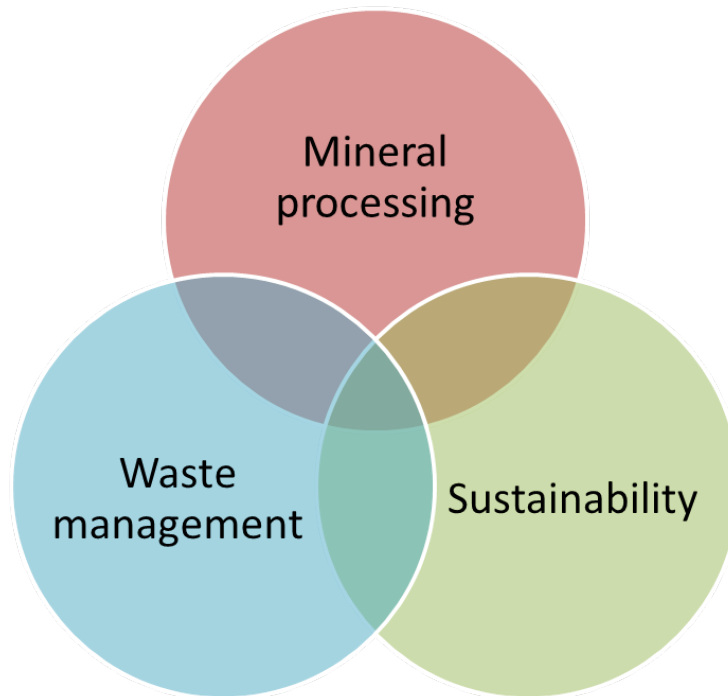
The selection of an appropriate research approach was important for the successful answering of the research question. The problem was that the problem statement could not be addressed by any one specific scientific discipline. The opportunities for successful reuse of ferrochrome slag are dependent on various factors. Therefore, a multidisciplinary approach was chosen to consider social, economic, environmental, technological and legal aspects.

The main research fields were mineral processing, waste management and sustainability as indicated in Figure 1.1. The mineral processing research area is of grave importance due to the many technological aspects that determine whether slag is suitable for reuse or not. The waste management field addresses the issues of how slag, which is in the first place seen as a waste product, can be transformed into a suitable by-product. The sustainability study field influences the whole system and can be seen as an important driver for recovery and reuse scenarios. This multidisciplinary approach used both theory and empirical data to evaluate the best possible options.

The problems that were addressed in this research can be divided into convergent and divergent problems. describes convergent problems as problems that can be solved by generally accepted solutions in contrast to divergent problems wherein the solutions can differ widely (Schumacher, 1978).

Natural science problems are mainly convergent, and the solution will lead to one overall expected answer. Divergent problems are commonly found in social science in which due to the variety of individuals and opinions, a single clear answer is rarely accepted (Schumacher, 1978).

If we analyse the potential of the South African ferrochrome industry to improve the value generation from waste products, we need to consider the



**Figure 1.1:** Main research fields

technological, convergent problems and the broader social, divergent problems. The social aspect is mainly represented by the role of the South African government, which should represent society and its social norms and values. This is done by a variety of regulatory and public policy instruments.

The approach in this research on the one hand had a strong focus on theoretical elements, which are responsible for the frame of the industry, and on the other hand on empirical data as evidence from the industry's point of view. The combination of theory and empirical data underpinned the whole study. Theory was used to identify the current surroundings and the borders of possible ferrochrome slag scenarios. Empirical data on the one hand identified problems and opportunities that were not covered by the theory and on the other hand it was used to support the barriers and opportunities discussed by the theory.

For this study, a mixed method research approach was chosen, namely a combination of qualitative and quantitative research. In scientific research, it is often difficult to clearly separate the quantitative and qualitative methods. The quantitative approach uses deductive elements for empirical testing of theory while the qualitative approach uses induction to generate theory from data. Both approaches were used in combination, the quantitative one to identify how theory should or could support reuse scenarios and the qualitative one to highlight how changing theory would affect the opportunities for reuse scenarios in practice. In consideration of epistemology, the existing theory was viewed from a positivistic perspective, contrary to the outcome and the proposed new theory that was created through an interpretative point of view (Bryman *et al.*, 2014).

The reason for this research approach is the complexity of an industrial system. It is possible to invent a technological process or to set up a waste management strategy from a theoretic point of view, but it seems to be very difficult to reach the formulated goals and to apply new knowledge in praxis.

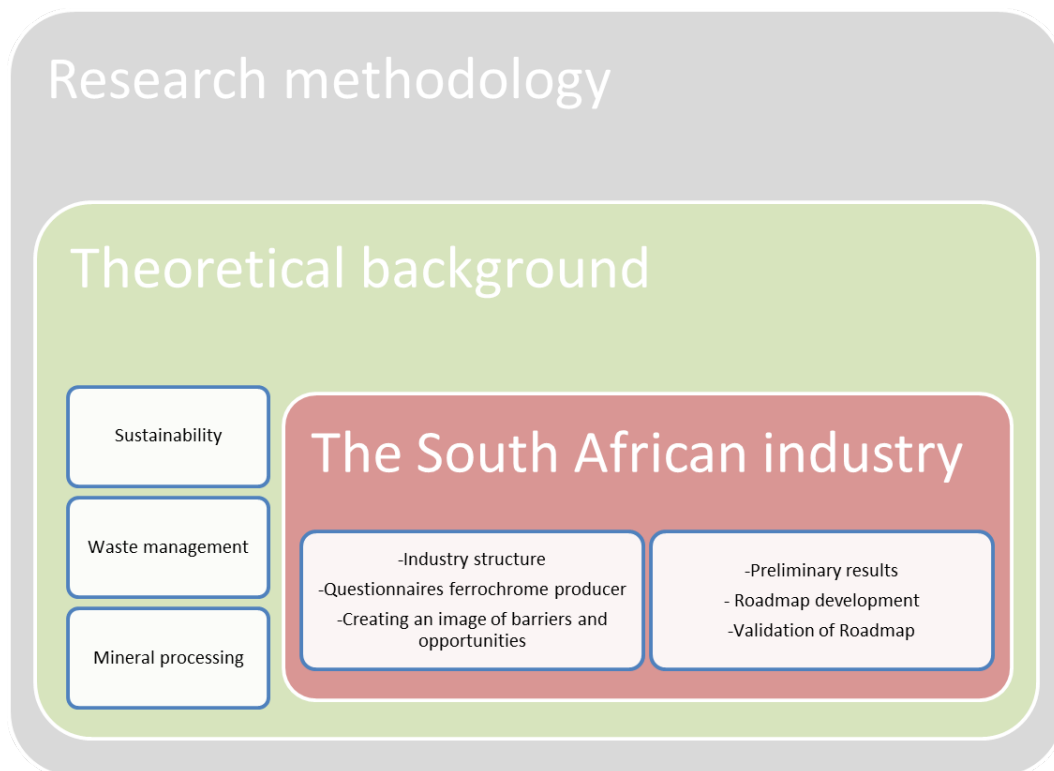
### 1.4.3 Structure of the thesis

The entire study can be seen as a framework to identify barriers and opportunities for reuse of ferrochrome slag. The starting point of this work was a review of national and international literature concerned with the topic of ferrochrome slag reuse (Chapter 2). Chapter 2 also aims to provide all the information needed to answer the research question. This includes detailed information about technical knowledge of the ferrochrome production process, environmental standards and regulations, and waste management practice. It also addresses different tools and models that can be used to support a decision-making process regarding the reuse of ferrochrome slag.



Figure 1.2 shows that the empirical section and the case study of the South African industry are imbedded in the theory and surrounded by the research methodology. That means that the scientific process and the selected research design starts at a broad theoretic level and leads to a specific applied level, the South African ferrochrome industry.

Chapter 3 focuses on the evaluation of the South African ferrochrome production industry by discussing national practices regarding regulations, waste management, production processes and the government's role in supporting the reuse of slag. The descriptive part of the chapter is supported by the empirical data: the experiences of the South African industry.



**Figure 1.2:** Thesis structure

This research project placed a strong emphasis on the international practice of ferrochrome slag handling. Chapter 3 evaluates on the international ferrochrome industries and the European steel industry, especially Finland, and provides a different view of waste management, which was used for new input of investigations and discussion.

The identification of barriers and opportunities during the data collection is then compared to the theoretical findings described in Chapter 2. The internationally applied solutions, which led Finland to become the leading country regarding the successful utilisation of ferrochrome slag, are then evaluated and discussed with a view to South African practice. The aim is to close the gap between theory (Chapter 2) and the South African practice (Chapter 3). Possible improvements and findings regarding a better utilisation of slag are discussed in Chapter 3. These results were used to develop a roadmap to overcome the identified barriers (Chapter 4). In addition, the roadmap was presented to one participant from the industry, the government and research organizations to validate the correctness and to identify limitations of the roadmap from the stakeholders' point of view (Chapter 5). The last chapter provides an overview of the findings and presents solutions that could lead to an increased beneficial utilisation of ferrochrome slag (Chapter 6).

#### **1.4.4 Data collection**

Due to the limited literature about South African ferrochrome reuse, ferrochrome producers were invited to participate in a questionnaire with the goal to identify barriers to and opportunities for ferrochrome slag reuse. The target were members of the industry such as operational plant managers, production manager and environmental manager. The focus was on considering the different production routes and locations of the operations. Therefore, participants from both DC arc furnace operations and AC arc furnace operations

were invited. The inclusion of location as selection criterion for participants was based on the assumption that the geographical location of an operation could be a barrier to or an opportunity for reuse. This was of particular importance with a view to possible industrial symbioses.

Questionnaires were selected as method of data collection to make a comparison of the answers possible. Bryman *et al.* (2014) note that the particular problem with questionnaires sent by post is the low response rate. This disadvantage was considered, and therefore an online survey, using the Stellenbosch University survey service via Checkbox, was selected to increase the feedback response time and to make the survey as convenient as possible. Furthermore, the selection of closed-ended questions and the use of Likert scales aimed to support the analysis and to contribute to the effectiveness of the data collection process (Bryman *et al.*, 2014).

The questionnaire aimed to evaluate whether the challenges faced by the ferrochrome industry could be generalised to the industry or whether the challenges were unique to specific producers.

The validation of the results provided further data for new discussion. Due to the complexity of the study, semistructured interviews were chosen as method for validation. The advantage of these interviews was the possibility of new information that had not been gathered by the questionnaires. Open-ended questions gave the participants the opportunity to answer in more detail and in particular to offer criticism and to identify gaps in the study.

#### 1.4.5 Validity and reliability

The general problem regarding validity and reliability is seen in the difficulties in breaking down theory to praxis. This problem was mentioned above and was an important consideration in this research and can also be seen as the biggest

problem regarding validity. Especially the data collection process, which was based on the experiences of industry experts, was influenced by a subjective way of thinking. This led to the problem that the information from the various experts could differ extensively, not because of crucial differences in operational behaviour but rather because of personal behaviour and subjective opinions about how the South African industry should look like.

Another important aspect was the complexity of this research. The requirement to think 'out of the box' and the general approach that merged different research fields made it difficult to find a generally accepted solution. Depending on the world view of the participants, the outcome could lead to inequalities. These inequalities were evident, especially with regard to long-term decisions such as sustainable development or industry-overarching scenarios such as industrial symbioses.

#### **1.4.6 Data analysis**

The strategy for the successful analysis of the collected data made use of univariate analysis instruments. This means that the starting point of the analysis only considers one variable at the same time. The goal was to identify the variation of answers regarding a specific question within the experiences of participants in the industry.

#### **1.4.7 Research limitations**

The number of participants in the study were limited due to the small number of ferrochrome producers in South Africa. In addition, finding participants who were willing to take part in the study was difficult because of a lack of interest of the industry. This limitation makes it difficult to generalise the results on an industry level. The study therefore only provided a small-scale

presentation and a restricted image of the South African situation regarding the reuse of ferrochrome slag.

The researcher argues that the opportunities for and barriers to reuse are strongly affected by the specific behaviour of ferrochrome producers. This results in opportunities and barriers that were not considered in this study. The wide research approach of this study addressed barriers and opportunities from an eco-perspective by including only a small number of industry experts. The results are therefore only an assumption for the industry. Furthermore, the lack of inclusion of possible industries that could use ferrochrome slag as new resource instead of using natural materials is a further limitation.

In the next chapter background information is reviewed to provide the necessary knowledge to support the argumentation in this work. Sustainable concepts are briefly described, followed by theoretical aspects of the ferrochrome production process. In addition, the waste management practice and legislation is considered. Also failures which can hinder innovation are provided. The focus in the end of the chapter is on ferrochrome slag, its suitability for reuse and potential risks.

## Chapter 2

# Theoretical background

In order to support the argumentation of the research, the wider context of the mineral processing industry in terms of production technology and sustainability needs to be outlined. In addition to this outline, the development of industrial ecology, industrial symbiosis and the role of institutional frameworks, legislation and waste management concepts are addressed and the relevance for the South African industry is shown.

Institutional dimensions are considered to address the different problems that arise in the identification of possible reuse scenarios of ferrochrome slag. This covers different approaches, methods and tools in the field of mineral processes, waste management and sustainability. In general, research that focuses on ferrochrome slag is either of a technological, an environmental or an institutional nature. This research, conducted from a broader perspective, tried to consider all these aspects. Nearly every approach, method and tool that was used in this study is applicable to the mineral processing industry in general. The specific focus on the South African ferrochrome industry is therefore outlined in the next chapter.

## 2.1 Sustainability

The last decades of economic transformation have influenced the awareness of challenges resulting from a growing economy and the impact on the environment. In 1972 Meadows *et al.* (1972) started addressing these problems in their famous work *The Limits to Growth*. Since then, the awareness of the need for sustainability has increased significantly and it is now an important part of modern business practice. This process and awareness of Sustainable development have influenced and transformed the ways in which modern industries operate. However, the level of awareness differs from industry to industry as not all companies take into consideration the importance of sustainable development and modify their business operations accordingly.

The process of integrating environmental, economic and social consideration is commonly described as the 'triangle relationship' and defines a new approach of sustainability. All the efforts to move the natural environment into the focus of economic decisions and to start considering the long-term effects of human development and a more effective relationship between natural and social systems shape sustainability (Ranking, 2011).

Neglect of the possible negative impacts of the ferrochrome industry on the environment is on the decrease as modern society now considers the conflicts between the economy and natural systems. Much more attention is being given to topics such as resource utilisation, environmental impacts and social responsibility. Another vital document, *Our Common Future* by the World Commission on Environment and Development (1987), led to a deeper understanding of the increasing role of sustainability considerations and how sustainability affects modern industry (WCED (World Commission on Environment and Development), 1987).

The mineral processing industry, which is expected to grow due to an increasing demand for commodities to satisfy society's needs, plays a crucial part in the movement towards a more sustainable world Ranking (2011). The production of commodities is energy intensive and mostly connected with negative environmental impacts. The negative environmental impact of the mineral processing industry results mainly from unutilised waste. The challenge thus is to close material cycles to save virgin materials and to reduce the amount of waste. Medvecka and Bangerter (2007) discussed the a five-level hierarchy of sustainability (see table 2.1). Every level of sustainability involves different actions. This model gives a good overview how different institutions are involved in sustainability. Daily work and decisions are related to low levels, long term strategic goals take place on top.

#### **2.1.0.1 Sustainable development**

The term 'sustainable development' represents a wide range of ideas. The Brundtland definition of 'sustainable development' "Sustainable development is development that meets the needs for the present without compromising the ability of future generations to meet their own needs" (IIED, 2002) is only one example of how 'sustainable development' is defined. In the modern world, different views on sustainable development exist. As mentioned earlier, the integration of sustainability into business practice is important for the industry of the 21st century. Therefore, it is crucial to understand the different perceptions of sustainable development. Hopwood *et al.* (2005) summarized different views on sustainable development and identified three main approaches. The first approach is the status quo approach. Supporters of this approach are aware of the problems regarding a more sustainable world but do not see the need for radical change. Supporters of this approach are of the opinion that the current system is able to solve the challenges represented to the environment. The key factor is economic growth. In other words, economic growth



**Table 2.1:** Integrating Sustainability into Business Practice (reproduced from Medvecka and Bangertner (2007))

Level 1	Eco-Sphere The context	The constitution of the overall system: Understanding the world we live in an what makes life possible: social and ecological principles.
Level 2	Sustainability The goal	Principles of Sustainability. Defining the goal: conditions for a state of social sustainability within the eco-shere: principles for a favourable outcome.
Level 3	Sustainable Development The strategies	Principles of Sustainable Development. Strategic guidelines for the process to reach a sustainable outcome: technical strategies and process principles that underpin the transition to sustainability.
Level 4	Actions The tasks	Actions. Specific activities, projects and initiatives that should contribute towards the goal of sustainability: concrete actions not principles.
Level 5	Tools & Metrics The tools	Tools and Metrics. Frameworks for monitoring and reporting progress: are the actions being implemented effectively and are there consequent outcomes.

will result in a more sustainable world and technology is seen to replace nature.

Supporters of the second approach, the reform approach, share the opinion that the current nature of government and policy needs to be changed. Like the supporters of the status quo approach, however, they do not see the need for a crucial change in the system. Technology is seen as an instrument to protect nature instead of replacing it.

Supporters of the transformation approach share the opinion that the way in which humans interact with nature will end in the collapse of the whole system (Hopwood *et al.*, 2005).

## 2.2 Industrial ecology and Industrial symbiosis

The challenge to an industrialised and emerging economy is to maximise the value of mineral resources to optimise the quality of life within the constraints of our natural ecosystem. Industrial ecology and industrial symbiosis are two concepts with the goal to support the vision of a more sustainable world (Ranking, 2011).

### 2.2.1 Industrial ecology

The approach of sustainable ecology is based on the idea of a dynamic system in which human interactions are in harmony with the natural system. This approach is moving from the classical linear model to a closed-loop system. The linear model describes a system in which the input and output are limitless. The closed-loop system describes a system without borders. That means that no resources or waste products can leave the system. This idea is based on the natural ecosystem. According to Graedel and Allenby (2003), industrial ecology has been defined as:

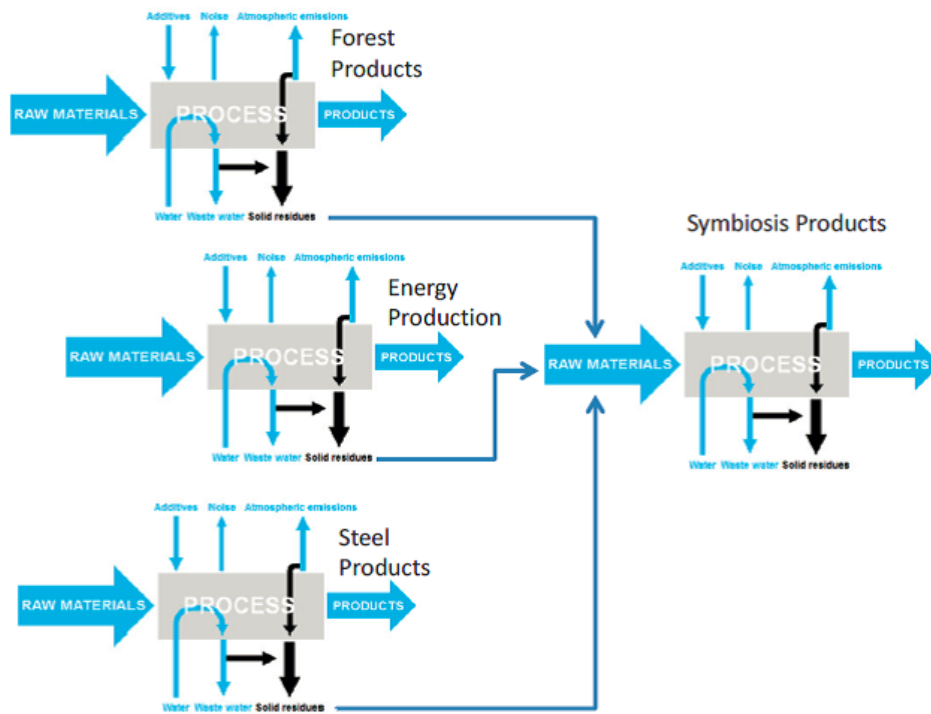
*„The means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution [...]; the concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them [...]; a system view; in which one seeks to optimize the total material cycle from virgin material, to finished material, to product, to waste product, and to ultimate disposal [...]; factors to be optimized include resources, energy and capital [...].“*

This results in considerations whereby the natural ecosystem is seen as the perfect example of a closed system. Industrial ecology addresses the design, operation and decommissioning of an industrial system to be more sustainable.

## **2.2.2 Industrial Symbiosis**

Industrial symbiosis is a concept resulting from the idea of industrial ecology. According to this concept, the waste of one industry is seen as raw material for another industry. The material cycles are viewed not from an industry perspective but rather from the perspective of the whole system. Information about material cycles is shared among different actors in one industrial system. This concept allows us to identify inefficient or unused resources that can be utilised in another industry (Mangan and Olivetti, 2008). Figure 2.1 illustrates the basic concept of an industrial symbiosis whereby waste streams are utilised.

The example of an industrial symbiosis is originated in Finland where the forest and pulp industry interacts with a local steel producer and the producer of energy. The consolidation of the different industries results in a decreased waste stream and a reduced need for natural raw materials. The results are economic and sustainable improvement.



**Figure 2.1:** Basic concept of an industrial symbiosis (reproduced from Watkins (2014))

The term 'industrial symbiosis' is similar to 'by-product synergy'. The exchange of waste streams can be described as a static process. By-product synergy allows for the adaptation of changes in the production process and is therefore described as a dynamic process. Another term that is used to describe a case where a waste product from one producer is used as a raw material for another producer is 'green twinning' (US EPA (U.S. Environmental Protection Agency), 1995). However, the academic literature describes industrial symbiosis as „traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and/or by-products together with collaboration on the shared use of assets, logistics and expertise“ (Chertow, 2000). In the United Kingdom, both the terms industrial symbiosis and by-product synergy are used in the same context. In the United States of America, the EPA makes use of 'beneficial use of indus-

trial by-products', which is similar to the definition of industrial symbiosis or by-product synergy.

Besides the different terminology, all synergies have the same goal, namely to cut costs and to increase environmental benefits through reduction of landfills. In addition, the economic activity of industrial symbiosis can generate jobs (Managan and Olivetti, 2010). The most common example of an industrial symbiosis is the project at Kalundborg, Denmark.

The successful implementation of an industrial symbiosis can be a very difficult and time-consuming process. The main challenges and barriers that need to be overcome are addressed by Managan and Olivetti (2010) and are briefly described below.

Legal challenges: National environmental requirements can be a barrier to the implementation of industrial symbioses. These requirements often affect the handling and transportation of waste streams, which prevents the exchange of materials. In the United States of America, the EPA published a report commonly known as the RCRA Vision 2020, which focuses on the support of sustainability and more efficient use of resources (US EPA (U.S. Environmental Protection Agency), 2007). The steps undertaken by the EPA are addressing the legal challenges, but improvement is still needed.

In addition, the importance of involvement of all relevant stakeholders from the beginning of a proposed industrial symbiosis project. They argue that a proposed industrial network should see regulators as partners rather than obstacles. If that is the case, the network can respond to regulations while the development of innovative processes is in progress without taking the risk of spending time and resources due to unexpected legal requirements. The

approach of industrial symbiosis is of a cooperative nature rather than of a confrontational nature (Harmsen and Powell, 2010)).

**Technical challenges:** The technical feasibility of exchanged material streams could lead to another barrier. The development of innovative technologies can be a factor in the success of an industrial symbiosis. The opportunity that is addressed by Managan and Olivetti (2010) lies in networks where people with different backgrounds can share their knowledge and provide training to other participants. Experience showed that companies that worked within networks to implement strategies and to create databases for the exchange of knowledge were more likely to be successful.

**Economic challenges:** Due to the objective of businesses to be profitable, the most common behaviour is to act in the interest of the own company. Therefore, it is important to document the potential benefits of a proposed industrial symbiosis. Only if the industrial symbiosis highlights an economical advantage will companies be likely to invest in such a symbiosis. This can be achieved through the use of life-cycle cost analysis tools, including the environmental and societal aspects addressed by reliable metrics. The consideration of environmental cost can increase the motivation of implementing industrial cooperation (Managan and Olivetti, 2010).

**Informational challenges:** Industrial symbioses are dependent on communication among all stakeholders. Only when companies are willing to provide the necessary information, such as waste and by-product characteristics, resource requirements, conversion technologies, economic information and other relevant information, can the synergy be feasible. Communication and trust are crucial especially in the case of potential liabilities (Managan and Olivetti, 2010).

