worldsteel ASSOCIATION

STEEL INDUSTRY BY-PRODUCTS

Steel Industry By-Products

Project group report 2007-2009

Steel Industry By-Products

Director General
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Foreword from the Technology and Environment Committee (TECO) Chairman

February 2010

This project was started under the TECHCO chairmanship of Dr Tridibesh Mukherjee of Tata Steel and completed under Professor Hans Lindenberg of ThyssenKrupp Steel. It spanned two years from early-2007 to mid-2009 and managed to continue under the most difficult economic conditions the industry had seen for some time. This shows the determination of the project team to complete the work assigned to them.

This study on by-products delivers important insights and challenges for the entire industry: in particular, to reach a near-zero landfill position. The report describes the current state of by-products generation and use, and includes comparisons to a previous study undertaken by the World Steel Association in 1994 (then IISI). The generation of by-products is inevitable and it is interesting to see that there has been little change in the rate per tonne since that time.

The present report shows an encouraging outcome on the issue of near-zero landfill for some of the organisations surveyed. These companies have focused on waste reduction and by-product reuse internally or sales externally as a value-adding product. The progress demonstrates that there is a high level of technical skill and management techniques in the steel industry. Having achieved this quality, it is critical that the product is standardised and assured to enable market confidence and use to grow. The techniques and use opportunities achieved by the best performers should be seen as a challenge for the rest of the industry.

The study shows that the steel industry has reached a sustainable and viable state of operation. The industry is clearly aware of its responsibilities in managing by-products.

It is very pleasing to see this project team continue with the tradition of delivering professional studies that are useful to the industry globally. I would like to thank the project Chairman Koichi Endoh from Nippon Steel Corporation, project leader Jerome Lambert seconded to worldsteel from ArcelorMittal, and the project team for delivering this report under adverse economic conditions. I would also like to thank the two previous Chairmen and the two Committees on Technology and Environmental affairs for strongly supporting and encouraging this project throughout its process. Thank you also to the many worldsteel members who supported the project with site visits, data and staff time.

Pierre Gugliermina
ArcelorMittal

Foreword from the Project Chairman

January 2010

The project on by-products has been a very challenging and rewarding activity. Within the project group we gained a lot of experience from the work, site visits and each other. We hope that this report makes a significant contribution to the continuous improvement of the world steel industry's processes and operations.

The complex task of dealing with the ironmaking and steelmaking process by-products has necessitated some ingenious solutions by many organisations in different ways, in the face of tight environmental and commercial constraints. The focus for this project has been on the large volumes of material generated as part of the ironmaking and steelmaking processes in two categories: slag, and dusts and sludges.

This report follows an earlier undertaking by IISI (now worldsteel) in 1994 to investigate the use of by-products. Where possible, changes or trends have been compared.

From the comparison there appears to have been little change in the rate of by-product generation over the past 15 years. However, the use or reuse of by-products has increased significantly with many companies no longer having to divert standard by-products to landfill. Generation of dusts and sludges has increased as environmental abatement equipment has become more commonplace and water and emitted gas is cleaned of most particulate matter.

The key to ensuring this level of use of by-products is possible in the future is quality. Maintaining quality enables a confident and reliable market to be supported. The various by-products are recovered and used internally at the producing sites, sold to other industries or directly to end-use customers. Naturally, customers need the products to be consistent and available.

This study would not have been possible without a group of dedicated project participants from worldsteel member companies. And their dedication alone would not have been sufficient without the member companies sharing their hard-earned knowledge and information. It is encouraging to find this level of cooperation on technical and environmental issues in the steel industry. It is becoming more open, and we are indebted to those who contributed and supported the project.

We are particularly grateful to those companies who invited us to visit their facilities, hosted our meetings and made their local experts available for discussions. This has added greatly to our understanding and to the learning of the project group.