Time challenges and competing priorities: Depending on the competition, companies are more or less engaged in keeping up with challenges in their own industry. The investigation of potential industrial symbiosis takes time, and the success thereof, which in the beginning is not guaranteed, can prevent the identification of value-adding synergies. In addition, companies might be content with the current situation and might therefore not be willing to investigate new opportunities and modify business practices beyond their boundaries (Managan and Olivetti, 2010).

Geographic challenges: Depending on the availability of the materials exchanged and the cost of transport, industrial symbiosis can be limited to a geographic region. The potential benefits are vital for the geographic range of proposed partners.

Perception challenges: The term 'waste' is generally associated with something unwanted or not usable. Producers of waste may be reluctant to participate in an industrial symbiosis because of the ensuing attention to their waste streams. However, as mentioned earlier, the participation of all stakeholders is crucial for success. Collaboration, motivation, innovation and participation are described as the keys to industrial symbioses. The sharing of information on a safe forum without concealing or enhancing is crucial (Managan and Olivetti, 2010).

## **2.3 Beneficial utilization of residues in the mineral industry**

The use of solid residues from the mineral processing industry dates back to the romans, which used crude iron slags for road building over 2000 years ago. The commercial use of slags increased dramatically in the last century

(Lewis, 1982). Today's industry produces more than 400 million tons of iron and steel slag per year and uses approximately 80% of steelmaking slag and nearly 100% for iron-making slag as by-products in industrial applications (Worldsteel Associations, 2016). The global ferrochrome production reached estimated 8.9 million tons in 2011, with a slag production of 1.1-1.6t per ton of ferrochrome (Kumar *et al.*, 2014).

The concept of industrial symbioses sounds simple but can be difficult to apply in practice. The waste produced by the mineral processing industry is not always seen as a by-product, especially when the waste contains hazardous components. In this case, the waste material needs to be investigated regarding the suitability for reuse and the environmental risk. Depending on the type of waste and the proposed reuse scenario, different regulations and standards are used to measure the suitability for reuse. Different tests are commonly used for the evaluation of the potential reuse material. In general, the tests are divided into physical, mineralogical and chemical tests.

The suitability for reuse is therefore dependent on environmental, legal and technological preconditions. The technological preconditions evaluate the specific material characteristics compared to natural materials. The environmental preconditions investigate any negative impact on the environment or humans. The legal preconditions are the norms and requirements that are formulated to achieve the best possible outcome with a view to material quality and environmental protection. The suitability of solid residues from the mineral processing industry for different reuse purposes is discussed in more detail in the following section.



### 2.3.1 The ferrochrome production process

Chromium ferroalloys are used in a wide range of specifications. The ISO distinguishes between high-, medium- and low-carbon ferrochrome. This research focused on the production of high-carbon ferrochrome/charged chrome, due to the characteristics of South African chromite, this type of ferrochrome is the most common. High-carbon ferrochrome typically has a chrome content of between 60% and 70% and a carbon content of between 4% and 5%. For the production of high-carbon ferrochrome, a chromite ore with a high Cr/Fe ratio of  $> 2$  is used. South African chromite has a Cr/Fe ratio of 1.5-1.6, which makes it unsuitable for the traditional production route (Gasik, 2013, p.289).

However, since the development of the argon oxygen decarburisation process, it has become possible to produce lower grade chromite ores to charged chrome in an economically efficient way. Charged chrome (ChCr) typically consists of 50-55% chrome and a carbon content of between 6% and 8%. ChCr is an intermediate product in the production chain of stainless steel. Charged chrome does not have one particular specification. The type of specification depends on the ores used, the different smelting processes and the reductants used. The specification differs from producer to producer. The subsequent paragraph will elaborate on the different production routes (Gasik, 2013, p.318).

High-carbon ferrochrome is mostly produced in submerged AC arc furnaces. Beside this, various production routes are also available. Most of the production routes are covered by one of the following four (Gasik, 2013, p.328):

1. **Open/semi-closed submerged AC arc furnaces**
2. **Closed submerged AC arc furnaces**
3. **Pre-reduction followed by closed submerged AC arc furnaces**
4. **Open DC arc furnaces**

The utilisation of a specific production route is dependent on various factors, including access to particular technology, availability of raw materials, cost of electricity, environmental and occupational health and legislation. Some of the technology that is applied for ferrochrome production is not available to the public due to intellectual property and patents. For this reason, some production routes are more commonly used than others. The four main production routes are described briefly below.

### 2.3.1.1 Alternating current arc furnaces

**Open/Semiclosed submerged AC arc furnaces:** As mentioned above, this production route is the most commonly used. The furnace size is usually  $< 30$  MVA. The main characteristics are a simple raw material feed system, lack of gas cleaning equipment and manual labour practice. The significance of this route lies in its diversity, that is, the ability to use a wide spectrum of raw materials.

Another benefit of this route is that the high content of ore fines can be processed easily. Due to the ability to use lower quality ores, the open arc furnaces require frequent rabbling of the furnace bed to improve bed porosity and to break crust and bank formations.

Open arc furnaces generally operate on a low thermal and metallurgical efficiency. The low thermal efficiency is caused by suboptimal heat transfer in the furnace. The reason for this lies in the design of the furnace that results in heat losses at the bottom of the furnace and the sidewalls. The weakness of the heat transfer also addresses the metallurgical efficiency. Furthermore, not all ore fines are reduced and are tapped with the slag. This results in a slag that still contains unreduced material. The advantages of this process are the simplicity of the operation, easy access to the furnace bed and electrodes,

visibility of the furnace bed and low capital investment cost (Gasik, 2013, 331-332).

**Closed submerged AC arc furnace:** Closed submerged arc furnaces are generally larger than 30 MVA. Through to the closed design, the gas scrubbing equipment is built to process lower gas volumes compared to an open arc furnace. The closed system makes it possible to use the process gas, mainly carbon monoxide, for the preheating process. The result is a process with high thermodynamic and energy efficiency. Compared to the open submerged AC arc operation, the raw material feed is very important. Due to the size of the closed operation, it is crucial to use agglomerated or screened lumpy ores. The feed system and the coke used are very important for the success of the operation. Besides the strict requirements for the raw materials, the economic scale benefits and the high metallurgical and electrical efficiencies make this production route attractive for ferrochrome producers.

The best example of a closed submerged AC arc furnace is the Outokumpu operation in Tornio, Finland (Riekkola-Vanhanen, 1999). The process is described here to gain a better understanding of the different processing steps. The first step is the pelletising and sintering process. All raw materials are mixed together and milled to obtain a homogenous feed material. The milling process provides the perfect grain size of the material for pelletising and sintering. To improve the pelletising, bentonite is added as a binding agent. The actual pelletising step takes place in a pelletising drum. The pellets are then sintered at a temperature of between 1 400°C- 1 500°C, depending on the ore quality. After cooling and screening, the sintered pellets are transported to the smelting furnace. The smelting process can take place only with pellets, but a mix of pellets and lumpy ores is possible as well. Because pellets are normally produced from fine concentrates, the chromium content in the feed is very high. That results in a low slag-to-metal ratio. During the sintering

process, the chromite ore is preoxidated, which increases the smelting process. Overall, the smelting of pellets results in improved recovery rates and specific energy consumption. Before the smelting process, the feed material is controlled in a batching system. Final changes regarding the raw materials take place here. The following steps take place in a closed system. The preheating process increases the temperature to the highest possible level without igniting or oxidising the coke. The preheating process is limited by the Boudouard reaction:  $\text{CO}_2 + \text{C} \longrightarrow 2 \text{CO}$ . The temperature in the preheating kiln is normally between 450°C and 500°C, depending on the coke quality. The purpose of preheating is to improve the operation, production and safety of the smelting process (Gasik, 2013, 335-342).

### 2.3.1.2 Direct current DC arc furnaces

The technology of open DC arc furnaces for the production of high-carbon ferrochrome is closely linked to South Africa. The Council for Mineral Technology (MINTEK) in Randburg provided, through intense research, the way to the commercialisation of the DC arc technology. The first test work using the new technology dates back to 1979-1980 and was conducted by MINTEK and Middelburg Steel Alloys (now part of Samancor Chrome). The test work was successful from a metallurgical point of view, but the aim of enlarging the operation was at this time not possible due to technological limits with the electrodes. Only after the development of high-power thyristor rectifiers and the identification of a graphite cathode by ASEA in Sweden did the process become viable for larger scales. The result was the transformation of an existing AC arc furnace to a 12 MW DC arc furnace at Middleburg Steel Alloys using the ASEA design in 1984. One year earlier, MINTEK had built a 1.2 MW DC arc furnace (Jones, 2015; Hockaday and Bisaka, 2010).

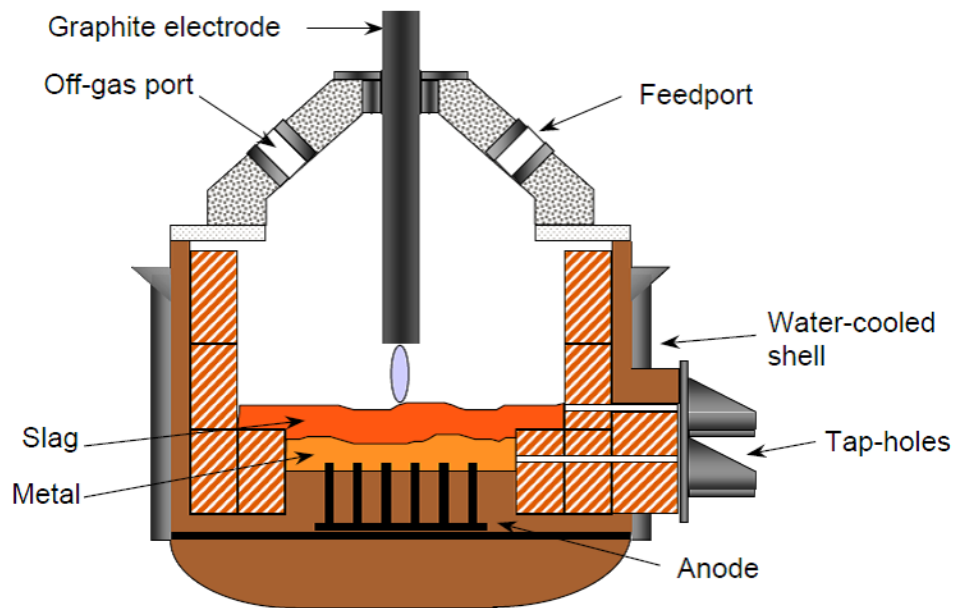
The DC arc technology operates on an open-bath system, which results in the need for a power/feed control system. The main advantages of the DC arc technologies include:

- - Utilization of fine, nonagglomerated (lower-grade) ore
- - Utilization of fine, lower-value reductants
- - High metallurgical efficiencies (recovery)
- - Simplified furnaces control

A prime example of the technology of DC arc furnaces is the current process route that is in operation at Middleburg Ferrochrome. The use of DC arc technology allows the utilisation of high-grade fine ores and chemically low-grade fine ores, which makes the technology very suitable for the processing of tailings from the Upper Grade 2 of platinum operations. Compared to AC arc furnaces, the electrical conductivity of materials being processed is not limited. The thermal efficiency of DC arc furnaces is lower than that of AC furnaces due to the loss of energy through the walls and roof and the loss of off-gas.

The advantage of an open-bath system is the increased metallurgical process control compared to coke-fed systems. The operation at Middleburg uses a single electrode supported by a mechanical arm that can raise or lower the electrode to achieve optimal process conditions. The electrode is placed in the middle of the molten alloy on a copper dish. The energy that is needed for the process is supplied by an open plasma arc on the molten material. The generation of the arc is a result of interaction between the fluid flow, the thermal field and the electromagnetic fields (Gasik, 2013, 345-348).

Figure 3.2 shows the basic concept of a DC arc furnace. The position of the electrode that was discussed earlier is indicated in the figure. The anode is



**Figure 2.2:** Schematic view of DC Arc furnace (reproduced from Gasik (2013, p.346))

imbedded in the hearth. The metal layer is in direct contact with the anode followed by the layer of slag. The energy that is required for the melting process is provided by the open plasma arc in the heart of the furnace (Jones, 2015).

The melting process in a DC arc furnace is an open-bath carbothermic reduction of metal oxides in the presence of slag. The first step in the melting process is the dissolution of metal oxides into the slag phase. The second step is the reaction of dissolved metal oxide with solid carbon. The typical feed for the production process consists of dry ore with a particle size of 6 mm, limestone and quartzite used as fluxing agents and lower-grade anthracite, coal and char used as reductants. After the melting process, the slag and metal are separated through two tap holes, the higher one for the slag and the lower one for the alloy. The tapping process takes place in intervals, approximately every 70 to 80 tons of alloy produced. The alloy is tapped until the slag appears. The

alloy is then cast into ingots and transported to stockpiles and then crushed (Gasik, 2013).

### 2.3.1.3 Effect on slag

The slag that is tapped after the alloy is in most cases tapped directly into a slag pit filled with water. The slag cools down and solidifies before being sent to a dumping or stockpiling area. The resulting slag is a large, lumpy product that needs to be crushed if further processing is required. Another option is to use water jets, which directly results in the solidification of small slag particles. The different alloy properties and tapping configurations result in a variety of metal consistencies in the slag. Generally, 1-4% of the total alloy tapped in the process is left over in the slag. The most common method to recover this alloy in the slag is by a wet jiggling process. In some cases, magnetic separation is used for the recovery of alloy. The recovery process of alloy from the slag is a trade-off between alloy recovery and alloy quality. A high recovery of alloy will decrease the quality of the recovered alloy (Gasik, 2013).

Depending on the production route of the ferrochrome operation, the resulting slag can have different compositions and pH values. The following formula is used to define the basicity factor:

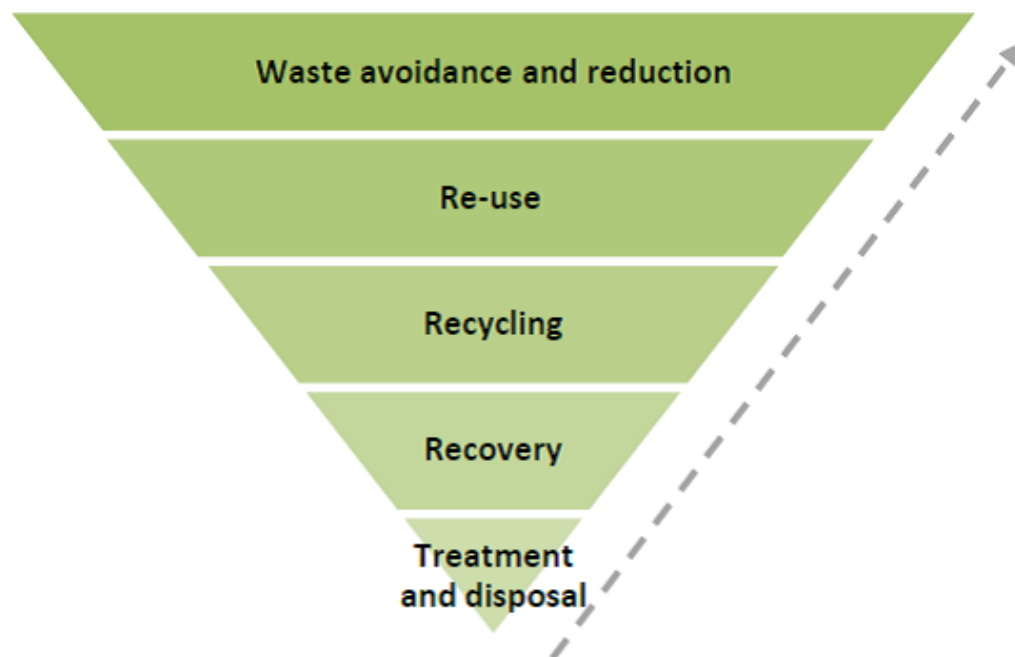
$$BF = \frac{\%CaO + \%MgO}{\%SiO_2 + \%Al_2O_3}$$

The conventional semiclosed furnace operation normally operates on an acid slag with a basicity factor smaller than 1. The same basicity factor usually applies to closed operations as well. Basic slag is produced usually in closed AC arc furnace operations and DC arc furnace operations, resulting in a basicity factor larger than 1 Beukes *et al.* (2010).

### 2.3.2 Environmental legislation related to the mineral processing industry

The Organization for Economic Co-operation and Development(2001) defines solid waste management as “the supervised handling of waste material from generation at the source through the recovery processes to disposal“(Statistics, 1997).

Despite the international acceptance of waste management hierarchies, a guide on how waste should be treated, national practices in waste management have reached different levels. The waste management hierarchy in Figure 2.3 presented by the DEA of South Africa shows that disposal to landfills is considered as the last option.



**Figure 2.3:** Waste hierarchy by the DEA (reproduced by DEA (2011))



At the top of the waste management hierarchy, and therefore the top priority, is the goal to minimise the waste streams, followed by reuse, recycling, recovery and, finally, disposal (Department of Environmental Affairs, 2011). This waste management hierarchy is adopted in similar form by nearly every developed country in the world, for example the Waste Framework Directive (WFD) by the European Union (2008c) (EC, 2008).

The focus of this research was on reuse as an integrated part of the recycling process. In Figure 3.3, the term 'reuse' denotes a situation where material or products are reused for the same purpose, for example reuse of glass bottles. The term reuse in this report refers to the reuse of a waste material by converting the waste into a by-product for new application. This process is discussed in further detail in later chapters by applying the example of ferrochrome slag in South Africa.

Before an analysis of the South African ferrochrome industry and the barriers to and opportunities for reuse, the concept of waste management needs to be addressed. The traditional way of waste management is regulated by legislation. Environmental permits, emission limits and technical standards are used to achieve the best possible outcome of waste management. These legal instruments differ from country to country and result in different practices in the way in which waste is managed. In order to address the right waste management strategy, it is important to have a clear definition about what is considered as waste. Different authors, both international and South African, noted the obscurity in the definition of waste in a legal system. Even the member countries of the European Union are not in possession of a clear definition of waste. In South Africa, the definition of waste is addressed in three different legal documents. This results in a misleading and inefficient waste management practice (Godfrey *et al.*, 2007).

The first definition of waste is provided by the National Environmental Management: Waste Amendment Act 26 of 2014. According to this act, waste is defined as follows: “any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, by the holder of the substance, material or object, whether or not such substance, material or object can be re-used, recycled“ (Department of Environmental Affairs, 2014). The act provides further understanding of waste by providing different classifications for waste. Waste can be classified either as hazardous or nonhazardous, depending on the potential harm to humans and the environment.

Department of Environmental Affairs (1989) defines waste as ... *„matter, whether gaseous, liquid or solid or any combination thereof, which is from time to time designated by the Minister by notice in the Gazette as an undesirable or superfluous by-product, emission, residue or remainder of any process or activity “.*

The third definition of waste states: *„waste includes any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted “,* is provided by the National Water Act of 1998 (Department of Water Affairs and Forestry, 1998).

For the utilisation of residues from the mineral processing industry, it is important to see the residues as by-products and not as waste. What is considered as by-products is also regulated by legal documents. In the European Union, the term 'production residue' is defined as *„a material that is not deliberately produced in a production process but may or may not be a waste“* (EC, 2008).

Whether a production residue is a by-product or waste is dependent on four conditions:

- Further use of the substance or object is certain;
- The substance or object can be used directly without any further processing other than normal industrial practice;
- The substance or object is produced as an integral part of a production process;
- Further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health-protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts (EC, 2008).

The National Environmental Management: Waste Amendment Act 26 of 2014 includes the deletion of the definition of 'by-product' (Department of Environmental Affairs, 2014). The previous definition of by-product provided by the National Environmental Management: Waste Act 59 of 2008 entailed the following: „by-product means a substance that is produced as part of a process that is primarily intended to produce another substance or product and that has the characteristics of an equivalent virgin product or material“ (Department of Environmental Affairs, 2008).

### 2.3.3 Innovation

The mentioned legislation forms the basis of decisions regarding waste management. In practice, especially when innovative solutions are considered to improve the current waste management practice, the waste management system fails and the best possible outcome is not achieved. The failures that can result from an innovative process, such as the handling of hazardous waste, are

discussed by Woolthuis *et al.* (2005) and Hauknes and Nordgren (1999). The authors mention important aspects of an innovation system: Firstly, innovation does not take place in isolation. Secondly, there is always a relationship between institutions and economic behaviour and performance. Thirdly, the evolutionary process, the ability to create variety due to constant interaction of actors, plays a crucial role. These important aspects of an innovation system, especially the interaction among heterogeneous actors, result in a system that is vulnerable to failures. The most common system failures according to Woolthuis *et al.* (2005) are reviewed below:

1. **Infrastructural failures:** This type of failure appears due to a lack of necessary infrastructure physical as well as knowledge infrastructure. Due to its large scale (usually on a national level) and high costs, it is undesirable for a private company to invest money to eliminate this failure. On this broader level, the government should provide the resources to prevent this failure.
2. **Transition failures:** These failures can be described as a lack of the ability and flexibility to acclimate to new technologies.
3. **Lock-in/path dependency failures:** These are a broader form of transition failures that address a whole social system.
4. **Hard (formal) institutional failures:** This refers to general legislation and regulation that, under certain circumstances, may potentially be a barrier to innovation. These failures can be technical standards, health and safety regulations and so on. An important statement, as we will observe later when we analyse the actual problem, is the following: “A too stringent appropriability regime may greatly limit the diffusion of advanced technological knowledge and eventually block the development of differentiated technological capabilities within an industry “.

5. **Soft (informal) institutional failures:** In contrast to hard institutional failures, soft institutional failures refer to social and cultural norms that can affect the regulation and standards provided by 'hard' institutions. As much as hard institutional failures, soft institutional failures can prevent innovation through specific behaviour.
6. **Strong network failure.** On the one hand, it can be argued that well-connected actors have an advantage in sharing information and know-how, but on the other hand, networking may be vulnerable to failures. This can occur when one actor is in a dominant role and as a result is misleading the whole group. Reasons for these kinds of failures are described in more detail.
7. **Weak network failures:** These failures are described as the result of poor communication among actors, which can hinder innovation (Woolthuis *et al.*, 2005).

The second paper that provides theory for solving the mentioned problem is "Economic rationales of government involvement in innovation and the supply of innovation-related services" by Hauknes and Nordgren (1999).

The authors discuss the role of governments in supporting innovation and innovation-related service. The starting point of the discussion regarding government involvement is the Arrow-Nelson rationale. Arrow and Nelson explored the topic of whether innovation always achieved the best possible outcome in a market. The authors concluded that an efficient market for innovation did not exist. Market failures could be attributed to externalities, asymmetric information, indivisibilities or barriers to entry.

Externalities are costs that are transferred to a third party who does not have control over them. For example, this may include the air pollution caused

by a coal power plant, with the third party being the society that has to live in a polluted environment.

Asymmetric information describes the problem between two individuals who are willing to sign a contract. As a result of unequally distributed information, the outcome of the contract does not reflect the most efficient way.

In the case of innovation, appropriation of returns and uncertainty are mentioned by Hauknes Nordgren as the most common types of market failures. Appropriation of returns describes the fact that returns from research and development are rated higher by society than by the private sector. No innovator will ever collect all of the benefits resulting from his/her work. The implementation of an innovation will always have a spillover effect to the other participant. This spillover effect of knowledge has a positive effect on the one hand, but on the other hand, it leads to a decreased input into research and development (Hauknes and Nordgren, 1999).

## 2.4 Valorisation of ferrochrome slag

Due to the different production routes of ferrochrome slag, fluxing agents and additional materials, the resulting slags differ in their composition and characteristics. It is a common fact for every ferrochrome production operation that the end of the process cycle will result in huge amounts of slag. Not only are the large amounts of slag of significance, but the composition of the slag is also noteworthy: All ferrochrome slags are based on  $\text{Al}_2\text{O}_3\text{-MgO-SiO}_2$  with minor contents of CaO and CrOx (Holappa and Xiao, 2004).

The presence of chromium, especial the hexavalent form of Cr(VI) and the trivalent form Cr(III), leads to environmental concerns about the valorisation of ferrochrome slag. Chromium is one of the most toxic heavy metal ele-

ments found in the environment. From this point of view, it is understandable to have concerns about potential reuse scenarios. Worldwide, scientists have studied the composition of ferrochrome slags and investigated the environmental concerns regarding the presence of Cr(VI) and Cr(III). This chapter aims to provide a better understanding of ferrochrome slag and the valorisation thereof.

Different authors emphasize the suitability of ferrochrome slag as a construction material. According to Niemelä and Kauppi (2007), ferrochrome slag is a suitable road construction material, which has been used in Finland over the last 40 years. They obtained this result after a number of physical and chemical tests; one, for example, is the column test, which is a solubility test for environmental qualifications. Additionally, they evaluated ferrochrome slag by comparing it to natural materials used in civil engineering and road construction (Niemelä and Kauppi, 2007).

Panda *et al.* (2013) investigated the suitability of ferrochrome slag as a concrete aggregate material. To achieve this, the authors collected slag samples from the Kalinganagar industrial complex in Odisha, India. They studied both air-cooled slag - after size reduction and recovering alloys (using the jigging process) for application as coarse aggregate as well as granulated slag which was subjected to high-pressure water jets - for application as fine aggregate. For the evaluation of the aggregate properties specification, the International Standard IS 383-1997<sup>1</sup> was used as benchmark. According to this standard, the ferrochrome slag samples showed desired physical and mechanical properties Panda *et al.* (2013).

To form the concrete aggregate samples, three different cements were used (Portland cement, ordinary Portland cement and Portland Pozzolana cement).

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<sup>1</sup>IS 383-1997: Indian Standard Specification for coarse and fine Aggregates from Natural Source for concrete.

The chemical analysis of the samples was conducted by X-ray fluorescence spectroscopy. X-ray diffraction was used to analyse the mineralogical characteristics of the samples. Different concrete cubes were formed by using ferrochrome slag, cement and natural aggregates in different proportions.

The environmental assessment of possible leaching of chromium was done by different leaching tests. An availability screening test was carried out to investigate the possible release of chromium into the environment. In addition, a toxic characteristic leaching procedure test was carried out. The mineralogical and chemical studies showed that Cr(III) was mostly immobilised in highly stable spinel phases, which resulted in inhibition of chromium release into the environment. The studies also found a very low Cr(VI) content that resulted in the exclusion of any environmental risk. Furthermore, leaching studies indicated that the leaching of Cr(III) and Cr(VI) was relatively high for the ferrochrome slag samples higher than the minimum Indian regulatory discharge standard.

However, the samples of the concrete blocks using ferrochrome slag as aggregate material showed excellent results. This was due to the solid concrete matrix that led to immobilisation of chromium (Panda et al., 2013). The small amount of leaching from the unprepared slag was completely immobilised in every type of cement and concrete, resulting in a good environmental performance. The authors came to the conclusion that ferrochrome slag could be utilised as concrete aggregate material without causing significant environmental pollution (Panda *et al.*, 2013)

Luga *et al.* (2011) compared different samples of aggregate material. The results showed, that the sample prepared of ferrochrome slag had better characteristics than the samples of natural river aggregate. The reuse of ferrochrome



slag would result in better environmental performance than it is the case with landfill. .

Korkiala-Tanttú and Rathmayer (2000) published a paper on the valorisation of ferrochrome slag as road construction material in Finland. The authors investigated the mechanical and leaching properties, requirements and long-term stability of ferrochrome slag in road construction. Due to the climate conditions in Finland, the authors performed a climate chamber test that took into consideration the changing weather conditions. The material tested was air-cooled ferrochrome slag with major components of silica, aluminium and magnesium oxides.

The leaching results focused on chrome and aluminium, which were of interest from an environmental point of view. The amount of chromium (6.5) was higher than the Dutch directions allow. However, the chromium appeared in the form of Cr(III) and Cr(II), which are very stable forms of chromium. That led to the result that the leaching of chromium into the environment was very moderate and fulfilled the Dutch requirements. The results were compared to other leaching studies in which the possibility of leachants was investigated as a function of pH (Wahlström *et al.*, 2000). The climate chamber test showed the same results. The leaching of chromium would increase only if the pH value of the ferrochrome slag reached values under six. According to Wahlström *et al.* (2000), it would take 270 years to decrease the pH level from pH 10 to pH 7. The final results indicated that ferrochrome slag was suitable for every part of road construction because chromium was immobilised (Korkiala-Tanttú and Rathmayer, 2000).

With a view on the performance of the mentioned tests it must be emphasized that the studies are often used to measure the total concentration of harmful components of the proposed secondary material. Mäkelä *et al.* investi-

gated the mobility and availability of trace elements such as As, Ba, Cd, Co, Cr, Cu from a Solid Residue Matrix Designed for Soil Amendment. The results of the sequential extraction procedures show that the actual leaching is much lower as assumed by the total concentration. In practice the total concentration determination is still widely used by legislative authorities (Mäkelä *et al.*, 2011).

### 2.4.1 Reuse scenarios of ferrochrome slag

The best positive example of the reuse of ferrochrome slag can be found in Finland. The Tornio Works ferrochrome smelter achieved a zero-waste ferrochrome production process. All the slag produced during the smelting process in AC arc furnaces is utilised either in the steel production plant or in other industries in the form of a material with a new purpose. Since the beginning of ferrochrome production in 1968, over six million tons of ferrochrome have been utilised for different purposes. Up to date, Outokumpu Chrome Oy's Tornio Works have produced 270 000 tons of ferrochrome using chromite from the Kemi Mine in Finland.

The production process uses coke for the reduction of chromite into metallic ferrochrome in an electric arc furnace. In this process, 320 000 tons of ferrochrome slag are produced out of which 300 000 tons are utilised and sold as OKTO construction materials. The materials, OKTO insulation material and OKTO aggregates, are the result of a carefully selection of input materials and analysis of the production process. The production process represents the best available technique in ferrochrome production. The manufacturing process is controlled by a strict quality control system, and the material properties adhere to a strict set of standards set by the Finnish government (Kallio *et al.*).

**Table 2.2:** Requirements for OKTO products (reproduced from Kallio *et al.*)

Property, standard	Testing interval
Flatness rate, SFS-EN 933-3	1/month
Granularity, SFS-EN 933-1	1/week
Ball mill, SFS-EN 1097-9	1/month
Los Angeles value, SFS-EN 1097-2	1/year
Resistance to freezing and thawing, SFS-EN 1367-6	AS required
Adhering to bituminous binders, prEN 12697	1/year

Table 2.2 gives an overview of the standards used to evaluate the properties and minimum requirements for OKTO products. Additionally, a leaching test (L/S 10) is used to evaluate the risk of leaching of metals into the environment.

The test focuses on Cr, Cr(VI), Mo and F-. To ensure a permanent quality and to exclude any environmental risk, the test is conducted on a regular basis. Niemelä and Kauppi (2007) investigated the suitability of the ferrochrome slag of Tornio Works. The slag produced as integrated part of the production process is used for reuse without any negative environmental effects since over 40 years. Besides the promising research regarding the utilization of ferrochrome slag, potential risk does exist.

### 2.4.2 Requirements and Risks

The possible negative environmental effects due to the carcinogen classification of Cr(VI) are the biggest risk regarding the utilisation of ferrochrome slag. The possible negative impact on the environment and human health is classified by the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). The GHS is an attempt to create an internationally accepted framework for standardising and harmonising the classification and labelling of chemicals. The system is used to define the health, physical and environmental hazards of chemicals. In addition, it creates a platform for communication and the opportunity to share available data for comparison

**Table 2.3:** Hazardous Ratings in SA (DEA (2011))

LD 50 (mg/kg)	LC 50 (mg/l)	Hazard Rating
<5	<1	HR1
5 to 50	1 to 10	HR2
50 to 500	10 to 100	HR3
500 to 5000	100 to 1000	HR4

(Nations, 2013). South Africa implemented the GHS in 2008 by providing the National Standard SANS 10234 (SANS 10234:2008, 2008).

For the assessment of the toxicity of chemicals, the lethal concentration (LC) is used. LC 50 (50% lethal concentration) is the concentration of a specific chemical in air or water that kills 50% of a group of test animals. LD 50 means the amount of a chemical, given all at once, that kills 50% of a group of test animals (Nations, 2013).

The values LC 50 and LD 50 are used to define different hazard ratings (see table 2.3). In South Africa, the factor 0.1 is used to set an acceptable risk level (Forestry, 1998).

Lind *et al.* (2000) investigated the environmental impact of ferrochrome slag in road construction. The authors came to the conclusion that no significant leaching into the groundwater had taken place. The only negative environmental impact that was detected and that needs to be addressed in future research is the uptake of chrome by plants growing with their roots in the slag (Lind *et al.*, 2000). Beukes *et al.* (2010) performed a study on the possible negative effects of Cr(VI). The results indicated that ferrochrome dust was the waste product with the greatest health concern. The authors criticised the overmanagement of South African handling of slag, which had led to the buildup of huge amounts of ferrochrome slag on landfill sites.

In addition, Lidelöw and Mácsik performed leaching studies on test roads in Sweden. The authors investigated the potential leaching of different slags used in road construction over a period of ten years. The results showed that significant amounts of trace elements could leach to the ground water. The minerals of concern were mainly Cu and Zn.

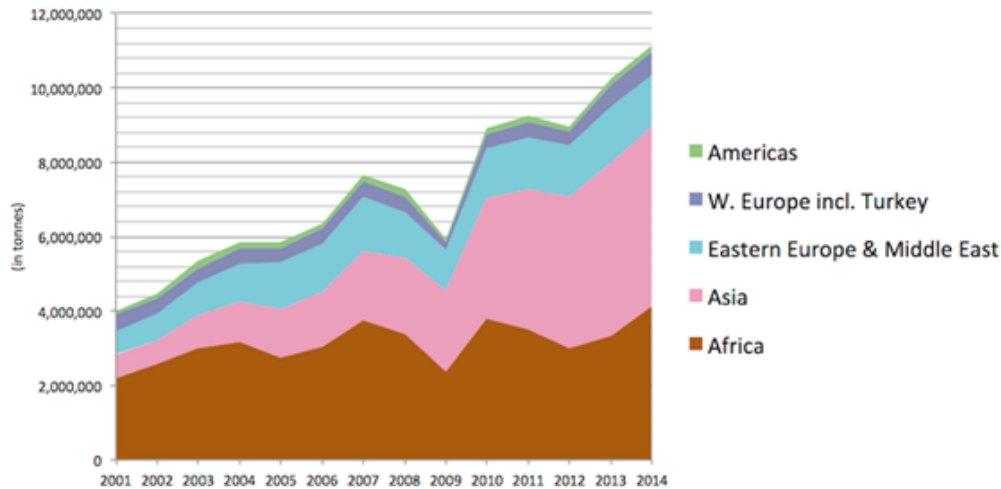
## Chapter 3

# The South African ferrochrome industry

### 3.1 Overview of industry

South Africa is the leading player in international ferrochrome production. This is due to the existence of substantial amounts of chromite in the country. The Bushveld Complex contains the largest amount of chromite in the world. The estimated resource base of South Africa is 6 860 million tons (Pariser, 2013).

Chromite is an iron chromium oxide,  $\text{FeCr}_2\text{O}_4$ . Chromite is used to produce either metallic chromium or ferrochrome. 95% of chromite is utilised in the form of ferrochrome due to the important characteristics of chrome. Ferrochromium is one of the most important alloys used for the production of stainless steel. The utilisation of ferrochrome in stainless steel production provides the steel with corrosion- and oxidation-resistant properties (Gasik, 2013).



**Figure 3.1:** HC FeCr/Charge chrome production by region 2001-2014 (adapted from ICDA (2015))

Figure 3.1 shows the allocation of world ferrochrome production over a period of 13 years. The major producer of ferrochrome are South Africa, China, Kazakhstan and India.

### 3.1.1 History

The history of the South African ferrochrome industry dates back to the year 1939 when the decision was taken to build two electric arc furnaces for the production of ferro-alloys. In the beginning, the focus was on high carbon ferromanganese and ferrosilicon. In 1960, Transalloy started the production of high-carbon and low-carbon ferrochrome (LCFeCr) in Witbank. Middleburg Ferrochrome, which is now a part of Samancor Chrome, started the production of ferrochrome in 1963. In the same year, the Palmiet Chrome Corporation commissioned the first operation for the production of charged chrome near Krugersdorp. The first use of DC arc technology also dates back to Palmiet in the year 1983. Ferroalloy Limited began the production of ChCr and LCFeCr at Machadodorp in 1971. Samancor Limited, one of the biggest ferrochrome

producers in South Africa, was the result of the merger of Amcor and S.A. Manganese in 1975. The present operation in Steelpoort dates back to the year 1975 when Glencore Ltd and Union Carbide Inc (USA) started the Tubatse ferrochrome operation. In 1987, Chromecorp Technology (Pty) started the production of ferrochrome in Bathlako and two years later in Rustenburg. The company was acquired by Sudelectra South Africa Holding (Pty) Ltd. in 1998. The name Sudelectra was changed to Xstrata South Africa (Pty) in 1999 and the company is currently the largest ferrochrome producer in the world. The operation of Heric Ferrochrome dates back to the year 1995. Purity Ferrochrome operated two furnaces in Rustenburg for the production of charged chrome in 1995 and was taken over by Xstrata in 1998. ASA Metals (Pty) started the production of charged chrome in 1997 near Polokwane. South African Chrome Alloy Limited, renamed SA Chrome in 1999, started production in 1987 and has been in a joint venture with Xstrata since 2004. The industry transformed to bigger operations and joint ventures in the last decades. The current status is shortly described in the next chapter to get a better understanding of the industry structure.(Basson *et al.*, 2007).

### 3.1.2 Current status

The current state of the industry is the domination of two major players in South Africa, Glencore and Samancor. The previous history of the industry showed different mergers between the players. The Glencore Merafe Venture is by far the largest producer of ferrochrome in South Africa, followed by Samancor. The industry trend over the last years leads to the construction of larger ferrochrome smelters. Table 3.1 shows the producer of ferrochrome in South Africa with their annual capacities. Those capacities are not fully used at the moment. Last year, the capacity utilization for high carbon ferrochrome was 79% (Roskill Information Service, 2016).



**Table 3.1:** Ferrochrome producer South Africa (Data source:Internet,MINTEK)

Company	Operation/Location	Capacity (kt/a)
Samancor	Ferrometals	550
	Middleburg Ferrochrome	285
	Tubatse Ferrochrome	380
	Bathlako Ferrochrome	25
Afarak	Mogale Alloys	110
Glencore (Xstrata) (Merafe Venture)	Wonderkop	553
	Rustenburg	430
	Boshoek	240
	Lydenburg	396
	Lion Phase 1	360
	Lion Phase 2	360
Hernic Ferrochrome	Brits	420
Assmang	Machadodorp	300
International Ferrometals	Moonooi	267
Sinosteel	ASA Metals, Dilokong	410
Tata	Tata Steel KZN, Richards Bay	150
<b>Total</b>		<b>5246</b>

The South African industry temporally lost the status as leading ferrochrome producer in the world to China. That was primarily the case of rising electricity costs in South Africa and environmental pressure in China. In addition, low ferrochrome prices resulted in weak economical performance of small chinese ferrochrome producers (ICDA, 2015). During the first half of this year South Africa reclaimed its status as leading ferrochrome producer. The global output of ferrochrome declined by 4% to 5.2 million tons in the beginning of this year. The fact that the Chinese ferrochrome production fell by 17% resulted South Africa reclaiming the first spot again. The ferrochrome price dropped in the beginning of this year to \$0,82/pound (lb), reaching the price of the weak year 2009, followed by a strong increase to 98c/lb in the third quarter of this year (Seccombe, 2016). The trend of ferrochrome prices over a period of ten years is shown in Figure 3.2.



**Figure 3.2:** Ferrochrome price trend (InfoMine (2016))

Table 3.2 shows the ferrochrome production and sales over a period of ten years, indicating a new peak in 2014. The data shows the trend of a growing industry which is the result of an increasing demand of stainless steel especially from China. The total sales are considering local and export sales of ferrochrome. The South African ferrochrome industry is very export oriented due to a small domestic stainless steel production, which led to local sales of only 571 300 tons, while 3 192 000 tons were exported in 2014 (DMR, 2015).

The increasing production of ferrochrome will also lead to increased generation of ferrochrome slag. The presented data in Figure 3.1 and Table 3.2 make it possible to visualise the massive streams of solid residues from the production of ferrochrome in the future. While the South African Industry seems to be prepared for an increased demand of ferrochrome, due to unused capacity, the massive problem regarding the handling of waste still remains.

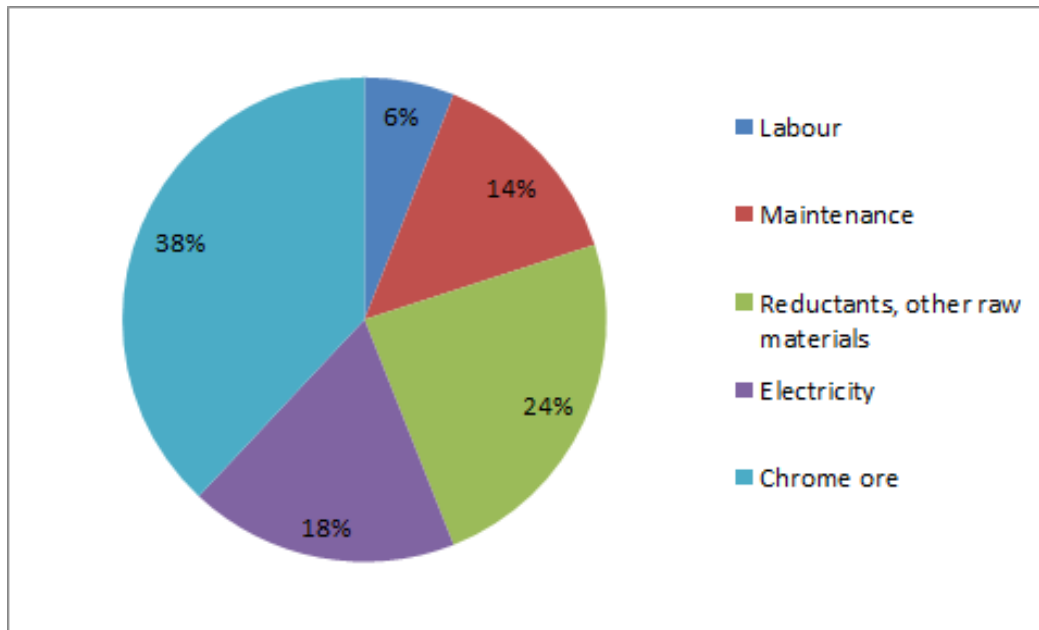
**Table 3.2:** Ferrochrome production and sales in South Africa 2004-2014 (Data source:DMR (2015))

Year	Production (100t)	Total sales	
		Mass (1000t)	Value (R1000)
2004	3 032	3 130	11 966 134
2005	2 802	2 838	11 344 966
2006	3 030	2 934	11 722 645
2007	3 552	3 364	17 515 499
2008	3 269	2 859	31 771 589
2009	2 346	3 053	18 134 572
2010	3 607	3 513	27 067 906
2011	3 426	3 499	27 224 005
2012	3 063	3 188	25 693 086
2013	3 219	3 162	28 535 964
2014	3 719	3 763	36 185 534

The input costs of ferrochrome production are very different from country to country. Figure 3.3 shows the general cost allocation of a typical ferrochrome production. The cost for chrome ore and electricity account for just over half of the total costs of production. The electricity costs are the result of the high energy consumption of the smelting process of chromite. On average 4000 kWh/t are needed. The seconded highest costs are caused by the need of reductants. Due to the production of ferrochrome in low income countries the costs for labour is not a major challenge (Cartman, 2008).

The four major ferrochrome producing countries; South Africa, Kazakhstan, India and China vary in their input costs. For China, due to the lack of own mineral resources, the highest costs are caused by expensive chrome ore imports. The biggest advantages of the Chinese industry are the cheap labour and maintenance cost, followed by relatively cheap prices for reductants and other raw materials (Cartman, 2008).

The advantages for the South African industry can be seen in the largest chromite reserves in the world, which results in low costs for chromite. However, this advantage only exists if the ferrochrome smelters can rely on fully



**Figure 3.3:** Typical cost allocation for ferrochrome production (Data source:(Cartman, 2008))

integrated supply of ore. Three ferrochrome producers; Tata KZN, International Ferro Metals and ASA metals had to close their operation mainly due to the missing of an integrated ore supply last year. The example of the ferrochrome operation in Richards Bay of Tata Steel KZN, shows how difficult it is to stay competitive without own supply of chromite. The operation started producing HC ferrochrome in 2006 with an annual output of 150kt/a. Last year the operation was forced to shut down. Since then a bidding war started to buy the insolvent Tata Steel KZN. The operation was finally sold for R90 million in August this year to the trading company Traxys headquartered in Luxembourg (Broughton, 2016). Traxys owns chromite mines in Steelport and Sefateng which will secure the supply with chromite, even though the mines are over 600km away.

In the case of International Ferrometals and ASA an integrated ore supply did exist, but due to high costs as a result of unproductive mines the operations

were not able to keep the production running. Similarly, Herculite Ferrochrome who is still operating had such struggles. This shows how competitive the industry is and the importance of having an integrated supply of chromite. Besides the acquisition of Tata Steel KZN by Traxys, Samancor successfully acquired the IFM plant. In addition, the takeover of ASA Metals seems to be another opportunity for Samancor. This might motivate Glencore to consider a takeover of the weak performing Herculite Ferrochrome operation. The major stakeholder of Herculite Ferrochrome, Mitsubishi said he is open for offers. This would increase the dominance by Glencore and Samancor (Beveridge, 2016).

### 3.1.3 Status of Ferrochrome Slag Dumps

The South African ferrochrome industry, as mentioned earlier, produces 1.1-1.8 t of slag per ton of ferrochrome. Unfortunately, no exact data is available as to how much ferrochrome slag is sent to landfill on an annual basis. Approximately, if we choose a slag to ferrochrome ratio of 1.4 and the amount of ferrochrome slag produced in 2014, the industry produced 5.18 million tons of ferrochrome in 2014. The data of those waste streams should be available from the South African Waste Information Centre (SAWIC), however the statistical reports of the SAWIC system do not allow specifying the search on ferrochrome slag. The available data only considers hazardous and general ferrous metal slag, which includes other materials like ferromanganese. The provided data indicates waste streams of 224 363.5 tons of general ferrous slag and 3 362 046.2 tons of hazardous ferrous metal slag, which adds up to 3 586 409.7 tons of ferrous metal slag (SAWIC, 2015). Because, we are only interested in ferrochrome slag the SAWIC was contacted to receive the necessary data, which should be available. The respondent referred the researcher back to the SAWIC and mentioned that all data which is available can be found there.

In addition, every waste producer needs to be in possession of a license to send slag to landfill. Those licenses are provided by the DEA to control waste streams. The licensing process requires producer to report on an annual basis the amount and composition of the material which was sent to landfill during the year (see Appendix A.1). The mentioned requirements lead to the assumption that the DEA should be in possession of data regarding the amount and composition of ferrochrome slag which was sent to landfill.

The Promotion to Access to Information Act 2 of 2000 gives every person the right to get access to information held by the state. The procedure to receive data from the state was followed in order to obtain the described amount and composition of ferrochrome slag sent to landfill in the last ten years. The application process, consisting of a written application (see Appendix A.2), was sent to the DEA together with the proof of payment for the required request fee of R 35,00. This step of the process, that is, the attainment of access to the data of the DEA ensures that the requested data is available and processing time is limited to one month. After this period the DEA can extend the period to another month if more time is needed without giving a specific reason. The latter one happened in the case of this study (see Appendix A.3). Finally after 2 months, the DEA answered the request and stated that the requested data is available and access is granted (Appendix A.4). The next step was to pay the required access fee which was R 104.00 calculated at R 0.40 per page to receive the 260 pages of data. The last step, the actual receiving of the data, took another month - allegedly due to problems with copier machines and the need to redact some of the information in the documents such as company logos (see Appendix A.5).

The data which was received was not in accordance with the request. The DEA provided four PDF documents. Document 1 was part of an empty waste management license form which did not include any information. Document 2

was the auditing report of one specific landfill side. Document 3 provided 73 pages of risk assessment. The ground water borehole monitoring of one landfill side was described in Document 4. The 260 pages received did not provide any information about the requested amounts which were sent to landfill and should be reported to the DEA on an annual basis. The reason why the DEA could not provide the requested data is unknown. The DEA had two month time to process the request and check if the data is available. The unsuccessful inquiry could be the result of bad and inefficient communication in the department. That would coincide with the experiences from the industry, where the assessment of ferrochrome slag ended in a burocratical obstacle (Oelofse *et al.*, 2005).