Koichi Endoh
Nippon Steel Corporation

Executive summary

Between March 2007 and May 2009, the World Steel Association (formerly the International Iron and Steel Institute, IISI) undertook a global benchmarking study to examine the management of key by-products from the various iron and steel production processes. The project had been requested by the Committee on Technology (TECHCO) and was endorsed by the Committee on Environmental Affairs (ENCO).

The study involved the submission of data and information from 25 companies, covering 60 plants and 24 countries.

The project mainly focussed on by-products produced in significant quantities and those difficult to use because of their physical or chemical nature. These by-products fell into two categories: slags, and dusts and sludges.

Slags

Slags from the various iron and steelmaking processes account for a significant proportion of by-products. Within the scope of the project, information was obtained on basic oxygen furnace (BOF) converter slag, BOF secondary metallurgy (SM) slag, BOF de-sulphurisation (de-S) slag, electric arc furnace (EAF) slag and EAF SM slag. These slags are challenging to use. Whilst information was also gathered on blast furnace (BF) slag, this was purely to compare and contrast with the situation reported in a 1994 report. BF slag is widely used.

Dusts and sludges

The majority of dusts and sludges come from the pollution abatement equipment that clean the gases and wastewater discharges from the various iron and steelmaking processes. This abatement equipment may be dry, wet or a combination of both.

This report focuses on the dusts and sludges from:

- the iron ore sintering process (a preparatory process for material fed to the BF)
- the BF itself (as well as some short analysis on 'alternative ironmaking' processes)
- the BOF and EAF.

It also looks at some of the minor sludges arising from the continuous casting and rolling processes (used to clean the water arising from these processes and not air pollution abatement equipment). Finally, there is a small summary about cold rolling, annealing and galvanising dust and sludges.

The data requested for each of the by-products included:

- the quantity generated or collected (along with steel or iron production so that the figures could be normalised in relation to the production rates of the main product)
- the levels of recovery, utilisation (either internally or via external 'routes') and disposal (where utilisation is not technically or economically feasible)
- information on the chemistry of these by-products
- any issues, concerns or challenges that the companies have regarding these by-products
- potential solutions, including treatment processes, marketing and other technical solutions that companies may have developed or implemented for the various materials
- evaluation of relevant regulations in the areas of operation, organisational structures, current and potential technologies, marketing strategies and management systems, with a specific emphasis on best performers.

Information relating to each of these aspects is tabulated at the beginning of each chapter. More information is in the report appendix, available on a CD.

Efforts were also made to compare and contrast the results of this study with the 1994 study, 'The Management of Steel Plant Ferruginous By-Products'. However, the unavailability of data from the earlier study meant that this was not always possible.

Between the previous study and the present one, the steel industry has made significant advances in increasing the quantities of by-products used. As a consequence, the industry has dramatically reduced the levels of materials it disposes of in landfills.

Whilst the use of BF slag has become globally accepted, there are still some concerns over the use of BOF slag, mainly relating to issues concerning its integrity and stability. This is due in part to the free lime content of this material. This report discusses some solutions worthy of investigation by steel companies.

It is noted that there are no significant changes in the relative generation/collection rate associated with the dusts and sludges. In comparison with the earlier studies, however, there does appear to have been a significant reduction in the level of materials sent to landfills. These by-products are increasingly being reprocessed internally.

Another point to note is that whilst slag tends to be recovered or used 'externally' to site, dust and sludge utilisation is on the whole recovered using 'internal' processes and means.

This different approach to the two by-product streams suggests that slag is viewed more as a material which can and should be marketed and managed accordingly, whereas for dusts and sludges, legislative and sustainability drivers lead more towards technical and innovative solutions.

Recycling 100% of BOF or EAF slag is possible today, and it is achieved in the world's main plants. No innovation in processing technology is needed. The key is to manage slags and sell slags as products, meeting specifications of a standard, through a quality control system.