Because of the time consuming data collection process which probably would have been unsuccessful even with further efforts and the limited time frame of this study, the data collection from the DEA was discontinued. This data would have been a valuable input to this work in terms of identifying ferrochrome slag waste streams and the composition thereof. The data could have been used to identify potential for metal recovery from the slags and to address in more detail the composition of ferrochrome slags in South Africa, which would have resulted in a more detailed discussion about suitability and opportunities for reuse.

### **3.1.4 The Ferro Alloy Producer Association (FAPA)**

The FAPA is a member of the Steel and Engineering Industries Federation of South Africa, which provides support to improve the business environment for its members. In regard to the utilisation of ferrochrome slag, the FAPA assigned JMA Consulting (Pty) Ltd to conduct a motivational report on the beneficial use of ferrochrome slag. This report will be reviewed shortly to improve the integrity of this study. The report aims to show that ferrochrome

slag should not be considered as hazardous waste. The argumentation in this report is based on the GHS of classification and labelling of chemicals. The methods used for the assessment process followed the approach provided by SANS 10234:2008 and led to the conclusion that ferrochrome slag was not hazardous to human health or to the aquatic environment (Van Niekerk and Fourie, 2011). In addition, the Generic Assessment of Exposure to Dust from Ferrochrome slag was investigated as well as the pH dependence of leaching characteristics and ageing characteristics of ferrochrome slag. All tests showed positive results, leading to the conclusion that ferrochrome slag should be considered as an inert waste instead of a hazardous waste. Similarly, the criteria document for the classification of ferrochrome slag in accordance with SANS 10234:2008 Ed 1.1 also showed that the provided sample was consistent with the classification of inert waste instead of hazardous waste in all hazard classes.

The results of the JMA Consulting report show that no negative impacts on the environment or human health could be detected, which supports the work by other researchers reviewed in Chapter 3 of this work. It is of vital importance to mention that this report does not allow for the conclusion that ferrochrome slag is in general not hazardous. This is because the report only investigated the possible negative impacts of one ferrochrome sample. The results are therefore not useful for an argument in favour of considering ferrochrome slag as a by-product by law but show the necessity for further investigation of ferrochrome slag due to the positive results of the report (FAPA, 2013).

### 3.1.5 Reuse of ferrochrome slag in South Africa

The literature on case studies of ferrochrome slag reuse in South Africa is very limited. The only useful documents which provide information about success-



ful reuse scenarios were provided by the FAPA of South Africa, which is not available to the public and the South African Pavement Engineering Manual. The research that resulted in the document ,Beneficial Use of Ferrochrome Slag, was conducted by an independent consulting company on behalf of the FAPA. Ferrochrome slag was used as drainage material, as layer work material, for asphalt manufacture and for seal work. Approximately 7 000 tons of ferrochrome slag were used as drainage material on the N4 between Witbank and Middleburg. The slag fulfilled all the requirements of the Standard Specification for Road and Bridge Works for State Authorities 1998 (COLTO, 1998).

Ferrochrome slag as base material was used in small quantities on the N4 between Belfast and Machadodorp. Ferrochrome slag mixed with sand was used for rebuilding shoulders along the N4 (approximately 10 000 tons) and on the N4/5 for subbase construction (approximately 20 000 tons) (South African National Roads Agency (NRA), 2013)

The use of ferrochrome slag in asphalt works is the most common reuse scenario in South Africa. During the upgrade of the N4 in 1999-2000 and on road works on the N4/3 in 2004, a ferrochrome slag/asphalt mixture was used. Approximately 74 650 tons of ferrochrome slag were also used on the N4 between Machadodorp and Montrose. In 2008, the N4/3 was upgraded by using 25 900 tons of ferrochrome slag as an overlay. That resulted in approximately 175 030 tons of ferrochrome slag utilised on the N4 (South African National Roads Agency (NRA), 2013).

The use of ferrochrome slag for seal work is suitable from a technical point of view but was only implemented on a small scale due to the need to wash the slag before use, which increased the cost and led to an unattractive alternative. Nevertheless, approximately 15 030 tons of ferrochrome slag were used for this

purpose, without any negative impacts. The overall use of ferrochrome slag provided by the FAPA is therefore approximately 272 060 tons (FAPA, 2013; South African National Roads Agency (NRA), 2013).

## 3.2 Identifying barriers and opportunities

Chapter 3 provided a short introduction to the theory used in this work regarding the identification of barriers to and opportunities for the reuse of ferrochrome slag. As mentioned earlier, the literature does not consider the ferrochrome producer's point of view, which is important for potential reuse scenarios in South Africa. This section therefore aims to present the producer's perspective in the form of the analysis of an industry survey. The following subchapter presents the results of an online questionnaire that was conducted to include the producer's point of view.

### 3.2.1 Interviews Industry Experts

The interviews with industry experts aimed to collect primary data from different ferrochrome operations. The 10 largest ferrochrome-producing operations were invited to participate in a short questionnaire regarding their experience of ferrochrome slag. Only four ferrochrome producers were willing to participate in the study. It is important to mention that the 16 operations were not 16 companies. The participants were selected according to the size of the ferrochrome smelting operation, independent of the owner of the operation. The participants in the survey were from four different operations and companies and could share to some extent experience on a company level and not only on an operational level. The following section presents the survey questions and the results followed by an analysis through consideration of theoretical aspects. The original questionnaires are available in appendix B.

### 3.2.2 Presentation of results

#### **Question 1: How would you describe the potential for the reuse of ferrochrome slag in South Africa?**

The first question aimed to obtain an overview of how the South African industry sees the opportunity to reuse ferrochrome slag. Producers 1 and 2 see substantial opportunities for reuse, and Producer 3 rates the opportunities as having very high potential. This initial question, which identifies opportunities from the producer's point of view, shows that more research needs to be conducted to fill the gap between opportunities and successful implementation.

#### **Question 2: Which reuse scenario is in your opinion the most promising?**

The previous chapters have already indicated that ferrochrome can be utilised for a variety of different applications. Depending on the slag composition, the proposed reuse scenarios are limited. Figure 3.4 demonstrates the results of Question 2.

Similar to the first question, the participants were asked to rate the most promising reuse scenario on a scale from 1 to 5 (1 = very low, 2 = low, 3 = medium, 4 = high, 5 = very high). The reuse of ferrochrome slag in civil engineering and road construction was seen as the most promising opportunity for reuse. The proposed reuse of ferrochrome slag as refractory materials was seen as the weakest opportunity. The results share the general opinion about the reuse of ferrochrome slag, namely that the use of slag in civil engineering and road construction is internationally seen as the most promising scenario for reuse (Niemelä and Kauppi, 2007; Panda *et al.*, 2013; Korkiala-Tanttu and Rathmayer, 2000; Luga *et al.*, 2011).

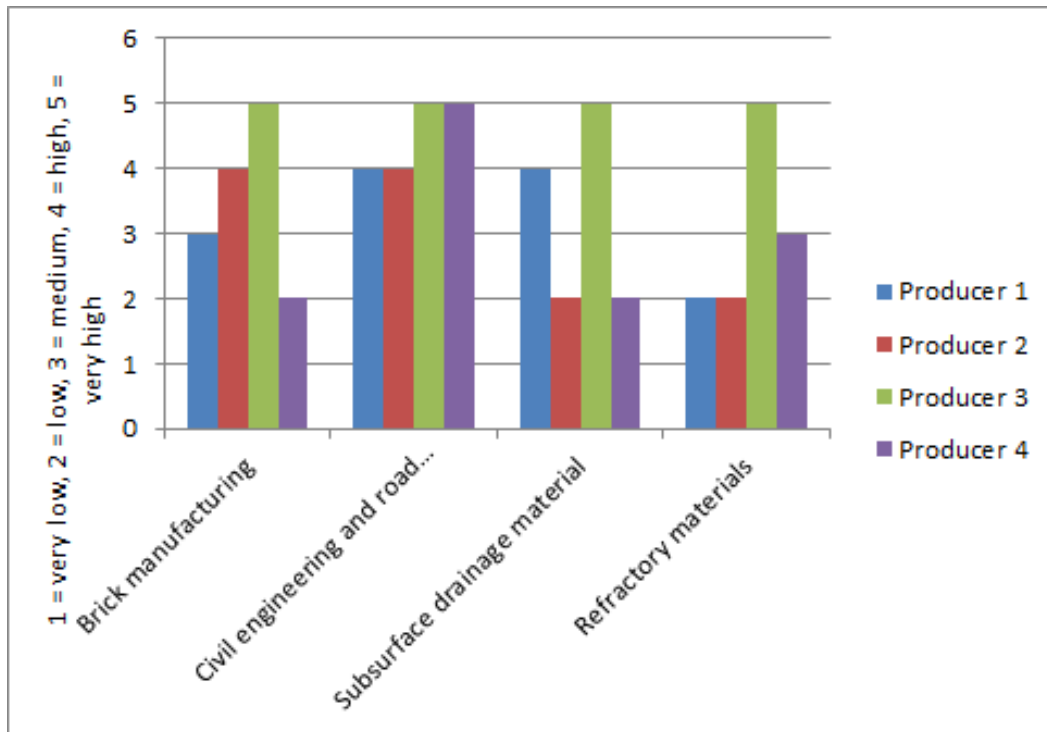


Figure 3.4: Proposed reuse scenarios in South Africa

**Question 3: Where do you see the biggest barriers for reuse scenarios of ferrochrome slag in South Africa?**

The literature review already identified the possible barriers regarding the reuse of the slag from a theoretical point of view. Environmental standards, nonexistent market for slag, economic factors, customer demands not met due to the composition of the slag and the waste management process regarding the reuse were provided as possible answers to Question 3. The results are presented in Figure 3.5.

Environmental standards and waste management practice and policies were identified as the biggest barriers. At the beginning of this study, industry experts were asked to name the reasons for the paucity of reuse scenarios in South Africa. One explanation was the missing market for ferrochrome slag products due to the enormous availability of crushed rock material from mining

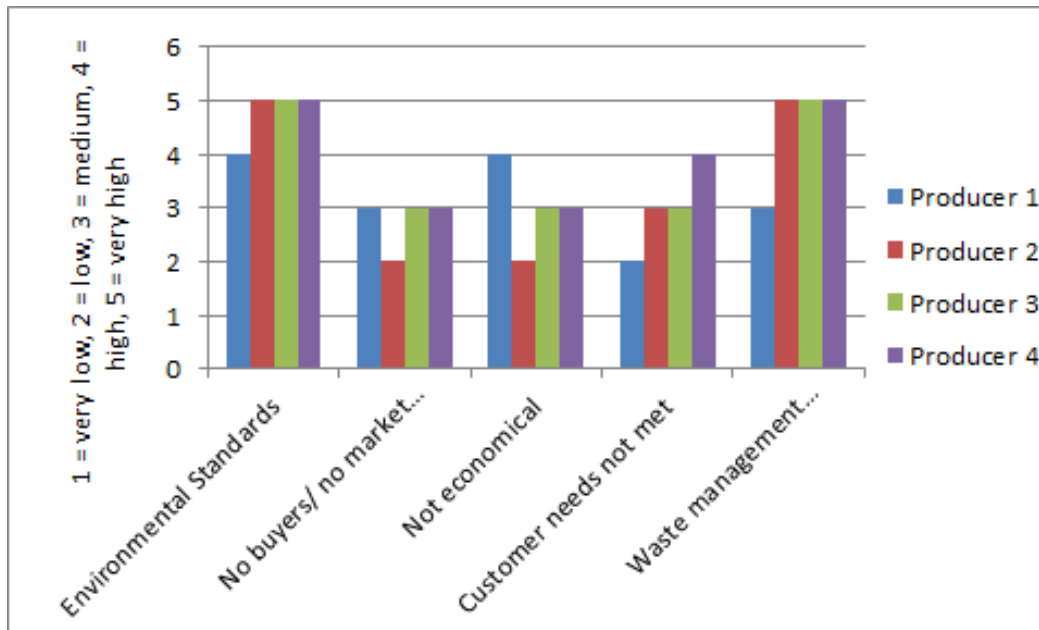


Figure 3.5: Barriers for reuse scenarios

operations. This barrier was rated by the participants with ‘medium’ barrier (Producer 1, 3 and 4) and ‘low’ barrier (Producer 2). It is important to mention that the market size for ferrochrome slag is highly dependent on the location of the operation. The results from the questionnaires only consider three producers. Other producers in different locations would maybe have rated this barrier as 5 - ‘very high’.

**Question 4: Do you see any barriers that are not mentioned in the previous question?**

Barriers can vary from producer to producer, depending on various factors unique to single operations. This was addressed by the option to add more barriers to the one mentioned. Three out of four participants used this option to name experienced barriers. Two producers agreed with this and added environmental legislation, especially waste management practice, to the barriers. Producer 1 described a barrier whereby government and policy makers did not

understand the issues related to the reuse of slag. Producer 2 argued that the current Waste Management Act was the biggest barrier of all. Only Producer 4 saw a barrier from a technological point of view. In his opinion, the different slag compositions ( $\text{Cr}_2\text{O}_3\%$ ,  $\text{SiO}_2\%$  and  $\text{Al}_2\text{O}_3\%$ ), which vary from smelter to smelter, will affect the confidence in the use of ferrochrome slag. In other words, the performance of slag by-products is inconsistent, which will lead to the use of natural aggregates such as rock and stone of which the specific composition is consistent.

**Question 5: Have you experienced problems with the delisting process of hazardous slag?**

The problems regarding the delisting process of hazardous materials were already described by Hattingh et al. Three ferrochrome producers shared the experience of problems regarding the delisting process. The delisting process, the reaching of a lower hazardous rating, is actually not part of the waste management process in South Africa. However, it is still worth mentioning because the procedures for delisting a material and proofing suitability are similar. Unfortunately, the new waste management strategy whereby the government only differentiates between hazardous or nonhazardous waste is not covered by the literature due to recent changes.

The problems identified regarding the delisting process are still available by applying the new legislation. Producer 1 viewed the barrier as too strict with incorrect measurement standards to determine the suitability of ferrochrome slag. Producer 2 referred to the standards set by the government whereby ferrochrome slag is due to the huge amount generally rated as hazardous. Producer 3 argued that the biggest problems in the delisting process included the following: The challenge that even nonhazardous slag needs a waste management activity license, the government's lack of understanding the specific

waste type and the overregulation of end-user responsibility. Only Producer 4 had not experienced problems with the delisting process.

**Question 6: Are possible reuse scenarios blocked by geographic and infrastructural circumstances?**

This question is related to the structure of the South African ferrochrome industry discussed in the previous chapter. The geographical position of a ferrochrome producer could lead to a barrier due to the absence of a market for ferrochrome slag products. The possibility of transporting the slag to potential customers is limited due to the high transportation costs. The ferrochrome producers that participated in the survey shared different opinions about geographic and infrastructural barriers. Two producers experienced problems relating to geographical location and infrastructure whereas the other two producers disagreed.

Producer 2 regarded the distance between a ferrochrome producer and densely populated cities, where the need for construction material is the highest, as the main problem. Producer 3 shared the opinion of Producer 2 but also added the problem of competitive materials. The huge amount of mining activity in the Bushveld Complex provides an abundance of natural aggregates such as crushed rocks that can be used as filler or construction material and are therefore a competitive material to ferrochrome slag.

**Question 7: Is the environmental legislation regarding reuse of slag overly protective?**

The legislation for reuse of ferrochrome slag was seen as overly protective by all ferrochrome producers. Two producers agreed with and the other two totally agreed with the statement regarding overly protective legislation.

**Question 8: Better collaboration and communication between public bodies and the South African ferrochrome industry would improve reuse opportunities.**

The communication between ferrochrome producers and public authorities was identified as an additional barrier. Three out of four producers totally agreed that better communication would have a positive impact on proposed reuse scenarios, while one producer only agreed.

**Question 9: Do you see opportunities for 'industrial symbiosis' programmes to facilitate the handling of slag? Are you aware of any industrial symbiosis in the ferrochrome industry (successful/-unsuccessful, -or in planning)?**

One producer did not answer this question. All the other producers saw potential for industrial symbiosis to improve the successful utilisation of ferrochrome slag. Producer 1 added that industry forums already existed to change the legislation regarding the reuse of slag. Those initiatives have, however, been unsuccessful to the present day. Producer 3 had investigated the opportunities for industrial symbiosis with several road construction companies. In most of the cases, the projects were unsuccessful because of the legal requirements and the availability of natural materials without the need for permission. In addition, opportunities to use slag in cement production had been investigated but still without conclusion. Producer 4 saw strong opportunities for industrial symbiosis. In his opinion, the biggest problem was the limited ability to see the overall picture. He argued that the current relationships were not on a par with each other regarding the main goal of improving the South African gross domestic product.



**Question 10: Would a framework with the goal to support and identify reuse opportunities of ferrochrome slag be useful to the industry?**

All ferrochrome producers shared the opinion that a framework would be helpful to achieve better utilisation of ferrochrome slag. Only Producer 1 rated the existence of a framework as 'necessary' instead of 'very necessary'. The additional information regarding opportunities for industrial symbiosis highlights the lack of communication between the industry and government. Producer 1 argued that a framework would only be productive if it would be supported by the government. Producer 3 noted that the opportunities for reuse were well documented and that the problem therefore lay in the implementation. This once again emphasises the lack of governmental support. The development of reuse applications and the possibility that growing academic research would result in increased industrial applications were the opinion of Producer 4.

### **3.2.3 Analysis of results**

From the results of the questionnaires and the theory provided in Chapter 3, the opportunities for reuse scenarios are seen as very promising. Depending on different operation-specific characteristics, such as site location, production routes and raw materials used, the proposed purpose for reuse and the possible amounts of utilisation are different. All the producers and all the researchers who had investigated the suitability of ferrochrome slag for reuse reached this conclusion. In addition, all the producers experienced barriers within the waste management process, including the assessment of reuse as a by-product and environmental legislation.

### 3.3 Comparison to other industries

Despite the focus on the South African industry, the consideration of other industries can help to gain a broader perspective and therefore a better understanding of the problem. The Finnish ferrochrome industry was previously mentioned as a prime example of successful utilisation of residues from the mineral processing industry. The following section aims to compare South Africa to Finland, to find similarities and differences and identify potential opportunities to learn from the Finnish industry. The focus is on industry structure, the role of public involvement in the form of research and waste management practice.

#### 3.3.1 Industry structure

The South African ferrochrome industry is nearly ten times larger than the Finnish industry. In Finland, Outokumpu is the only ferrochrome producer. The closed production system of Outokumpu, which consists of the Kemi Mine, the ferrochrome operation in Tornio and the stainless steel plant in Ulu, result in an industry that focuses on the export of stainless steel (References).

The huge South African ferrochrome industry is mainly exporting ferrochrome (DMR, 2015). The fact that in South Africa many producers are active in the market makes the discussion of the utilisation of ferrochrome more complex. The various operations with different technologies (DC vs. AC) and with different locations lead to a more complex starting point of considerations - more complex than in Finland where the focus is on only one producer.

#### 3.3.2 Waste management practice and legislation

Regarding the literature focusing on the reuse of ferrochrome slag, numerous authors mention the advanced international practice regarding the reuse of

ferrochrome slag (Beukes *et al.*, 2010; Oelofse *et al.*, 2005). South African researchers and the survey conducted within the South African ferrochrome industry suggest that inefficient and misleading waste management practices by the government are a barrier to ferrochrome reuse. One of the reasons for this can be attributed to the fact that the recent amendments in the National Environmental Management: Waste Amendment Act 26 of 2014 include the deletion of the term ‘by-product’ (Department of Environmental Affairs, 2014).

The argument that ferrochrome slag is specified as a by-product in other countries is not 100% correct. The slag of the well-documented ferrochrome operation in Tornio, Finland, is indeed specified as a by-product but not because of the general waste management practice and policy. The status of by-product was given to the Tornio ferrochrome slag only after a site-specific evaluation of the slag (Kallio *et al.*). A look into the Finnish definition of waste and the corresponding legislation shows that Finland is also missing an efficient procedure for the assessment of by-products (Pongrácz, 2002). However, because the Tornio operation is the only ferrochrome producer in Finland, this leads to the general assumption that ferrochrome slag is a by-product. South African authors such as Oelofse *et al.* (2005) mention the problem with the correct handling of waste but are incorrect in pointing to Finland. There is no doubt about the misleading waste management practice in South Africa, but Finland also does not provide a solution to the problem (Pongrácz, 2002). The lack of clear definitions of waste and by-products is a problem that is found in both countries.

### 3.3.3 Experiences from the European steel industry

The positive development of the utilisation of steel slag in Europe can be attributed on the one hand to an increased demand for aggregates and on the other hand to declared targets of the European Community. These targets,

namely protection of the environment and human health and efficient use of natural resources, were all drivers that led to an increase in the utilisation of industrial by-products.

In Europe, approximately 12 million tons of steel slag are produced per year. The utilisation rate of steel slag is about 65%; in Germany, it is as high as 93%. This is the result of 30 years of intensive research. The investigation of slag properties was crucial for the successful utilisation of steel slag. The *Forschungsgemeinschaft Eisenhuettenschlacken e.V.* was the major investigator who studied those properties, which led to the high utilisation rate of steel slag. The environmental risks regarding the reuse of steel slag in road construction were investigated by building test roads. The positive results of those test works increased the research on achieving higher utilisation rates of steel slag (Motz and Geiseler, 2001).

According to Motz and Geiseler (2001), quality control is the basis for successful utilisation of steel slag. German slag producers exercise quality control of slag products on a regular basis to ensure the suitability of the products. The production process is certified by a third party control institute. The system of controlling the production process of slag was established by the German association for quality control of metallurgical slags-*Guetegemeinschaft Eisenhuetten e.V.*. The quality control process is revised continuously in order to adapt to the newest research in slag handling and processing.

The main aspects of the integrated factory production control system include the following (Motz and Geiseler, 2001):

- Production management
- Process control
- Inspection, calibration and testing of the equipment

- Inspection and testing of the slag products
- Handling and delivery

The goal of the third party evaluation process is to investigate all the relevant technical and environmental properties. The successful evaluation process provides the slag producer with a quality mark (Motz and Geiseler, 2001). The example of the steel industry in Europe, Germany, shows how important intensive research is to improve utilisation of by-products. Without the efforts driven by the steel producers and government, the utilisation of steel slag would have remained on a low level.

The example of the steel industry is mentioned here to show the long-term development of the utilisation of ferrochrome slag. Steel slag only became a suitable substitute for natural aggregates after investigating the technical and environmental properties. Especially the possible environmental impacts need to be studied by means of long-term fieldwork, as was done in Europe by building test roads.

The ferrochrome slag that was used in a hot-mix asphalt on the N4 in South Africa showed good properties when the slag mix was investigated. Unfortunately, the conducted test cannot be used to investigate the long-term performance (Jooste *et al.*, 1999). The public domain does not provide any documentation of the long-term performance of ferrochrome slag reuse in South Africa. Proper documentation of reuse scenarios would provide a better understanding of the long-term performance of ferrochrome slag. Those results would help to gain a better understanding of ferrochrome slag and its behaviour in reuse scenarios. In addition, the results of those studies could on the one hand, if positive, decrease the negative environmental impacts associated with ferrochrome slag and on the other hand, if negative, increase the

efforts to conduct research on slag to achieve the right slag composition for reuse.

The current trend in South Africa is to look to other ferrochrome-producing countries, especially Finland, where the utilisation is 100%.

The results of the JMA Consulting report show that no negative impacts on the environment or human health could be detected, which supports the work by other researchers reviewed in Chapter 3 of this work. It is of vital importance to mention that this report does not allow for the conclusion that ferrochrome slag is in general not hazardous. This is because the report only investigated the possible negative impacts of one ferrochrome sample. The results are therefore not useful for an argument in favour of considering ferrochrome slag as a by-product by law but show the necessity for further investigation of ferrochrome slag due to the positive results of the report.

### 3.4 Theory in context

The previous chapter addressed theoretical elements regarding the utilisation of solid residues from the mineral processing industry. The starting point was the general trend towards a more sustainable world. In this context, different approaches, models and frameworks were presented to achieve the goal of sustainable development. The theory then provided further aspects regarding the definition of waste and the management thereof, the utilisation of slag and failures that can occur by implementing innovative solutions. These aspects will be discussed in further detail with a view to the South African ferrochrome industry and the newly gained information from the industry.

### 3.4.1 Sustainability

The idea of industrial symbioses is very promising for a more efficient material utilisation and the reduction of waste streams (Mangan and Olivetti, 2008). This is not only a result from the reviewed theory and case studies but is also evident from conclusions reached from the conducted survey. It was also identified that the problem for the South African industry lay in inefficient waste management practice, which makes natural primary materials much more attractive than secondary materials from the mineral processing industry. The fact that the right actions that would result in a more efficient and sustainable application are blocked by the government due to time-consuming and confusing application procedures does not make sense regarding the national waste management strategy.

Chapter 2 provided the legislative foundation for the implementation of a more sustainable industry. The primary goal of policy makers is to protect the environment. That is indeed the right approach, but as is apparent from the conducted research and already existing reuse applications, the suitability of ferrochrome slag has been proven. The apprehension about following a more innovate route results in not achieving the goals of the waste management hierarchy in South Africa. The last option, dumping the slag on landfills, is seen as a better option than reuse.

### 3.4.2 By-product versus waste

Another important concept regarding the utilisation of ferrochrome slag is the definition of waste and by-products. The identified barrier, the way in which waste is managed, was addressed by every participant in the survey. The time-consuming application for the downstream use of ferrochrome slag would not be necessary if the slag would be considered as a by-product. The literature, which was previously mentioned in the third chapter, identified the problem with the

delisting process of hazardous slag. This research was conducted before the change in legislation in 2014. Authors such as Oelofse et al. criticise the delisting of hazardous waste, which means the change from a hazardous rating to a lower hazard or nonhazardous rating. The procedure of delisting does not exist anymore. The National Environmental Management: Waste Amendment Act 26 of 2014 does not include the term ‘delisting’. The challenging waste management process for downstream application still remains.

While the international industry and researchers recognise the need for more detailed definitions regarding waste streams and by-products, the South African industry is of the opposite opinion, resulting in deleting existing definitions. This was the case when the government decided to omit the definition of by-product in the new Waste Amendment Act of 2014 (Department of Environmental Affairs, 2014). The old definition read as follows: “by-product means a substance that is produced as part of a process that is primarily intended to produce another substance or product and that has the characteristics of an equivalent virgin product or material” (Department of Environmental Affairs, 2008).

Wierink *et al.* (2010) highlight the importance of the differentiation between waste and by-products. Pajunen *et al.* (2012), with a view to material utilisation, also mention this fact. This research was conducted to overcome barriers, leading to a better utilisation of ferrochrome slag, and not to discuss waste treatment options of ferrochrome slag. The deletion of the term by-product unfortunately resulted in the handling of ferrochrome slag as a waste, which is consequently much more difficult to reuse because of the necessary permission procedure of the DEA.

In other words, the deletion of the term by-product is contradictory to the long-term goals formulated in the Waste Act of 2008. The deletion results in



the transformation of possible by-products into waste without considering the overall environmental and economic benefits of reuse.

The definition of waste management and the waste hierarchy by the DEA in Chapter 2 states that the primary goal of waste management is not the management of handling waste and the final step of storage. The goal is rather the avoidance of waste, minimising waste streams and closing material cycles (Department of Environmental Affairs, 2011; Statistics, 1997).

Furthermore, the comparison to the Finnish industry showed that Finnish researchers tried to investigate new methods for the classification of by-products. The general opinion of Finnish industry experts is that waste management needs a more efficient assessment procedure for the classification of by-products. Only with more detailed regulations regarding whether a material is classified as a by-product or waste can the ultimate goal towards a zero-waste industry be achieved (Pajunen *et al.*, 2012).

The advantage of by-products should be emphasised, and the positive economic and environmental aspects should be considered, resulting in a more convenient way for reuse than is the case for waste. A material that has the same or even better characteristics compared to competitive natural material should not be treated as waste, even if it is not the outcome of a primary production process.

### 3.4.3 Innovation and system failures

The investigation of new opportunities for ferrochrome slag reuse is affected by system failures, which were addressed in Chapter 2 (Woolthuis, Lankhuizen and Gilsing, 2005). The first system failure that was addressed by Woolthuis occurs due to a lack of infrastructure. In this context, to address the barriers identified earlier in this chapter, the focus is on knowledge infrastructure rather

than physical infrastructure. The difference between government and producer regarding the suitability and potential risk of ferrochrome slag is a result of a gap in knowledge. Woolthuis *et al.* (2005) argue that those infrastructural failures are mostly not removed by the industry due to the large scale, resulting in high costs. The government should provide the resources to overcome this failure. Hard institutional failures were found in the environmental regulations. The survey indicated that too strict environmental standards were the main barriers to reuse. The appearance of strong network failures might also be applicable to reuse scenarios. Those failures appear due to the dominant role of one player. In our case, this dominant role could be played by the FAPA. The government is concerned about the huge amount of ferrochrome slag but sees opportunities for reuse on a small scale due to the potential negative impacts. The FAPA, which speaks for the South African ferrochrome industry, aims to reuse ferrochrome slag on industrial scale. This effort to find a solution on industry level might be a barrier for a single producer to investigate reuse on a small scale. Weak network failures were identified by the industry survey regarding the communication of industry and government. All producers that participated in the study noted that better communication would increase the opportunity for reuse.

### 3.5 Preliminary results

The previous chapters provided information that was on the one hand of a theoretical nature and on the other hand empirical data. Chapter 2 started with general considerations about sustainability and sustainable development, how the idea of sustainability affects business and political decisions. In addition, the role of waste management was discussed and the challenge of clear definitions of waste and by-product was shown. The complexity of technology was illustrated in the context of the mineral processing industry and later in

more detail in the context of the ferrochrome industry.

The idea of sustainability is integrated into the long-term strategy of the South African government. Regarding the different levels of integrated sustainability in business practice, which were provided by Medvecka and Bangerter (2007), it can be stated that levels 1 to 3 have already been implemented. This is a result of the vision of the South African government, which is stated in different documents. The problem identified lies on levels 4 and 5 where specific actions are needed to implement the existing goals. The ferrochrome industry plays an important role in the achievement of the goals of sustainable development. Both parties, the ferrochrome industry and the government, are looking forward to increased sustainable development. The difference is observable in the driver of sustainable development. The primary goal of the government is to protect the environment and society from possible negative impacts of ferrochrome slag reuse.

The ferrochrome industry, acting in a very competitive market, is driven by economic reasons. The primary driver is the utilisation of waste material and improvement of the cash flow of operations. The three elements of sustainability are economy, environment and society. The author's opinion is that the gap between these three elements is too wide. Overprotection of the environment, as in the case of ferrochrome slag, can impair the economic and social situation. In a developing country such as South Africa, it is especially important to provide a business environment that can compete in an international market. The intention to protect the environment is laudable, but greater efforts need to be made to strengthen the domestic industry and to work together on the goals of sustainable development.

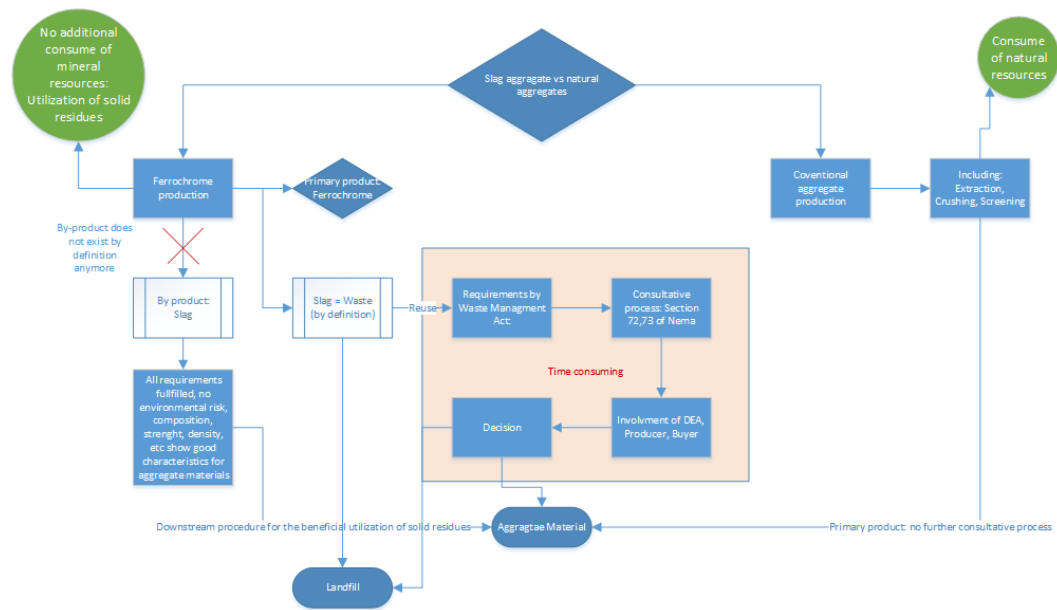
The identification of possible reuse scenarios for ferrochrome slag is an ongoing process. The gap between the government and industry can only be

narrowed by identifying and addressing the possible risk in a way that is understandable for all parties involved. The knowledge that is needed to understand the issues regarding the reuse of slag needs to be shared and if not available developed. South Africa is the largest producer of ferrochrome and ferrochrome slag. The research that identifies possible reuse scenarios is mainly provided by smaller producers such as Finland and India. As the largest producer of ferrochrome slag, South Africa is therefore responsible for playing a more dominant role in the research of ferrochrome slag.

The review of the steel industry showed that material streams could be utilised successfully without requiring the legal status of a by-product. This does not mean that the discussion of whether a material is waste or a by-product is not important. Pongrácz (2002) show conditions for whether a production residue is classified as a by-product or waste (see Chapter 3). The important idea is that ferrochrome slag can only be classified as a by-product if the use is certain, which needs to be investigated for every ferrochrome operation. Even for one operation, a regular evaluation process is necessary due to various factors during the smelting process that can influence the slag composition. The term by-product can only be used if the producer can ensure a stable quality of slag.

The work done by the FAPA therefore offers no information on whether ferrochrome slag can be considered a safe material. The investigation of ferrochrome slag that was used for a motivational letter to consider ferrochrome slag as inert waste instead of hazardous waste was only based on a single sample of one specific ferrochrome operation. In the author's opinion, the report only shows opportunities: that ferrochrome slag without any negative environmental impacts exists and that therefore future reuse scenarios on a large scale are possible. The producers want ferrochrome slag to be considered a by-product and are therefore responsible for providing the necessary information

for the assessment. Figure 3.6 shows a schematic flow diagram for reuse of ferrochrome slag competing with natural materials like crushed rocks. The figure clearly shows that the time consuming waste management process results in an economical unattractive alternative. Even if the slag-product shows high quality standards and suitability for reuse the proposed buyer cannot consider the slag material as an alternative, due to inefficient and expensive licensing procedures.



**Figure 3.6:** Ferrochrome slag aggregate vs. virgin material

The experience from the stainless steel industry in Europe showed that this barrier can be closed through internalized quality control systems. The role of the environmental authorities to interact in the market to protect the ecosystem from negative environmental effects is an result of missing trust and quality standards between producer and proposed buyer.

In author's opinion, it is only possible to overcome the identified barriers if the government, producers and proposed user of the slag work together on

solutions. The goal of the next chapter is to provide a roadmap that will hopefully motivate the industry and government to collaborate further on this important topic, to build trust between each other and create value for all parties involved.

# Chapter 4

## The Roadmap

### 4.1 Introduction to Roadmap development

Technology roadmapping originated in the 1970s when Motorola developed this approach to reinforce alignment between technology and product development. This approach depicted visually and structurally the strategy needed to achieve this improvement in alignment. Since then technology roadmapping as an approach has been widely applied by numerous organizations in different contexts at company, sector and national levels. The underlying idea of roadmap is very flexible as it can be modified to suit various need and achieve different goals (Phaal, 2015).

#### 4.1.1 Roadmaps as information organising frameworks

A roadmap graphically represents the interrelationships of various forces over time, usually aimed at platforms such as technology, markets or product development (Petrick, 2008). Petrick further describes a roadmap as a framework used to organise information and to accumulate diverse issues into a common view. Smith (2005) defines a roadmap as a tool that organisations can apply to visualise their essential assets, the linkages among these assets and the skills, technologies and competencies necessary to meet future market de-

mands. Phaal (2015) is of the opinion that there are many different approaches to roadmapping and that roadmaps can take various forms, although usually roadmaps are defined as ‘graphical representations’ that offer a ‘high- strategic view’ of the respective subjects of discussion.

The CEO of Motorola during the time when roadmapping was developed offered the following definition for a roadmap: “A ‘roadmap’ is an extended look at the future of a chosen field of inquiry composed from collective knowledge and imagination of the brightest drivers of change in that field” (Phaal, 2015). This definition highlights the necessity of knowledge and expertise when constructing a roadmap as well as the forward-looking nature of the approach and its flexibility (Phaal, 2015).

When referring to roadmaps in the context of industry or technology, the term ‘technology roadmaps’ is used. Phaal (2015) explains that many companies use a technology roadmap when focusing on topics such as technology forecasts, technology developments in key supporting industries and other industry roadmaps, and supplier information. When utilising technology roadmaps, the goal is to acquire the capabilities and timing of various competing technology solutions (Phaal, 2015).

As mentioned above, roadmaps are flexible and can be adapted to suit various contexts. Petrick notes that although roadmaps are flexible, there are some common traits to be found in roadmaps. These include breaking up complex systems into subsystems and ultimately into elements. Petrick (2008) explains that the roadmap is a representation of these elements. This then makes it more convenient to alter elements and to observe the impact that a modified element will have on the outcome on the complex system. As mentioned above, a technology roadmap is a type of roadmap that organisations



can utilise. Other types of roadmaps that can be used at various levels and in numerous different ways are listed below (Smith, 2005):

- Technology
- Services
- Market
- Knowledge asset
- Capability
- Science/research
- Project/issue
- Product/technology
- Technology opportunities
- Cross-industry
- Project/portfolio management
- Hybrid

Reasons for developing roadmaps

Drivers that are generally used for forming roadmaps include the following (Smith, 2005):

- More effective capture and use of business knowledge
- More effective product innovation
- More efficient research processes
- Technology planning

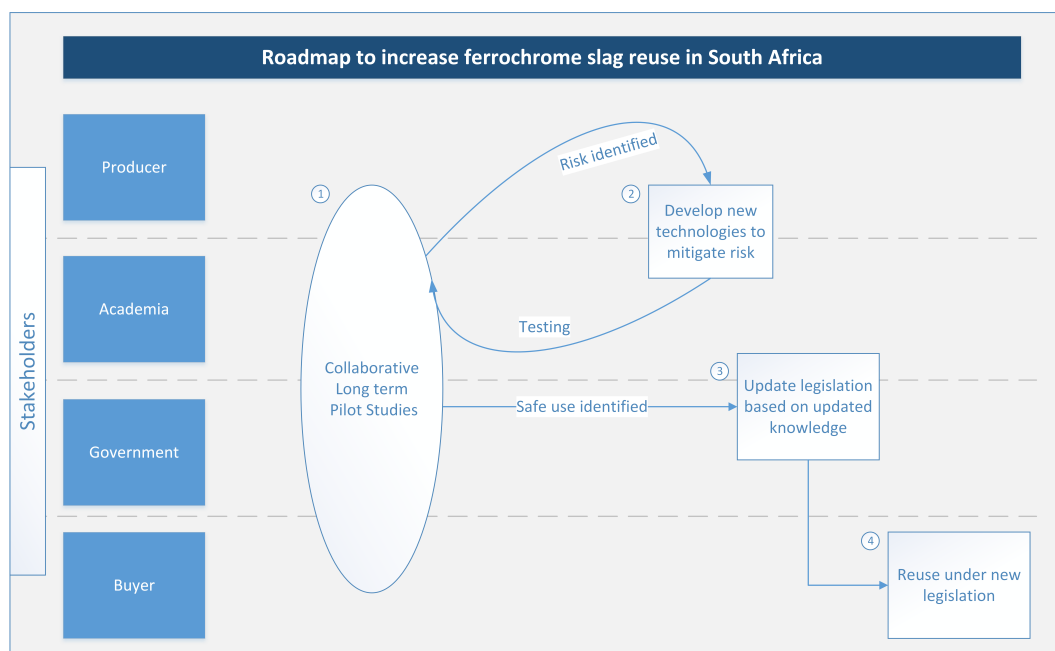
- Objectives relating to new products or services
- Assist with science and technology marketing
- Science and technology management including planning, executing, reviewing, and transitioning
- Business and value planning
- Enrichment communication among researchers, technologists, managers, users, and stakeholders
- Identification of gaps and opportunities in science and technology programmes
- Identification of obstacles to rapid and low-cost product development

According to Phaal (2015), developing a roadmap should be a team effort. Smith (2005) is of a similar opinion, arguing that the construction of a roadmap should take place in a collaborative manner as it is a collaborative effort. The best way to achieve this is through participation in workshops (Smith, 2005; Phaal, 2015).

## 4.2 The Roadmap

The development of a roadmap normally involves all the key players in the development process. The presented roadmap is a conceptualised draft that proposes an initial industry strategy from the perspective of academia. This roadmap is therefore not a finalised roadmap but a draft that needs to be refined through multiple stakeholder inputs. The preliminary roadmap presented in Figure 4.1 is divided into four steps that are briefly described below.

The major challenge in roadmap development is to address the identified problem in an easily understandable way. The content of the roadmap is reduced to the most important parts. The roadmap needs to address the right audience. Therefore, all stakeholders in the proposed reuse scenarios of ferrochrome slag are included. The roadmap presents a long-term strategy for the increased utilisation of ferrochrome slag. Time as a factor is not included in the roadmap. This is due to repeating processes in the roadmap and uncertainty about the outcome of the different subprocesses involved. Different scenarios, depending on the results of the proposed long-term pilot studies, are possible.



**Figure 4.1:** Roadmap: Utilization of ferrochrome slag

The roadmap addresses the different approaches that were mentioned in Chapter 3 of this work. These include the approach of industrial symbiosis, system failure identified and experiences from the steel industry in Europe.

The roadmap is described in more detail in the following chapter. In addition, the development process is argued to provide a reasonable outcome.

The initial step in the creation of the roadmap constitutes the setting up of long-term pilot studies. The current legislation in South Africa indeed provides opportunities for reuse of ferrochrome slag in a controlled environment, but the approved reuse scenarios are not accompanied by research to improve knowledge about future scenarios. The aim of the pilot studies is to involve all stakeholders, including academia, to shape the future of reuse of ferrochrome slag in South Africa.

### 4.2.1 Stage 1: Long-term pilot studies

The main goal of this stage is to perform various controlled long-term case studies to investigate the long-term performance of ferrochrome slag under different conditions. The participating producer would have to implement a material and process control system to regulate the ferrochrome output achieved. This control system must be certified to meet specified standards required by the government and the potential buyer of the product. The role of the government would be to provide authorisation for the small-scale direct streams of reuse between the participants in the case studies and to support and regulate the risk management of the players involved (Van Eijk and Brouwers, 2002).

The concept of industrial symbiosis can be adapted to develop long-term pilot studies. The advantage of an industrial symbiosis is the close cooperation between producer and buyer. The framework of the industrial symbiosis is to identify waste streams from the ferrochrome producer that can be used as raw materials for a potential buyer. The starting point of the industrial symbiosis is to identify those material streams and to specify the desired quality and amounts. This is primarily in the interest of the producer and the

potential buyer - to save natural materials, reduce waste streams and increase the efficiency of the production process.

In addition, regarding the roadmap, an industrial symbiosis would also give the government the desired information about material characteristics and amounts to keep the reuse scenarios in a controlled environment. The exchange of materials should be limited to an agreed amount, which would make it possible to monitor the field performance of reused material.

The potential roles of stakeholders are briefly discussed below. The author is of the opinion that the approach of producer responsibility is correct. The discussion about responsibility is critical, especially regarding reuse, in which the responsibility, due to the transference thereof to a new owner, changes. The ferrochrome industry is convinced that ferrochrome slag is a suitable by-product that could save natural materials under specific circumstances. The author agrees so far but is also aware that the possible negative effects of reuse are not in the range of influence after the responsibility and the possible risk have been transferred to a new owner. In other words, producers should extend their responsibility with a view to the proposed case studies. That does not mean that the producer is solely liable for the potential risk. All other stakeholders should have the same long-term goal of sustainable development and should be willing to accept the potential risk. The producer as generator of the waste stream is, however, responsible for minimising the potential risk inside his/her range of influence. Determining how risk management can be achieved and implemented (as has been done already in the earlier mentioned ferrochrome operation in Tornio, Finland) is the main responsibility of the producer.

The direct influence of the producer ends when ferrochrome slag leaves the operation. Therefore, internal material control streams are available during

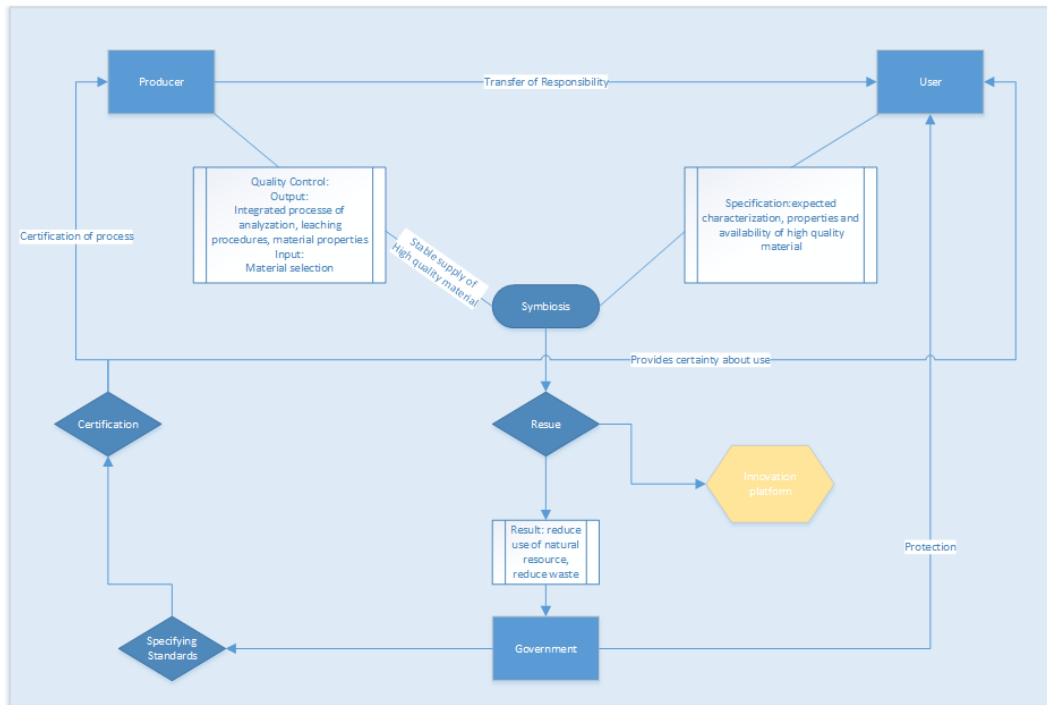
the production process. This control system ensures that a specific quality is achieved.

The role of the buyer is to provide information about the desired material and the performance of reuse. The experiences from other industries can help to identify suitable application for ferrochrome slag. Communication between the producer and the buyer is crucial to improve the performance of reused slag material.

The current state of legislation causes uncertainty for potential buyers. Why should a potential buyer choose the complicated way of reuse if cheap natural material is available? The low cost of ferrochrome slag or even the responsibility to save natural material could be a driver for reuse. The buyer desires high-quality material without any potential risk to the environment. Coverage of potential risk and material requirements is important to the buyer. This can be achieved by certification of material. A certificate ensures that a material complies with specific requirements. The certification process is normally carried out by an independent third party. Companies that offer certification of specific materials are available in South Africa (SGS South Africa, 2016).

Figure 4.2 illustrates the concept of industrial symbiosis to implement long-term pilot studies. The main responsibility lies hereby on the producer. The implementation of internal quality systems is the foundation for success. The governments role is to specify standards to provide certainty in the process of certification.

The idea is to select a producer with characteristics suitable for proposed reuse scenarios. The selected operation should operate on a modern level and must be able to form an industrial symbiosis. The interviews with producers in the ferrochrome industry and the experience with reuse showed that the



**Figure 4.2:** Roles and responsibilities in industrial symbioses

reuse of ferrochrome slag was most promising for construction purposes (see Appendix B.1). However, the proposed industrial symbiosis is not limited to this purpose; other downstream applications should also be considered.