However, markets and regulations change all the time. Increasing the value of these products and implementing sustainable business practices are key drivers. This requires innovation and the development of more effective applications. A clear trend is emerging, moving from selling basic aggregates to selling different products which have properties suitable for specific applications.

For dust and sludge, this study shows that both integrated and EAF routes have become more successful in recovering by-products (see Table 2). The results also show that best practice cannot be achieved by implementing a single technology or management method in isolation. Optimal performance is the result of a site-specific management system adapted to national or regional legislation and market conditions.

Total crude steel produced from integrated process in the survey	Total crude steel produced from EAF process in the survey	Total world integrated production (2006)	Total world EAF production (2006)
158,000	28,000	855,336	395,362

Table 1: Quantities available from survey data (in 1,000 t)

All quantities in kt (1,000 t)	BOF slag	EAF slag	BOF D&S*	EAF D&S	
Quantity in survey	18,000	4,500	3,600	450	
Quantity recovered %	82%	68%	88%	73%	
Quantity recovered	0.82	0.68	0.88	0.73	
Fe % in quantity recovered	20.2%	29.2%	62.5%	36.5%	Total Fe estimated recovered in the world
Quantity Fe	2,963	896	1,980	120	41,108
Lime % in quantity recovered	0.43	0.29	0.09	0.09	Total lime estimated recovered in the world
Quantity lime	6,308	890	293	29	48,709
Zn % in quantity recovered	n/a	n/a	0.01	0.12	Total Zn estimated recovered in the world
Quantity Zn			41	38	764

* D&S = dust and sludge

Table 2: Quantities of by-products recovered

In addition to the information collected on each of the by-products, total quantities of iron, lime and zinc recovered were calculated. It is clear that the use of these materials provides significant environment and financial savings, because additional primary raw materials would be required if these by-products were not recovered.

A review of the legislative situation in the European Union (EU) and the answers from the survey, described later in this report, indicated that legislative requirements vary greatly across the industry. The EU framework is often used as a reference as more and more countries move towards comprehensive legislation on by-product and solid waste.

About this report

This report is the result of more than two years' work, under the leadership of worldsteel, with contributions and input from experts representing steel companies from around the globe.

The first chapter discusses the methodology and approach of the study. The second chapter covers slags and the third chapter focuses on dusts and sludges.

'Phase 2: Results from best performers' is addressed in a separate chapter.

A chapter on plant visits and case studies summarises the technical presentations that were made by the host organisations, at each of the project meetings.

The final chapter of this report deals with the legislative framework and legal interpretations affecting waste and by-products.

About the World Steel Association (worldsteel)

The World Steel Association (worldsteel) is one of the largest and most dynamic industry associations in the world. worldsteel represents approximately 180 steel producers (including 19 of the world's 20 largest steel companies), national and regional steel industry associations, and steel research institutes. worldsteel members produce around 85% of the world's steel.

The association provides a forum for the world steel industry to address the major strategic issues and challenges it faces on a global basis. In addition, worldsteel facilitates the benchmarking of best practices amongst its members, across many aspects of steel manufacturing.

The association promotes steel as a product and the steel industry to customers, industry, media bodies, and the general public. It assists its members to develop the market for steel.

worldsteel promotes a zero-harm working environment for steel industry employees and contractors.

worldsteel was founded on 19 October 1967. It is a non-profit research organisation with headquarters in Brussels. In April 2006, worldsteel opened a second office in Beijing, China.

Introduction

Project aims, scope and objectives

The by-products project started in 2006. Its goal was to make steel-producing companies aware of management solutions for those by-products that pose the greatest challenges in terms of recovery and use.

The project team was asked to investigate the requirements for good management of these by-products, and more specifically, how to:

- optimise by-product management by reducing generation of unutilised by-products, improving external utilisation value for others and improving internal recovery rates
- share technologies and strategies.

One of the main benefits associated with participation is the interaction between the nominated experts and worldsteel member company representatives contributing to the project.