The success of the ferrochrome operation in Tornio, where slag is considered a by-product, is a result of strict quality control and operations management. Those two elements are seen as crucial for the implementation of an industrial symbiosis in South Africa. Strict quality control and operations management are on the one hand needed to ensure a constant output of high-quality material to the potential symbiotic partner and on the other hand to provide a constant base for research that will be the source of information for the potential innovation platform.

### 4.2.2 Stage 2: Technology development

The goal of the technology development step will be to develop technologies that can mitigate the risks identified during the case studies. The reported data and experiences of the case studies could be collected into a central database. This database will help to identify potential risks and further opportunities to investigate. The goal is to provide a starting point for future research that can shape the future of ferrochrome slag utilisation. The FAPA could act as the leading institution to organise a transparent and efficient data collection process.

Chapter 3 of this work showed different results of research in which opportunities for reuse were identified. Promising applications in civil engineering and cement production are only two examples. The main concern of possible leaching of harmful elements from the slag into the environment is addressed in a variety of papers (Lind *et al.*, 2000; Panda *et al.*, 2012; Hattingh and Friend, 2003; Ma and Garbers-Craig, 2006). Regarding the important role of South Africa in the production of ferrochrome, it is interesting that the available research has mainly been conducted abroad. Herein lies a general problem that needs to be addressed.

The future of a competitive and more sustainable industry is strongly connected to innovation. Those innovations that can strengthen the domestic ferrochrome industry are only achievable through intense research. The outcome of the long-term pilot study that was discussed earlier is dependent on research. Research within the steel industry in Europe, mentioned earlier, already showed the strong influence of research. The current situation of LD (Linz-Donawitz<sup>1</sup>) slag can provide a better understanding of how versatile the reuse of slag material can be.

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<sup>1</sup>A process for making steel from cast iron



The results of research are crucial to the development of standards for ferrochrome slag material. With a view to the application in road construction, the South African National Roads Agency plays an important role in adopting new knowledge about ferrochrome slag in its material specifications. Chapter 4 of the South African Pavement Engineering Manual provides standards for material used, both natural materials and secondary materials. Unfortunately, no specific standard could be found for ferrochrome slag. Chapter 8 of this document defines alternative material sources for road construction. Ferrochrome slag is only mentioned here in one small paragraph with the statement that the use of ferrochrome slag is uncertain. The document that should provide guidelines for road construction in South Africa is basically adopted from England. Comparing South Africa to England, a country that has a significantly smaller ferrochrome production industry than South Africa, results in English standards that do not consider ferrochrome slag as a material source.

The same applies to the South African Bureau of Standards. The standards are mainly adopted from the ISO or from European norms. This results in the nonexistence of specific up-to-date standards for ferrochrome slag, especially in a form that is needed in South Africa. The major ferrochrome producer is South Africa and not Europe. The European industry will therefore not invest money in research projects for the investigation and development of ferrochrome reuse. The development of those standards is the responsibility of South Africa.

This problem should be addressed in this stage of the roadmap. Technology development is a time-consuming and expensive process. Therefore, the stakeholders' goals n.

### 4.2.3 Stage 3: Legislation update

Depending on the results of the long-term pilot studies, possible risks could be mitigated, resulting in safe reuse opportunities. To promote the safe reuse of ferrochrome slag, the government can adopt the new knowledge to update the current legislation to be less cumbersome. This updating process could be gradual, depending on the safe uses identified. The proposed outcome is not directly the general classification of ferrochrome slag as by-product but the support of reuse for safe usage through a simplified evaluation process.

### 4.2.4 Stage 4: By-product assessment

New experiences with ferrochrome slag and the documentation and evaluation thereof will lead to increased trustworthiness of the reuse of ferrochrome slag. The long-term goal is to minimise the potential risk and to consider ferrochrome slag as a secondary product of the production process. With increased knowledge development, time-consuming waste management licensing could become redundant, which would turn ferrochrome slag into an attractive alternative material for natural aggregates. The long-term outcome would be a more sustainable and competitive industry.

The proposed by-product assessment describes an optimum outcome. The current situation is far from this point. At the moment, the ferrochrome producers try to convince the environmental authorities to consider ferrochrome slag as a suitable material for reuse, which has been unsuccessful over many years. The roadmap shows, and it is the author's opinion, that only intensive research will perhaps over many years result in legislation that will be more supportive for reuse of ferrochrome slag. As mentioned earlier, however,

that does not mean that without a change in legislation increased reuse is not possible.

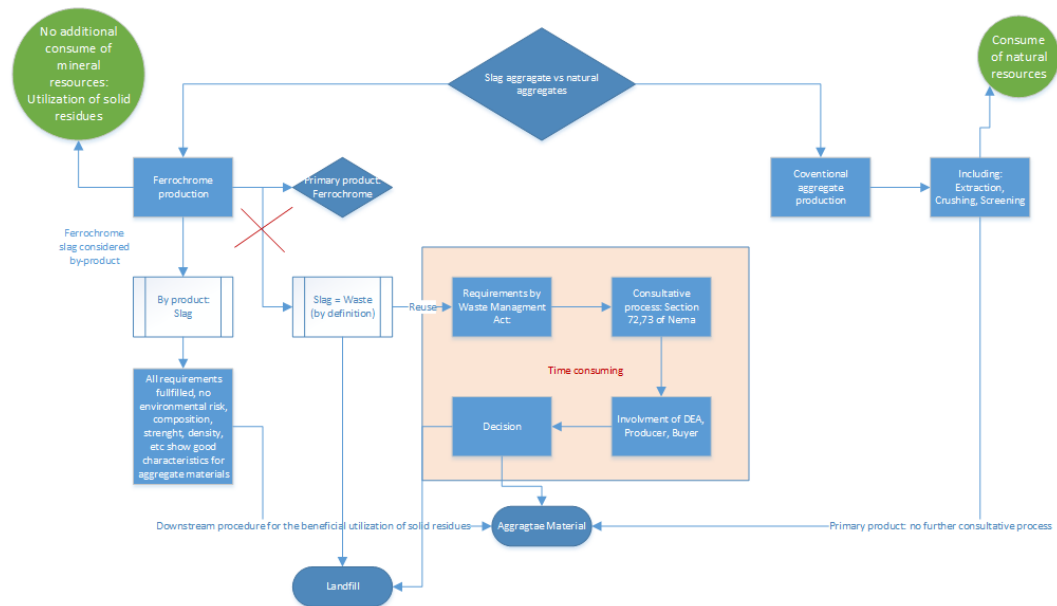


Figure 4.3: By-product assessment

The author is convinced that the development and implementation of quality and material handling systems, which are specified for the reuse of ferrochrome slag can create new opportunities for reuse. The existence of such instruments would make the decision making process, if a material is suitable for reuse or not, much easier. Figure 4.3 shows the scenario in which the time-consuming waste management licencing process is replaced through a permanent quality assessment of ferrochrome slag. In this case, ferrochrome slag could compete with natural material, which would increase the utilization of slag and result in decreased need of natural raw materials.

### 4.3 Limitations of the roadmap

The success of the proposed roadmap is dependent on the role and responsibility of the stakeholders. The author already mentioned that in his opinion the producer should be the initial stakeholder. The producer's responsibility is to provide the right starting point for future investigation. Another critical factor is the communication among the stakeholders. On the one hand, the roadmap aims to simplify the current waste management process, but on the other hand, the roadmap suggests more documentation and monitoring of reuse scenarios. That is somewhat contradictory. What is important, though, is the effort that results.

### 4.4 Support through innovation platforms

The successful implementation of the roadmap and the resulting increase in the utilisation of ferrochrome slag are strongly dependent on communication among the stakeholders. The lack of communication was identified in the industry survey described in Chapter 3. All four producers of ferrochrome slag indicated that better communication with stakeholders, especially the government, would improve the implementation of proposed reuse scenarios. One approach to overcoming this lack of communication, especially with the goal of an innovative way to handle ferrochrome slag, is innovation platforms. These platforms can help to identify common interests, barriers and opportunities and are seen as an important input to support the proposed framework. The following section aims to present the idea of innovation platforms and their strong and weak points.

Homann-Kee Tui *et al.* (2013) describe the general structure of innovation platforms. This structure can be adopted for the implementation of the proposed roadmap. The first step is the initiation, in which the focus and stake-

holders are identified. The roadmap already addressed all the stakeholders involved, but the current practice shows that the communication between producer and government is weak and that academia and buyers are basically excluded. Therefore, the initiation step brings all stakeholders together and discusses the focus of the proposed collaboration, in our case the implementation of long-term pilot studies (Van Rooyen *et al.*, 2013).

The second step of the structure focuses on the identification of bottlenecks, barriers and opportunities. This step defines the focus of the innovation platform. With reference to the roadmap, this step should identify the common goals of reuse and address the concerns and goals of all stakeholders involved (Victor *et al.*, 2013). The third step aims to identify the options to overcome the identified problems (Lema and Schut, 2013; Birachi *et al.*, 2013).

The goal of the fourth step is to test and refine the solutions and apply them to fieldwork. The solution can be a new technology, new policy or new way of reuse. Part of this step is the monitoring of those solutions to track the success back to the decisions made (Lema and Schut, 2013; Lundy *et al.*, 2013).

After the successful implementation of the solutions, capacities need to be developed to make sure that the necessary resources are available to achieve the formulated goals. This may involve training of people and implementing of material control systems or new technologies (Boogaard *et al.*, 2013).

The sixth step focuses on the implementation and upscaling of the innovation. If the proposed long-term pilot studies are successful, the concept can be adapted to more ferrochrome producers by sharing the experiences (Tucker *et al.*, 2013; Victor *et al.*, 2013).

The last step investigates the success of the innovation platform. Feedback about the decisions that lead to success is important for future challenges. Suc-

cessful aspects can play a stronger part in future decisions while unnecessary steps are omitted .

#### 4.4.1 Benefits of innovation platforms

The most important benefit of innovation platforms is the dialogue among the stakeholders. This dialogue can identify common goals and especially generate trust among the stakeholders. In addition, the group of stakeholders can develop solutions that are not possible to achieve by a single player. Institutional change and policy development are in particular much more efficient if all stakeholders are involved in the development process. The role of weaker stakeholders is also strengthened and considered. The dialogue thus leads to better decisions due to more information available. Cooperation and joint learning will reduce the uncertainties of the stakeholders involved. Innovation platforms promote research in which the platform stakeholders are involved. This will lead to stakeholders being more likely to be convinced by the outcomes Cullen *et al.* (2013); Victor *et al.* (2013).

#### 4.4.2 Disadvantages of innovation platforms

Besides the benefits of innovation platforms, constraints also occur. Innovation platforms can lead to unexpected outcomes. Of importance is the cooperation of the team members. A constructive outcome can only be achieved if members are willing to trust each other. Institutional conflicts and lack of political will are often barriers to a successful innovation platform. In addition, innovation platforms can become very time and resource consuming. Despite this, the costs should be seen as an investment to achieve common goals. The long-term thinking of stakeholders is crucial to success. The development of relationships takes time and requires system thinking. The stakeholders need to look beyond their own interests and must be willing to achieve higher goals. The motivation

of stakeholders is equally important. If tangible outputs are not available, stakeholders might lose interest in participating Homann-Kee Tui *et al.* (2013).

### 4.4.3 Roadmap in in the context of the innovation platform

The previous chapter provided a short introduction to roadmap development and showed how important the involvement of all stakeholders in the development process is. This chapter presented a proposed roadmap to increase the utilisation of ferrochrome slag and introduced the approach of innovation platforms. The last section will now show how an innovation platform can achieve what the author proposed: the development of a roadmap by the stakeholders identified.

We can skip the first step because the stakeholders have already been identified. Of significance is the question of common goals. The theoretical background chapter (Chapter 2) reviewed the increasing importance of sustainability and the opportunities regarding the utilisation of ferrochrome slag. The concept of industrial symbiosis was also considered to unlock unused potential benefits. If we consider those aspects, the utilisation of ferrochrome slag will result in decreased waste streams and decreased extraction of natural materials. The reduced extraction of natural resources will lead to energy savings and decreased emission. The concept of industrial symbiosis also showed how utilisation of waste streams could affect the economic performance of stakeholders positively.

In sum, the utilisation of ferrochrome slag will result in environmental, economic and therefore social benefits. The problem is that the idea of industrial symbioses requires system thinking. The positive effects for single stakeholders may not be enough motivation to participate in an innovation platform. The

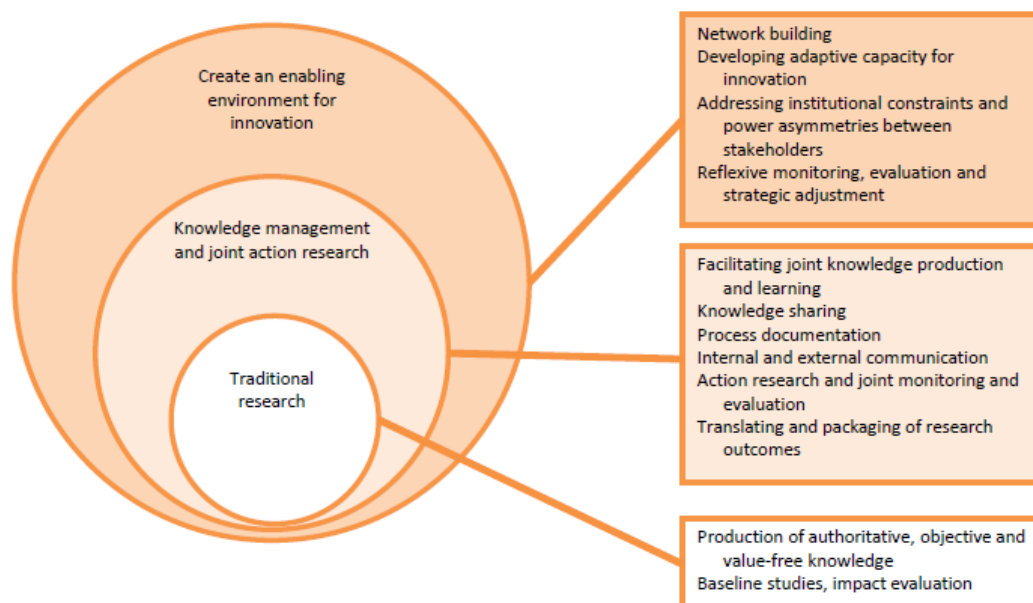
industry perspective showed that the main driver for reuse was the increasing problem of storage of slag. The industry does not consider that benefits have already been achieved if only a small amount of slag is reused. The government, in contrast, follows a strict approach to protecting the environment. This is the right approach, but are the benefits addressed in the right way? The concerns about the long-term performance of slag are justified, but the benefits are not considered. The question is how the environmental performance of the system is affected. The conservative approach used by the leaching test, which assumes that the total content of Cr(VI) is released into the environment, is not realistic. The possible leaching of Cr(VI) into a controlled environment may result in a better environmental performance due to the reduced negative environmental impact of natural raw material extraction. These aspects can only be addressed by evaluation of the whole ecosystem, which requires the involvement of all stakeholders. Only the communication among stakeholders allows making decisions regarding the best positive outcome for the ecosystem. The discussion of those questions is addressed in the second step of the described innovation platforms.

The third step directly targets the identified problems. Chapter 4 presented the barriers regarding reuse of ferrochrome slag. A strong point was seen in the assessment of ferrochrome slag as a secondary material. The opinions about suitability differ too widely to come to a conclusion. In addition, the environmental standards were rated as the greatest barrier of all. It is not important whether the standards are too strict or not. In this approach, the focus is on the making of policy. A policy created without experts of the field concerned will never result in an efficient and supporting policy. The goal of policymaking is to create an environment of regulations that supports society. Society is in this case all stakeholders that are affected by the policy. The development of a supportive and constructive policy is only possible if compromises can



be found. In most of the cases, it is not possible to satisfy all stakeholders. That is why the previous step aimed to identify focus points Cadilhon *et al.* (2013). Innovation platforms can facilitate interactions among all stakeholders, which can result in more effective policy development, implementation and monitoring.

The development of standards for ferrochrome slag material can be a result of national policy. Those standards can define quality and allay the uncertainties of stakeholders. Therefore, the roadmap was developed to involve all stakeholders by finding a way to maximise the value generated by the industry. The roadmap could be the outcome of an innovation platform that shows the way in which the stakeholders want to overcome the identified barriers.



**Figure 4.4:** Types of research (reproduced from Lema and Schut (2013))

The importance of research to identify and overcome barriers was already mentioned with a view to the stainless steel industry in Europe. Lema and

Schut (2013) describe three ways in which research can contribute to innovation platforms. Figure 4.4 shows the three types of research.

Traditional research aims to produce authoritative knowledge. The potential user of the knowledge has to make use of the knowledge on his/her own. In knowledge management and joint action research, the outcome is in general easier to access and understand. That might include the research done by the FAPA FAPA (2013). This kind of research resulted in non acceptance by the other proposed stakeholder of the framework. The second type of research involves all stakeholders to share knowledge and information and bring up solutions together. This kind of research will make possible results more acceptable Lema and Schut (2013). The final goal is it to enable an supportive environment for innovation. The author is of the opinion that the ferrochrome producer and all other stakeholders would come up with innovative solutions if the initial barrier of missing communication and trust is overcome.

# Chapter 5

## Validation of the roadmap

### 5.1 Introduction

The validity of a research outcome is described as one of the most important criteria by Bryman *et al.* (2014). The validation shows that results are replicable and understandable. Validation can be achieved in different ways. The literature mainly differs in internal, external and ecological validation. The internal validation process is of a causal nature. The question that needs to be answered is whether the right conclusion, through analysing the available data, is drawn. External validity focuses on the possibility of transferring the achieved outcomes to other research fields that are not in the context of the research conducted. Whether or not findings are applicable to real-life situations is addressed by ecological validity.

### 5.2 Purpose of validation

In this study, the purpose of validation was to demonstrate that the proposed roadmap addressed the right way to overcome the identified barriers. Due to the nature of the roadmap, the validation process addressed all stakeholders. The stakeholders, who had different goals and opinions regarding proposed

reuse scenarios, were invited to give feedback. This feedback allowed for the identification of the strengths of the roadmap as well as the identification of the limitations of the roadmap. In addition, the validation considered structural aspects too, which could help to draw a conclusion about the easiness of understanding the roadmap. Chapter 5 showed

### 5.3 Material and procedure

The validation of the roadmap was achieved by making use of questionnaires. The reason for selecting questionnaires to obtain the necessary feedback for validation was the easiness and time-saving nature of questionnaires.

The participants in the validation process were selected from the industry, government and academic institutions. Because the knowledge of the participants, depending on their professional experience, could differ, a short introduction to the research was provided.

The Figure 5.1 shows the validation process. In the beginning, a short introduction with the goal of providing an overview of the work conducted and the barriers identified (as described in Chapter 3 of this work) was provided. The developed roadmap was then presented and shortly described to ensure that the context of the roadmap was addressed in the right way. An opportunity for queries was offered to minimise the risk of misunderstanding.

In addition, Figure 5.1 indicates which parts were provided in the validation document, provided in Appendix C of this work. The feedback consisting of five questions was then evaluated and used to improve the roadmap. The subsequent paragraphs will present the results of the validation process, including the updated roadmap.

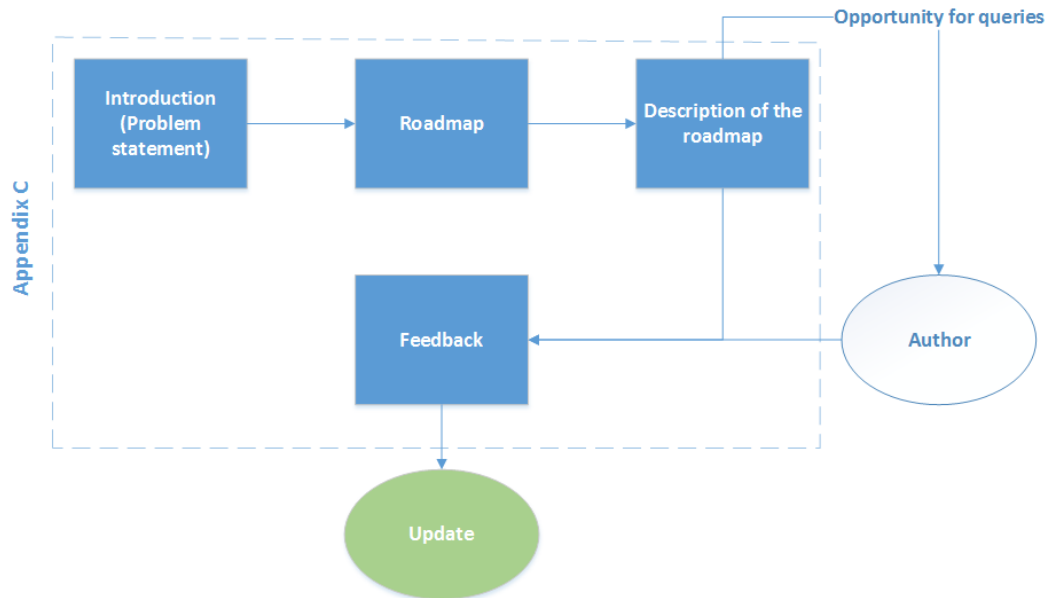


Figure 5.1: Roadmap: Validation process.

## 5.4 Results

The feedback from the validation survey was mainly positive. The producers stated that the roadmap was based on an innovative concept but criticised the need for long-term studies on the impact of ferrochrome slag. In the producers' opinion, those impacts had already been assessed and understood. The roadmap identified opportunities for determining how the lack of knowledge between producer and government could be eliminated. This lack of knowledge was from the producers' point of view the actual barrier to reuse. The issue was seen as that the government did not understand that the long-term impact assessment had been done already. The producers suggested focusing more on short-term solutions to address this issue, driven by massive problems regarding the storage of ferrochrome slag. That led to the conclusion that the proposed roadmap could help to overcome the identified problems but would only add value for the industry by providing quick solutions.

The participant from the government highlighted the fact that all stakeholders were addressed in the right places, leading to a roadmap that held potential to increase the utilisation of ferrochrome slag. The weak points of the roadmap were seen in the missing postdecision monitoring and evaluation. The government participants were of the opinion that the inclusion of those aspects would result in a perfect framework. In addition, a forum comprised of all the identified stakeholders could be established to focus on resolving the issue.

The participant from academia praised the identification and working together of the role players. Academia saw the identified problem as a multistakeholder problem and therefore as a multistakeholder opportunity. The weak points of the roadmap were seen as the missing support of statements with references in the public domain. The structural aspects and how the roadmap aligns with best practice are shown in Figure 5.2.

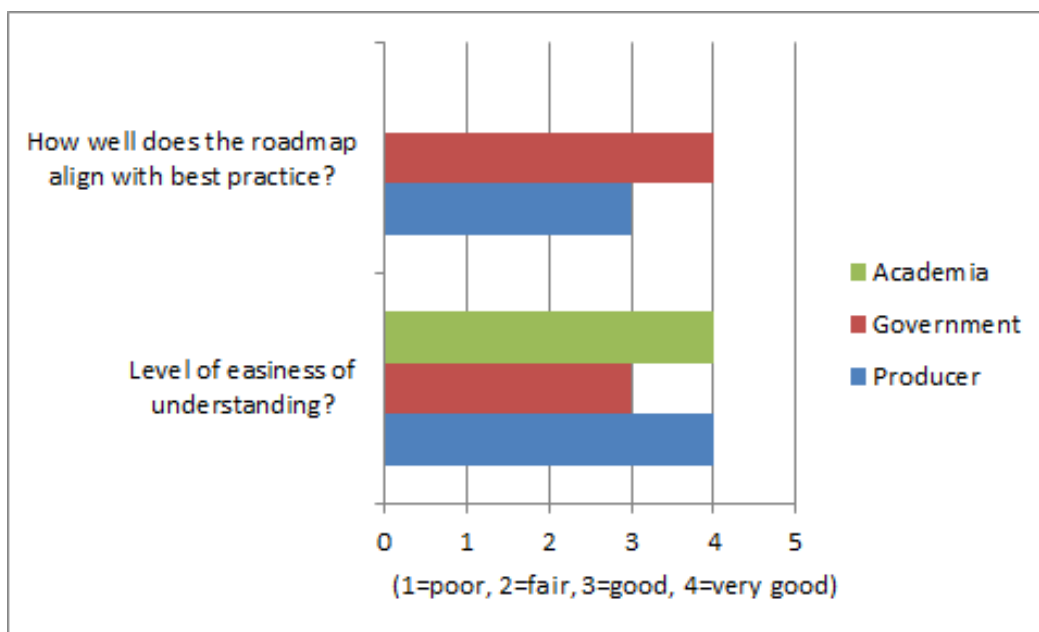


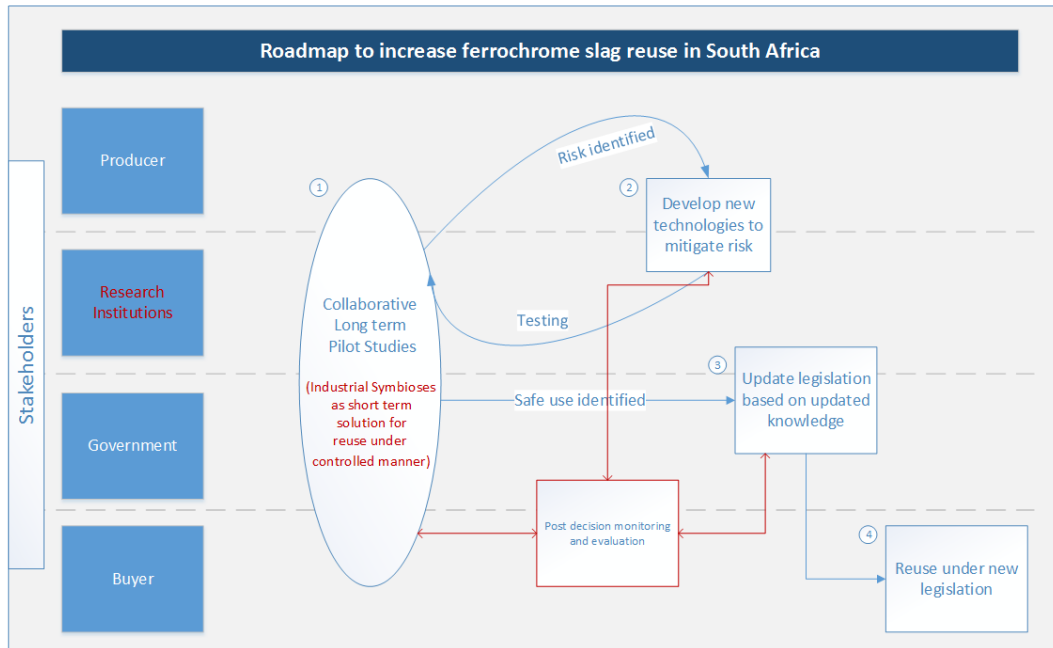
Figure 5.2: Validation roadmap: Structural aspects.

All stakeholders involved in the validation process rated the easiness of understanding the roadmap as 'good' or 'very good'. The simple structure and clear presentation of the roadmap successfully presented a potential solution. The producers answered the question „How well does the roadmap align with best practice? “with 'good'. This resulted in the conclusion that the proposed roadmap showed a realistic approach to overcoming barriers. The participant from the government could not provide a statement regarding the best practice about technologies or activities of use of slag. From a strategy point of view, the roadmap was seen by the government as best practice as it is most favoured regarding the involvement of all stakeholders and will provide consensus. The participant from academia did not respond to these specific questions. An additional point for improvement by the academia was to rename 'academia' to 'research institutions' to include both academics at universities and researchers at research councils. The results from the validation led to the update of the roadmap, which is presented in the following section.

## 5.5 Roadmap improvements

The results obtained led to the update of the roadmap. The difficulty was to satisfy all participants. The proposed short-term focus by the industry was considered in highlighting the time frame in the roadmap. In addition, a more detailed argumentation of industrial symbiosis was added to the long-term pilot study to show that industrial symbiosis focused on short-term outcomes of reuse under a controlled environment. Industrial reuse on industrial scale is not possible in the short term and can therefore not be part of the roadmap. The government's need for postdecision monitoring and evaluation was added as an additional step of the framework. The role of innovation platforms, which was discussed in Chapter 4 and denoted by the government participant as 'forums', was also included in the roadmap. Figure 5.3 shows the updated

roadmap.



**Figure 5.3:** Updated roadmap.

The red parts highlight the changes made based on the validation. The proposed short-term focus can only be addressed by the implementation of industrial symbioses. That step is not able to solve the industry's problem, but it provides an opportunity to start on a small scale. Future research and especially the efforts of the industry and stakeholders will be the key to increased reuse on industrial scale.

## 5.6 Conclusion

The validation showed that the roadmap addressed the pertinent issues regarding the goal to increase the utilisation of ferrochrome slag in South Africa. The involvement of all stakeholders was the key element that was seen as the right approach. Only the time frame for finding a solution to the problem was seen



as an issue. The supporting innovation platforms discussed in Chapter 4 were not mentioned in the roadmap presentation but were addressed by the participant from the government. This shows that the establishment of this platform could be a valuable starting point to improve the opportunities for ferrochrome slag reuse. In addition, the required short-term focus by the industry and the mentioned long-term impact of ferrochrome slag, which has already been addressed by the industry, can be discussed and evaluated using an innovation platform as medium for communication. The roadmap is limited in the sense that the potential buyers did not respond to the validation survey. Only if all stakeholders participate in the development of solutions as indicated in the roadmap can the problems be solved.

# Chapter 6

## Conclusion and Recommendation

### 6.1 Overview

The research conducted resulted in the development of a roadmap to increase the potential reuse of ferrochrome slag. This was done after evaluating existing literature regarding the beneficial use of ferrochrome slag, discussing opportunities for sustainable development and gathering data from the South African ferrochrome industry. In addition, the DEA provided valuable input to shape the future of the reuse of ferrochrome slag.

The findings and the advanced material handling in Finland at the Tornio Works influenced the roadmap development. In addition, the review of the steel industry in Europe provided valuable input about how waste material could be utilised.

### 6.2 Summary of findings

The main problem regarding the reuse of ferrochrome slag remains waste management practice. This problem was already addressed by other authors years before. The ferrochrome industry, acting as FAPA, tried to delist ferrochrome

slag from a hazardous waste to a nonhazardous waste. Those incentives were discussed earlier and it was shown that the rating of hazardous or not of a material is not definitive for proposed reuse scenarios. All the efforts to show the negative aspects regarding the potential leaching of Cr(VI) were necessary but did not result in the consideration of ferrochrome slag as a valuable resource. This is due to the variability in production.

Chapter 2 briefly reviewed the different production routes for ferrochrome slag that are currently used. The investigation of one slag sample does not consider this variety. In addition, the composition of slag can differ in the same smelter through the input of different reducing agents or fluxes. These facts and the short review of the stainless steel industry in Europe show that the only way to overcome uncertainties about the suitability of slag is strict operation and quality control. In addition, the classification of material streams as by-products is not necessary for downstream application. This was also shown by the steel industry, with many European countries still considering slag as a waste. The important point is to reduce the environmental uncertainties to a minimum.

The industry survey, constituting four ferrochrome producers of the South African ferrochrome industry, identified barriers and opportunities. The most promising reuse scenarios were seen in road construction. The opportunities for industrial symbioses were also addressed and discussed. The industry stated that opportunities for industrial symbioses existed and were currently being evaluated. In this context, the lack of understanding of how industrial symbioses can create value was highlighted.

The main barriers to successful reuse of ferrochrome slag lie in the current waste management licensing that is necessary for downstream applications. As mentioned earlier, the general discussion of whether a material is a by-product

or waste should not be the focus of investigations. The important aspect is how potential buyers are affected by the licensing process. Chapter 4 mentioned the potential buyer's point of view from an economic standpoint. The markets for ferrochrome slag and natural materials are in the first place driven by profitability. The markets do not consider the real costs and benefits. This results in ferrochrome slag materials and natural aggregates competing without considering benefits for the ecosystem. This has led to the assumption that ferrochrome slag material can only be a successful replacement for natural aggregates if the competitiveness of slag is increased. Subsequently, this resulted in a short discussion about responsibilities. In the author's opinion, it is the responsibility of the ferrochrome producer to provide a first-class material. This follows the approach of producer responsibility. The producer of ferrochrome slag is in charge of providing the necessary information for reuse. This information includes physical and chemical tests and, from the environmental point of view, studies about possible leaching of harmful elements. This can be done by material and operational control systems, as is the case at the ferrochrome operation in Tornio, Finland. The result would be an internalised assessment of ferrochrome slag without the involvement of environmental authorities and potential buyers. The need of the government to have control over reuse scenarios in order to protect the environment and humans from potential harmful materials can be fulfilled by standardisation and certification. The change to the current practice would be that the government would only be active in the formulation of standards for material specification. The costly and time-consuming licensing process would not be necessary anymore. Ferrochrome slag could compete with natural materials. Potential buyers would be more willing to use ferrochrome slag as a raw material.

The goal to achieve this outcome resulted in the development of a roadmap, presented in Chapter 5. The key point was working together to overcome the

identified problems. The stakeholders were addressed and motivated to work together on solutions. The idea of industrial symbioses was discussed to show opportunities to apply reuse on a small scale in a controlled manner. That would satisfy the needs of legal authorities and would be a step forward for the industry. Supported by research and input from all stakeholders, the concept of the long-term pilot study could be extended, resulting in value adding for all stakeholders on an industrial scale. The input of academia could fill the gap of missing knowledge and unlock new technologies for reuse. The final goal of by-product assessment could then be achieved.

The author has stated that the practice of ferrochrome handling in other countries is not applicable to South Africa. South Africa is the leading ferrochrome producer globally, which results in a huge generation of ferrochrome slag. The resulting opportunity for reuse is therefore high, but the possible negative environmental impact is also strong.

### 6.3 Limitations of the study

The study was conducted by combining different academic fields. Sustainability, mineral processing and waste management were the main fields that were reviewed to address the problem statement. Due to the broad perspective of the study, it was only possible to give an overview of specific factors that influenced the reuse of ferrochrome slag. The suitability of ferrochrome slag as a construction material was not primarily investigated. The author's opinion that ferrochrome slag is a suitable material for reuse is based on work conducted by other researchers all over the world. The literature on the investigation of reuse opportunities of ferrochrome slag specifically in South Africa is limited. The industry survey that was conducted only gave a broad overview of how operational managers of ferrochrome plants saw the future of reuse.

The fact that only four producers participated limits the study and it thus cannot be seen as representative of the whole industry.

The proposed roadmap, as already addressed earlier, only provides an idea of how to overcome the identified problems. Therefore, the future of the utilisation of ferrochrome slag is dependent on the stakeholder, especially the producer, to provide a basis for communication to provide the right environment to adopt the ideas presented in this work. In addition, this study did not consider the potential buyer's point of view. Future investigations and efforts should definitely include all stakeholders to maximise their success.

## 6.4 Recommendation and Future Research

The proposed solutions of the identified barriers are not strong enough to have a direct impact on the current practice of the industry on their own. The development of a roadmap normally takes place in a context where there is participation of the stakeholders. The development is therefore an outcome of the group work of the stakeholders involved in proposed reuse scenarios. Unfortunately, this working together, which depends on open and intense communication, is not available yet. Greater efforts are needed to increase the motivation of the stakeholders to collaborate in this field. This was also addressed by the introduction to innovation platforms. The most important question is how we can bring the stakeholders together to work on solutions that will result in benefits for the ecosystem, including increasing their own performance.

Life cycle cost analysis can play an important role in motivating stakeholders to collaborate. The current view of stakeholders is mainly limited to their own interests, which results in benefits from the broader perspective not being considered. The life cycle cost analysis should include the environmental

aspects. The opportunity to reuse ferrochrome slag might in some cases be unattractive for a producer due to high costs but could add value for a potential buyer, especially from an eco-perspective point of view. If it is possible to identify the benefits, it might be possible to allocate the costs, resulting in greater motivation to participate in a reuse scenario.

Another opportunity to support the beneficiation of ferrochrome slag is to refine the earlier mentioned innovation platforms, that is, how they can be structured and set up. The identified problem of verifying opinions about possible leaching of Cr(VI) and the resulting negative environmental impact can be overcome by sharing information and working together on research projects.

In addition, the responsibilities and roles of stakeholders need to be addressed in a more detailed way. Thus far, the focus of the industry has primarily been on the classification of waste, especially with regard to the hazardous rating of ferrochrome slag. The industry wants ferrochrome slag considered as a secondary product instead of waste. The still-remaining classification of ferrochrome slag as waste makes a downstream evaluation process necessary to show suitability for reuse. The involvement of potential buyers was addressed in this study as a barrier to reuse. Where does the responsibility for potential buyers start? In this work, the author has stated that the responsibility lies on the producer's side. The producer needs to provide a ferrochrome slag material that suits the market conditions and is therefore responsible for physical and chemical characterisation, which includes testing of possible leaching of harmful elements. However, this is only the author's opinion; the industry disagrees, and more research is needed to address this issue.

The role of the government in this study was limited to the waste management process by the DEA. The evaluation of a fiscal instrument was not part of

this study. The intervention of governments with taxes on virgin material and the effects of higher prices for landfill could motivate the industry to increase its efforts to collaborate with other industries to reduce waste streams. These steps might be successful for one industry but can also result in too much pressure and competitive disadvantage. Therefore, the implementation of possible interventions by the government needs to be evaluated and investigated further.



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# Appendices

# Appendix A

## PAIA

### A.1 Licence



## environmental affairs

Department:  
Environmental Affairs  
REPUBLIC OF SOUTH AFRICA

H:H Licence: Xstrata Alloy Lion Ferrochrome Smelter- Slimes dam, Slag dump & Salvage Yard

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### ANNEXURE IV

#### INFORMATION WHICH SHALL BE SUBMITTED ON AN ANNUAL BASIS: CONDITION 9.1

\* = Indicate with an X. Please print legibly.

NAME OF SITE: \_\_\_\_\_ DATE OF REPORT: \_\_\_\_\_ (y/m/d)

#### 1. Registered owner(s) of property on which waste management facility is situated:

Name	Telephone	
Postal Address	Fax	
	Postal Code	

#### 2. Operator in control of storage site:

Name	Telephone	
Identity number	Tel. After hours	
Educational Qualifications		
Other Relevant competencies:		

#### 3. Indicate the type of waste and approximate quantities of waste disposed on site during the year:

Type of waste (Specify)	Quantity (m <sup>3</sup> annum <sup>-1</sup> )	Source
<b>TOTAL</b>		

#### 4. Indicate the type of waste and approximate quantities of waste salvaged, transferred for recycling or disposed of during the year.:

Type of waste	Quantity (m <sup>3</sup> annum <sup>-1</sup> )	reused, recycled, recovered, or disposed
<b>TOTAL</b>		

I, the undersigned, declare that the information stated above is to my knowledge a true reflection of the status at the ..... Slime dam, slag dump and salvage yard.

Signature: \_\_\_\_\_

Name: \_\_\_\_\_

Capacity: \_\_\_\_\_

Place: \_\_\_\_\_

Date \_\_\_\_\_



**environmental affairs**

Department:  
Environmental Affairs  
REPUBLIC OF SOUTH AFRICA

**ANNEXURE V**

**FORM TO BE USED FOR CHEMICAL INFORMATION: CONDITION 9.3**

Name of Site				
Borehole/observation- point name/number				
Sampling date (y-m-d):		Method:	Bail	
Sampling Time			Pump	
Time after start of pump:	h min	Depth of sample		m
Date of analysis (y-m-d)		Laboratory		

General chemistry

Constituent	Unit	Required standard	Value	Constituent	Unit	Required standard	Value
pH	(-log[H <sup>+</sup> ])			As (III)	(mg/l)		
EC	(mS/m)			B	(mg/l)		
TDS	(mg/l)			Cd	(mg/l)		
Ca	(mg/l)			Free CN	(mg/l)		
Mg	(mg/l)			Cr (Total)	(mg/l)		
Na	(mg/l)			Cr (VI)	(mg/l)		
K	(mg/l)			Cu	(mg/l)		
Alkalinity	(mg CaCO <sub>3</sub> /l)			Mn	(mg/l)		
Cl	(mg/l)			Pb	(mg/l)		
SO <sub>4</sub>	(mg/l)			Hg	(mg/l)		
NO <sub>3</sub> -N	(mg/l)			S-	(mg/l)		
F	(mg/l)			Zn	(mg/l)		
COD	(mg/l)			Fe	(mg/l)		
NH <sub>4</sub> -N	(mg/l)			Al	(mg/l)		
Phenol	(mg/l)			Mn	(mg/l)		
PO <sub>4</sub>	(mg/l)						
TOX	(µg/l)						
TOC	(mg/l)						
Ba	(mg/l)						

## A.2 Application form

ANNEXURE A

**FORM A**

**REQUEST FOR ACCESS TO RECORD OF PUBLIC BODY**

(Section 18(1) of the Promotion of Access to Information Act, 2000

(Act No. 2 of 2000))

[Regulation 6]

**FOR DEPARTMENTAL USE**

Reference number: .....

Request received by \_\_\_\_\_ (state rank, name and surname of Information Officer/Deputy Information Officer) on \_\_\_\_\_ (date) at \_\_\_\_\_ (place).

Request fee (if any): R.....

Deposit (if any): R.....

Access fee: R.....

.....  
SIGNATURE OF INFORMATION OFFICER/DEPUTY INFORMATION OFFICER

**A. Particulars of public body**

The Information Officer/Deputy Information Officer:

.....

.....

.....

**B. Particulars of person requesting access to the record**

(a) The particulars of the person who requests access to the record must be given below.

(b) The address and/or fax number in the Republic to which the information is to be sent, must be given.

(c) Proof of the capacity in which the request is made, if applicable, must be attached.

Full names and surname: Franz Robert Maria SprinzelIdentity number: 630987411Postal address: Private Bag X1, Matieland, Stellenbosch 7602

Fax number: \_\_\_\_\_

Telephone number: 0217878181 E-mail address: 19600496@sun.ac.za

Capacity in which request is made, when made on behalf of another person:

## C. Particulars of person on whose behalf request is made

This section must be completed ONLY if a request for information is made on behalf of another person.

Full names and surname: \_\_\_\_\_

Identity number: \_\_\_\_\_

## D. Particulars of record

- (a) Provide full particulars of the record to which access is requested, including the reference number if that is known to you, to enable the record to be located.
- (b) If the provided space is inadequate, please continue on a separate folio and attach it to this form. The requester must sign all the additional folios.

## 1. Description of record or relevant part of the record:

According to LICENCE IN TERM OF SECTION 49(1)(a) OF THE NATIONAL ENVIRONMENTAL MANAGEMENT WASTE ACT, 2008 (ACT NO. 59 OF 2008), Condition 3.1 all ferrochrome producer have to report the type of waste and approximate quantities of waste disposed on site during the year. (ANNEXURE IV). This data for all

2. Reference number, if available: ferrochrome producer send every year available in

3. Any further particulars of record: requested.

For my studies (M.Eng. Industrial Engineering) at Stellenbosch University, I would appreciate to get every data about the

South African ferrochrome slag dumps, where available.

Proposed outcome of my data collection is to identify the amount of ferrochrome slag which was sent to landfill over the years.

--

E. Fees

- (a) A request for access to a record, other than a record containing personal information about yourself, will be processed only after a request fee has been paid.
- (b) You will be notified of the amount required to be paid as the request fee.
- (c) The fee payable for access to a record depends on the form in which access is required and the reasonable time required to search for and prepare a record.
- (d) If you qualify for exemption of the payment of any fee, please state the reason for exemption.

Reason for exemption from payment of fees

F. Form of access to record

If you are prevented by a disability to read, view or listen to the record in the form of access provided for in 1 to 4 below, state your disability and indicate in which form the record is required.

Disability: _____ _____ _____	Form in which record is required: _____ _____ _____
-------------------------------------	--

Mark the appropriate box with an X.

NOTES:

(a) Compliance with your request for access in the specified form may depend on the

Form in which the record is available.

(b) Access in the form requested may be refused in certain circumstances. In such a case you will be informed if access will be granted in another form.

(c) The fee payable for access to the record, if any, will be determined partly by the form in which access is requested.



1. If the record is in written or printed form:		
copy of record* <input checked="" type="checkbox"/>	inspection of record	
2. If record consists of visual images - (this includes photographs, slides, video recordings, computer-generated images, sketches, etc.):		
view the images	copy of the images* <input checked="" type="checkbox"/>	transcription of the images*

3. If record consists of recorded words or information which can be reproduced in sound:	
listen to the soundtrack (audio cassette) <input checked="" type="checkbox"/>	transcription of soundtrack* (written or printed document)

4. If record is held on computer or in an electronic or machine-readable form:		
printed copy of record*	printed copy of information derived from the record*	copy in computer readable form* <input checked="" type="checkbox"/> (stiffy or compact disc)

*If you requested a copy or transcription of a record (above), do you wish the copy or transcription to be posted to you? Postage is payable.	YES <input checked="" type="checkbox"/>	NO
--	---	----

Note that if the record is not available in the language you prefer, access may be granted in the language in which the record is available.

In which language would you prefer the record? English

G. Notice of decision regarding request for access

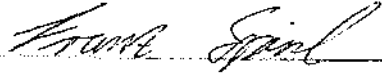
You will be notified in writing whether your request has been approved/denied. If you wish to be informed in another manner, please specify the manner and provide the necessary

[Redacted]

Particulars to enable compliance with your request.

How would you prefer to be informed of the decision regarding your request for access to the record? e-mail

Signed at Stellenbosch this 2nd day of November 2015

  
SIGNATURE OF REQUESTER / PERSON ON  
WHOSE BEHALF REQUEST IS MADE

## A.3 Notification of extension



### environmental affairs

Department:  
Environmental Affairs  
**REPUBLIC OF SOUTH AFRICA**

Private Bag X 447- PRETORIA · 0001-473 STEVE BIKO-ARCADIA-PRETORIA-0083- Tel (+27 12) 399 9778

**Our Reference:** PAIA 149040

**Enquiries:** Bonginkosi Dlamini **Telephone:** (012) 399-9778 **Email:** brdlamini@environment.gov.za

Mr Franz Robert Maria Sprinzl  
Private Bag x1  
Matieland,  
Stellebonch  
7602

Email: 19600496@sun.ac.za

Dear Mr Sprinzl

**NOTIFICATION IN TERMS OF THE PROMOTION OF ACCESS TO INFORMATION ACT, 2000 (ACT NO. 2 OF 2000) ("PAIA") IN RESPECT OF THE APPLICATION FOR ACCESS TO INFORMATION / RECORDS IN RELATION TO TOTAL VOLUMES OF FERROCHROME SLAG WASTE, AND THE COMPOSITION THEREOF, DISPOSED TO LANDFILL SITES IN SOUTH AFRICA OVER THE YEARS**

1. Your application for access to information for which payment of the request fee was made on 3 November 2015, has reference.
2. Kindly note that section 26(1) (c) of PAIA reads as follows:  
  
*"26.(1) The information officer to whom a request for access has been made or transferred, may extend the period of 30 days referred to in section 25 (1) (in this section referred to as the 'original period') once for a period of not more than 30 days, if-*  
  
*(c) consultation among divisions of the public body or with another public body is necessary or desirable to decide upon the request that cannot reasonably be completed within the original period;"*
3. Kindly note that consultation among various divisions of the Department is necessary and desirable to decide upon the request which cannot reasonably be completed within the original period, and therefore your request falls within the ambit of section 26(1) (c) of PAIA.
4. In the circumstances you are hereby informed that in terms of section 26(1) (c) of PAIA, I hereby extend the period of 30 days referred to in section 25(1) of PAIA, by a further period of 30 days, in order for my Department to be able to respond to your request.
5. You are, in accordance with section 75(1) of PAIA, entitled to exercise your right of an internal appeal against this notice of extension or to make an application to Court in terms of section 78 of PAIA.

NOTIFICATION IN TERMS OF THE PROMOTION OF ACCESS TO INFORMATION ACT, 2000 (ACT NO. 2 OF 2000) ("PAIA") IN RESPECT OF THE APPLICATION FOR ACCESS TO INFORMATION / RECORDS IN RELATION TO TOTAL VOLUMES OF FERROCHROME SLAG WASTE, AND THE COMPOSITION THEREOF, DISPOSED TO LANDFILL SITES IN SOUTH AFRICA OVER THE YEARS

Yours Sincerely



DEPUTY INFORMATION OFFICER  
DEPUTY DIRECTOR-GENERAL: CHEMICALS AND WASTE MANAGEMENT  
PRIVATE BAG X 447  
PRETORIA  
0001  
DATE: 03/12/2015

## A.4 Notification of access



### environmental affairs

Department:  
Environmental Affairs  
**REPUBLIC OF SOUTH AFRICA**  
Private Bag X 447 · PRETORIA · 0001 473 STEVE BIKO-ARCADIA-PRETORIA-0083 · Tel (+ 27 12) 399 9778

**Our Reference:** PAIA 149040

**Enquiries:** Bonginkosi Dlamini **Telephone:** (012) 399-9778 **Email:** brdlamini@environment.gov.za

Mr Franz Robert Maria Sprinzl  
Private Bag x1  
Matieland,  
Stellenbosch  
7602

Email: 19600496@sun.ac.za

Dear Mr Sprinzl

**NOTIFICATION IN TERMS OF THE PROMOTION OF ACCESS TO INFORMATION ACT, 2000 (ACT NO. 2 OF 2000) ("PAIA") IN RESPECT OF THE APPLICATION FOR ACCESS TO INFORMATION / RECORDS IN RELATION TO TOTAL VOLUMES OF FERROCHROME SLAG WASTE, AND THE COMPOSITION THEREOF, DISPOSED TO LANDFILL SITES IN SOUTH AFRICA OVER THE YEARS**

1. Your application for access to information for which payment of the request fee was made on 3 November 2015, has reference.
2. Kindly note that after due consideration of your request for access to information I have decided to grant you access to the information as requested.
3. Whichever information pertains to the identity of the waste generators or which falls under the protection of section 36(1) of PAIA will be redacted in accordance with your request. Section 36 (1) provides that -

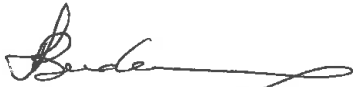
*"the information officer of a public body must refuse a request for access to a record of the body if the record contains – (a) trade secrets of a third party; (b) financial, commercial, scientific or technical information, other than trade secrets of a third party, the disclosure of which would be likely to cause harm to the commercial or financial interests of that third party; or (c) information supplied in confidence by a third party the disclosure of which could reasonably be expected – (i) to put that third party at a disadvantage in contractual or other negotiations; or (ii) to prejudice that third party in commercial competition."*

4. The access fee for the information granted is R 104.00 calculated at R 0.40 cents per page multiplied by 260 pages for the documents to be sent to you via email in accordance with your Form 'A' request.

**NOTIFICATION IN TERMS OF THE PROMOTION OF ACCESS TO INFORMATION ACT, 2000 (ACT NO. 2 OF 2000) ("PAIA") IN RESPECT OF THE APPLICATION FOR ACCESS TO INFORMATION / RECORDS IN RELATION TO TOTAL VOLUMES OF FERROCHROME SLAG WASTE, AND THE COMPOSITION THEREOF, DISPOSED TO LANDFILL SITES IN SOUTH AFRICA OVER THE YEARS**

5. Should you wish to appeal against the access fee to be paid or the form of access granted, you are referred to sections 74 and 75 of the Promotion of Access to Information Act, 2000 (Act No. 2 of 2000), which allows you to lodge an internal appeal together with the prescribed appeal fee, in the prescribed form to the Information Officer of the Department within 60 days. The subject and reasons for the internal appeal must be clearly indicated.

Yours Sincerely



**DEPUTY INFORMATION OFFICER  
(ACTING) DEPUTY DIRECTOR-GENERAL: LEGAL, AUTHORISATIONS, COMPLIANCE AND ENFORCEMENT  
PRIVATE BAG X 447  
PRETORIA  
0001  
DATE: 4/01/2016**

## A.5 Notification of delay



Steward Bishop <SBishop@environment.gov.za>

Di 02.02, 08:32

Sprinzi, FRM, Mnr <19600496@sun.ac.za> ↵



Allen antworten | ▾

Sie haben diese Nachricht am 02.02.2016 12:55 weitergeleitet.

Good Morning Mr Sprinzi,

Apologies for the delays. I did try getting hold of you telephonically.

We have been experiencing some challenges with broken copy machines and also with the process of redacting some of the information contained in the documents such as the company logos which proved more challenging. We are close to being complete and I am confident that the documents will be ready to be sent to you by this Friday for the very latest.

From my side, once again I apologise for the delay.

Kind Regards

**STEWART BISHOP**  
Deputy Director  
CORPORATE LEGAL SUPPORT  
012 399 9340

# Appendix B

## Questionnaires ferrochrome producers

### B.1 Producer 1-4



Response Information	
Started:	2016-05-23 15:11 PM
Completed:	2016-05-23 15:17 PM
Last Edited:	2016-05-23 15:17 PM
Total Time:	00:06:24.2730000
Is Test:	No
IP Address:	196.38.246.163

Login Info
User Name: AnonymousRespondent
Invitee:

**Response Details**

**Page 1**  
 1 - I accept the invitation to participate and give consent that my responses may be used confidentially and anonymously.

**Page 2**  
 2 - How would you describe the potential for the reuse of ferrochrome slag in South Africa?  
 Please select on the scale below (1=No potential, 2=Little potential, 3=Some potential, 4=Substantial potential, 5=Very good potential).  
 4

3 - Which reuse scenario is in your opinion the most promising?  
 Please rate the barriers on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Brick manufacturing	3
Civil engineering and road construction	4
Subsurface drainage material	4
Refractory materials	2
Others	3

4 - Other promising reuse scenarios:  
 cement industry for some type of slag

5 - **Where do you see the biggest barriers for reuse scenarios of ferrochrome slag in South Africa?**  
 Please rate the barriers of the previous question on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Environmental Standards	4
No buyers/ No market available	3
Not economical	4
Customer needs not met	2
Waste management practice and policies	3

6 - Do you see any barriers which are not mentioned in the previous question?  
 Government and policy makers do not understand the issues related to the re-use of slag

7 - Have you experienced problems with the delisting process of hazardous slag?  
 Yes

8 - If yes, please describe the experienced problems (missing communication, misleading regulation, lack of regulation and standardization...)  
 to strict and incorrect measurement standards used to determine suitability. Governments drive to re-use waste clashes with the various depts.'s efforts to stop the re-use of slag at all cost.

9 - Are possible reuse scenarios blocked by geographic and infrastructural circumstances?  
 No

**Page 3**  
 10 - The environmental legislation regarding reuse of slag is overly protective?  
 (1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)  
 4

11 - Better collaboration and communication between public bodies and the South African ferrochrome industry would improve reuse opportunities.  
 (1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)  
 4

12 - Do you see opportunities for "industrial symbiosis" programmes to facilitate the handling of slag?  
 Are you aware of any industrial symbiosis in the ferrochrome industry (successful, unsuccessful, in planning)?  
 (**Industrial symbiosis** is an association between two or more industrial facilities or companies in which the wastes or byproducts of one become the raw materials for another.)  
 yes, industry forums exist but has been unsuccessful (over many years) to change legislation to allow the re-use of slag.

13 - Would a framework with the goal to support and identify reuse opportunities of ferrochrome slag be useful to industry?  
 (1= not necessary at all, 2=not necessary, 3=indecisive, 4=necessary, 5=very necessary)  
 4

14 - Please elaborate:  
 current framework needs to be supported by government

15 - Would you be willing to provide information on a reuse scenario performed by, or on behalf of your company, to investigate barriers and opportunities of ferrochrome slag reuse? (Both successful and unsuccessful scenarios are welcome.)  
 No

**Response Information**

Started: 2016-05-24 15:15 PM

Completed: 2016-05-24 15:26 PM

Last Edited: 2016-05-24 15:26 PM

Total Time: 00:11:21.0770000

Is Test: No

IP Address: 197.96.94.1

**Login Info**

User Name: AnonymousRespondent

Invitee:

**Response Details**
**Page 1**

1 - I accept the invitation to participate and give consent that my responses may be used confidentially and anonymously.

**Page 2**

2 - How would you describe the potential for the reuse of ferrochrome slag in South Africa?

Please select on the scale below (1=No potential, 2=Little potential, 3=Some potential, 4=Substantial potential, 5=Very good potential).

4

3 - Which reuse scenario is in your opinion the most promising?

Please rate the barriers on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Brick manufacturing	4
Civil engineering and road construction	4
Subsurface drainage material	2
Refractory materials	2
Others	3

4 - Other promising reuse scenarios:

sandblasting

5 - Where do you see the biggest barriers for reuse scenarios of ferrochrome slag in South Africa?

Please rate the barriers of the previous question on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Environmental Standards	5
No buyers/ No market available	2
Not economical	2
Customer needs not met	3
Waste management practice and policies	5

7 - Have you experienced problems with the delisting process of hazardous slag?

Yes

8 - If yes, please describe the experienced problems (missing communication, misleading regulation, lack of regulation and standardization...).

The Ferro alloy producers association have been actively busy to delist the slag for more than 10 years. Formal approval will hopefully happen.

The biggest problem has been the standards set for slag as a hazardous waste.

9 - Are possible reuse scenarios blocked by geographic and infrastructural circumstances?

Yes

10 - If yes, please describe the experienced problems (e.g. high transport costs exclude possible customers).

Many of the smelters are far from the main cities and transport cost can make many of the opportunities fail.

**Page 3**

11 - The environmental legislation regarding reuse of slag is overly protective?

(1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)

5

12 - Better collaboration and communication between public bodies and the South African ferrochrome industry would improve reuse opportunities.

(1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)

5

14 - Would a framework with the goal to support and identify reuse opportunities of ferrochrome slag be useful to industry?

(1= not necessary at all, 2=not necessary, 3=indecisive, 4=necessary, 5=very necessary)

5

16 - Would you be willing to provide information on a reuse scenario performed by, or on behalf of your company, to investigate barriers and opportunities of ferrochrome slag reuse? (Both successful and unsuccessful scenarios are welcome.)

Yes

17 - Please provide your contact details in the following box (Name, contact number, email address).

Contact details will solely be used to contact the respondent regarding the possible reuse scenario and will not be passed to any third parties or used for any other purposes.

Response Information

Table with response metadata: Started: 2016-06-01 09:29 AM, Completed: 2016-06-01 09:44 AM, Last Edited: 2016-08-30 15:23 PM, Total Time: 00:15:53.4230000, Is Test: No, IP Address: 41.149.73.66

Login Info

Table with login details: User Name: AnonymousRespondent, Invitee:

Response Details

Page 1
1 - I accept the invitation to participate and give consent that my responses may be used confidentially and anonymously.

Page 2

3 - Which reuse scenario is in your opinion the most promising?
Please rate the barriers on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Table with 2 columns: Barrier, Rating. Rows include Brick manufacturing (5), Civil engineering and road construction (5), Subsurface drainage material (5), Refractory materials (5), Others (5).

4 - Other promising reuse scenarios:
cement readymix applications, backfilling material

5 - Where do you see the biggest barriers for reuse scenarios of ferrochrome slag in South Africa?
Please rate the barriers of the previous question on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Table with 2 columns: Barrier, Rating. Rows include Environmental Standards (5), No buyers/ No market available (3), Not economical (3), Customer needs not met (3), Waste management practice and policies (5).

6 - Do you see any barriers which are not mentioned in the previous question?
Current environmental legislation specifically relating to the Waste act. This is the biggest barrier of all.

7 - Have you experienced problems with the delisting process of hazardous slag?
Yes

8 - If yes, please describe the experienced problems (missing communication, misleading regulation, lack of regulation and standardization...).
Current legislation does not provide for delisting anymore. Waste is classified as hazardous or non-hazardous. The issue is that even the management of non-hazardous waste needs waste management activity licenses which makes it difficult for the specific applications of slag. Government lack of understanding the specific waste type, and they want to over regulate the use of slag and end user responsibilities. When does the responsibility or liability of the generator end?

9 - Are possible reuse scenarios blocked by geographic and infrastructural circumstances?
Yes

10 - If yes, please describe the experienced problems (e.g. high transport costs exclude possible customers).
In most cases the production of ferrochrome slag occurs in highly populated mining activity areas. So it competes against mining waste rock for use. Further several projects exist for the use of slag but these projects are not close enough so that the use of slag can be viable in terms of transport cost.

Page 3

11 - The environmental legislation regarding reuse of slag is overly protective?
(1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)
5

12 - Better collaboration and communication between public bodies and the South African ferrochrome industry would improve reuse opportunities.
(1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)
5

13 - Do you see opportunities for "industrial symbiosis" programmes to facilitate the handling of slag?
Are you aware of any industrial symbiosis in the ferrochrome industry (successful, unsuccessful, in planning)?
(Industrial symbiosis is an association between two or more industrial facilities or companies in which the wastes or byproducts of one become the raw materials for another.)
we have engaged several road construction and civil engineering firms for this but in most case the legal requirements and the availability of alternative aggregate material without these requirements made the project unsuccessful. We have also explored opportunities with the cement industry in the manufacturing of cement but with no conclusion to date.

14 - Would a framework with the goal to support and identify reuse opportunities of ferrochrome slag be useful to industry?
(1= not necessary at all, 2=not necessary, 3=indecisive, 4=necessary, 5=very necessary)
5

15 - Please elaborate:
The type of reuse opportunities is well documented. The issue is to establish the actual applications therefore.

16 - Would you be willing to provide information on a reuse scenario performed by, or on behalf of your company, to investigate barriers and opportunities of ferrochrome slag reuse? (Both successful and unsuccessful scenarios are welcome.)
Yes

**Response Information**

Started: 2016-06-07 10:17 AM

Completed: 2016-06-07 12:06 PM

Last Edited: 2016-06-07 12:06 PM

Total Time: 01:49:03.2200000

Is Test: No

IP Address: 41.160.13.212

**Login info**

User Name: AnonymousRespondent

Invitee:

**Response Details**
**Page 1**

1 - I accept the invitation to participate and give consent that my responses may be used confidentially and anonymously.

**Page 2**

2 - How would you describe the potential for the reuse of ferrochrome slag in South Africa?

Please select on the scale below (1=No potential, 2=Little potential, 3=Some potential, 4=Substantial potential, 5=Very good potential).

5

3 - Which reuse scenario is in your opinion the most promising?

Please rate the barriers on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Brick manufacturing	2
Civil engineering and road construction	5
Subsurface drainage material	2
Refractory materials	3
Others	

4 - Where do you see the biggest barriers for reuse scenarios of ferrochrome slag in South Africa?

Please rate the barriers of the previous question on the scale (1=very low, 2=low, 3=medium, 4=high, 5=very high).

Environmental Standards	5
No buyers/ No market available	3
Not economical	3
Customer needs not met	4
Waste management practice and policies	5

5 - Do you see any barriers which are not mentioned in the previous question?

Chemical consistency from different suppliers will affect customer confidence in the use of ferrochrome slags.

i.e. Cr2O3% / SiO2% / Al2O3% varies from smelter to smelter depending on the ores and furnace operations used. It would therefore be a concern that it may cause variable performance in certain applications.

6 - Have you experienced problems with the delisting process of hazardous slag?

No

7 - Are possible reuse scenarios blocked by geographic and infrastructural circumstances?

No

**Page 3**

8 - The environmental legislation regarding reuse of slag is overly protective?

(1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)

4

9 - Better collaboration and communication between public bodies and the South African ferrochrome industry would improve reuse opportunities.

(1=totally disagree, 2=disagree, 3=indecisive, 4=agree, 5=totally agree)

5

10 - Do you see opportunities for "industrial symbiosis" programmes to facilitate the handling of slag?

Are you aware of any industrial symbiosis in the ferrochrome industry (successful, unsuccessful, in planning)?

(Industrial symbiosis is an association between two or more industrial facilities or companies in which the wastes or byproducts of one become the raw materials for another.)

**There are surely opportunities for such a relationship to be established. I am of the humble opinion that the current relationship is not on par with each other as to the main goal of improving the RSA GDP.**

11 - Would a framework with the goal to support and identify reuse opportunities of ferrochrome slag be useful to industry?

(1= not necessary at all, 2=not necessary, 3=indecisive, 4=neccessary, 5=very neccessary)

5

12 - Please elaborate:

The overall development of new applications and reusable scenarios would fuel the growth of academic research institutions and potentially result in industrial application.

In most smelters the slag is a non-saleable commodity and does not contribute towards the COP of the operation. If a feasible reusable process is developed for Ferrochrome Slag, it would automatically contribute to the COP of the operation. i.e. Eskom paid for electricity to produce metal only, slag is a waste product. If the slag is no longer a waste product, the Eskom price will be diluted.

13 - Would you be willing to provide information on a reuse scenario performed by, or on behalf of your company, to investigate barriers and opportunities of ferrochrome slag reuse? (Both successful and unsuccessful scenarios are welcome.)

No

# Appendix C

## Validation

# Overcoming institutional barriers to improve beneficial utilization of ferrochrome slag

## Assessment roadmap validation

### Problem Statement

From a technical point of view ferrochrome slag exhibits very good properties for reuse. One of the applications that is considered most promising, is the use of ferrochrome slag as an aggregate material. Despite the excellent physical properties of ferrochrome slag, South African legislation considers slag as a waste material due to its potential negative environmental impact. This has hampered the large scale reuse of ferro-chrome slag within the country.

Despite facing the same legislative challenges, other countries have been able to attain much higher rates of reuse. However, the often held belief that ferrochrome slag is considered a by-product in the legislation of other countries is incorrect. Even Finland, considered to be a pioneer in the field with a utilization rate of ferrochrome slag of 100%, does not consider ferrochrome slag as a by-product. The high utilization obtained by Finland is a result of a decision by the Finnish Supreme Court, where the only ferrochrome producer obtained the right to sell their slag without an environmental licensing process to third parties. This is only possible due to an internalized material and production control system, including chemical and physical testing procedures at the single ferrochrome producer. As the volumes in Finland are much lower and only derive from a single tightly controlled source, the risks involved in allowing the reuse are much lower when compared to the large volumes produced by numerous players in South Africa.

In South Africa, the primary barrier to the increased use of slag under the current legislation, is the requirement for a time consuming licensing process between the ferrochrome producer and the legal authorities. The process is still considered necessary, as the knowledge about possible negative effects which could occur over time are limited. This is similar to the history of steel slag in Europe where intensive research over an extended period of time enabled steel slag to eventually be reclassified from being a waste product to being considered a valuable product.

In the author's opinion the demands of the ferrochrome producers to change the definition of ferrochrome by legal authorities to a by-product, is only possible if the uncertainty of the long term performance of the slag is addressed. This would require intense communication and collaboration between the parties involved to arrive at a sound knowledge foundation for increased reuse. As such, a Roadmap was developed (Figure 1) to propose a direction of how the uncertainty and missing knowledge can be reduced and lead to the increased utilization of ferrochrome slag.

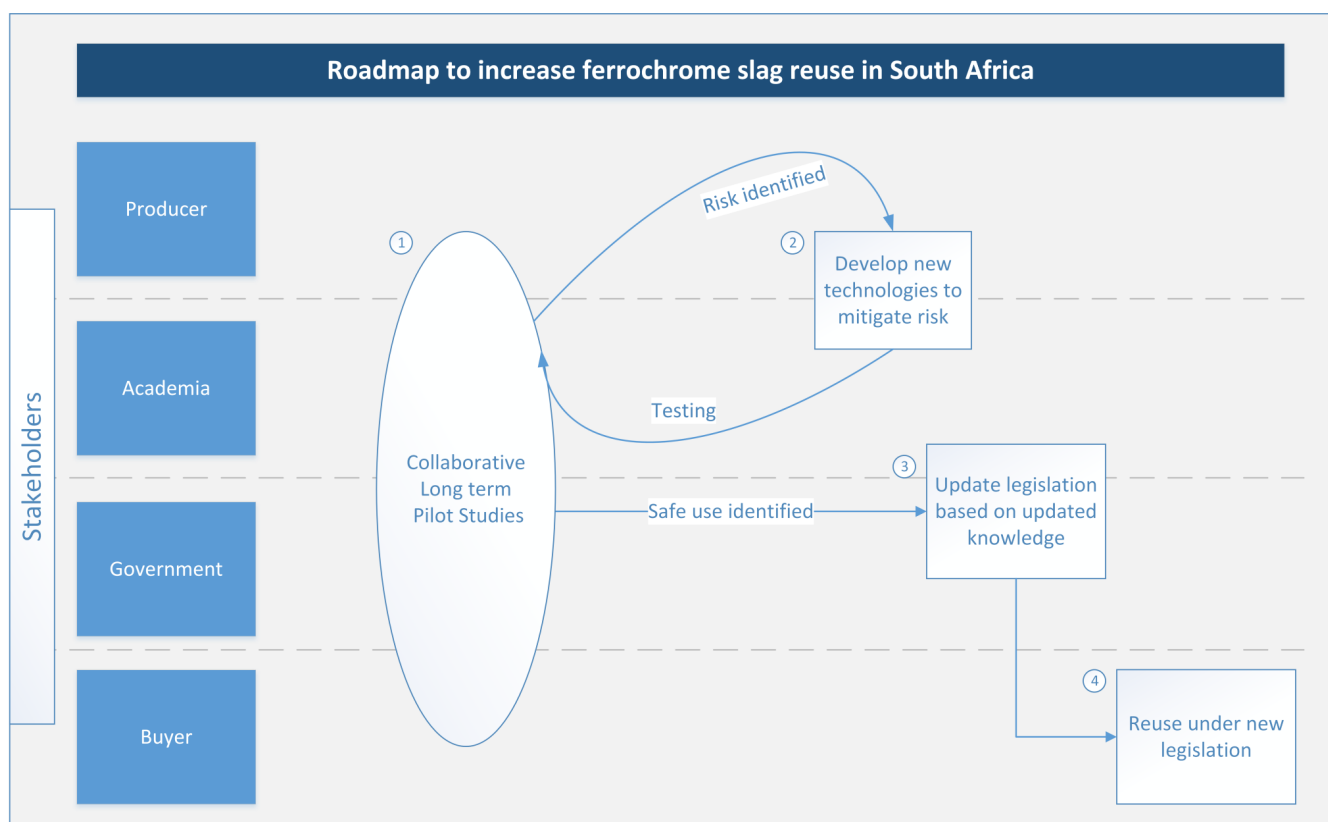


Figure 1: Strategic Roadmap

## **Appendix**

### **Description of the Roadmap**

The development of a roadmap normally involves the key players in the development process. The presented roadmap is a conceptualized draft, which proposes an initial industry strategy from the perspective of academia. This roadmap is therefore not a finalized roadmap, but a draft that needs to be refined through multiple stakeholder inputs. The preliminary roadmap presented in Figure 1 is divided into 4 steps, which are shortly described below.

#### **Step 1: Collaborative long term Pilot studies:**

The main goal of this stage is to perform various controlled long-term case studies to investigate the long term performance of ferrochrome slag under different conditions. The participating producer would have to implement a material and process control system to regulate the ferrochrome output achieved. This control system must be certified to meet specified standards required by the government and the potential buyer of the product. The role of the government would be to provide the authorization for the small scale direct streams of reuse between the participants in the case studies and to support and regulate the risk management of the players involved.

#### **Step 2: Technology Development**

The goal of the technology development step, will be to develop technologies that can mitigate the risks identified during the case studies. The reported data and experiences of the case studies could be collected in a central database. This database will help to identify potential risk and further opportunities to investigate. The goal is to provide a starting point for future research which can shape the future of ferrochrome slag utilization. The Ferro Alloy Producer Association could act as the leading institution to organize a transparent and efficient data collection process.

#### **Step 3: Update legislation**

Depending on the results of the long term pilot studies, possible risks could be mitigated and result in safe reuse opportunities. To promote this safe reuse of ferrochrome slag the government can adopt the new knowledge to update the current legislation to be less cumbersome. This update process could be gradual, depending on the safe uses identified. The proposed outcome is not directly the general classification of ferrochrome slag as by-product, but the support of reuse for safe usage through a simplified evaluation process.



#### **Step 4: By-product assessment**

New experiences with ferrochrome slag and the documentation and evaluation thereof will lead to increases trustworthiness of the reuse of ferrochrome slag. The long term goal is to minimize the potential risk and to consider ferrochrome slag as a secondary product of the production process. With increased knowledge development, time consuming waste management licensing could become redundant, which would turn ferrochrome slag into an attractive alternative material for natural aggregates. The long term output would be a more sustainable and competitive industry.

#### **Questionnaire and Feedback**

1. In your opinion, does the use of the roadmap hold potential to increase the utilization of ferrochrome slag? Please elaborate shortly.
2. In your opinion, what are the weak points of the Roadmap?
3. In your opinion, what are the strong points of the Roadmap?
4. How would you rate the following structural aspects of the framework?  
(Please rate on a scale from 1 to 4 (1=poor, 2=fair, 3=good, 4=very good))
  - Level of easiness of understanding the Roadmap?
  - How well does the Roadmap align with best practice?
5. In your opinion, how can the Roadmap be improved?