Where possible and practical, data obtained from this study was compared and contrasted with the information reported in earlier studies on the subject. Comparison was not always possible as data from earlier studies was not always reported in a suitable format.

The results obtained in this study were then analysed to:

a. determine the 'best performers' and ascertain reasons as to why certain companies/plants apparently performed better than others.
b. determine the means and ways, whether technological and managerial, in which these 'best performers' achieved high levels of utilisation (therefore low levels of disposal).

Additionally, a general summary of EU legislation (together with some key results on legislation from the survey's answers) was drafted. It provides an insight into the evolvement of legislation since the last project on by-products.

General information was also obtained on research and development initiatives underway at participating companies, which are aimed at increasing by-product utilisation.

Background

Previous studies

- Utilisation of Blast Furnace and BOF Slag (1984), under the Committee of Environmental Affairs. Data from 1980 and 1981.
  This study was only on BF and BOF slags. It had interesting insights on heat recovery from slag and odour nuisances.
- The management of Steel Industry By-products and Waste (1987), under the Committee of Environmental Affairs. Data from 1984.
  This study included, in addition to our scope, relining refractory by-products (two pages only), coke-oven battery by-products (two pages), stainless steel by-products and specific insights of oil removing technologies, leaching test and dumping technologies.
- The Management of Steel Plant Ferruginous By-Products (1994), under the Committee of Environmental Affairs and the Committee on Technology. Data from 1991.

Examining the focus, objectives and information provided in the earlier studies it is clear that the 1994 study is most closely aligned with the current report.

Changes since these studies

Studies of a similar nature have been periodically carried out by worldsteel since the 1980s. The 1994 study suggests that after the 1984 and 1987 studies there has been significant tightening of by-product and waste related legislation. Similarly, between the 1994 study and this current review, there have been further significant changes to both the legislation and general philosophy associated with wastes and by-products.

Today, there is a new focus on increasing the sustainable use of resources, i.e. increasing the use of secondary resources such as wastes and by-products, and minimising the consumption of primary resources. This focus is not solely environmental, but is also driven by the higher prices and continued depletion (both in quantity and quality) of primary resources.

Increasingly stringent air quality standards also impact upon the quantity and composition of some of the by-products produced from air pollution abatement equipment, i.e. dusts and sludges. This presents new challenges in terms of utilising these by-products.

Importance of by-product management and relevance of the study

For every tonne of steel produced in an integrated steelmaking plant, 450-500 kg of by-products are produced. The majority of these are slags (around 80%) and around half is BF slag. The majority of BF slag produced today is treated as a valuable resource.

Whereas the landfilling of waste (unwanted material which may sometimes include by-products) was once viewed as an inexpensive and technically simple way to dispose of such materials, times have changed. New legislation, higher costs from more stringent landfill engineering requirements, economic instruments such as landfill tax, and social acceptability mean that landfill is more expensive and undesirable from the persective of corporate social responsibility.

Project team

The project team consisted of representatives from the following organisations:

ArcelorMittal

Badische StahlWerke

Baosteel

BlueScope Steel

China Steel

FEhS

Hadeed (part of SABIC)

Nippon Steel

POSCO

Rautaruukki

Salzgitter

SSAB

Tata Steel - Corus*

TECHINT Group (Tenaris and Ternium)

ThyssenKrupp Steel

U. S. Steel Corporation

VDEh

*Tata acquired Corus during the project.

Figure 1: Geographic distribution of the project team

Company	Country	Meeting place
Tribovent	Austria	Duisburg, Germany
Shanghai Baotian New Building Material Co. LTD	China	Shanghai, China
Multiserv	UK	Pittsburgh, USA
DNIT/IPR (Brazilian National Department for Transportation Infrastructure / Road Research Institute)	Brazil	Vitoria, Brazil
Australian Slag Association (ASA)	Australia	Wollongong, Australia
Center for Sustainable Resource Processing (CSRP)	Australia	Wollongong, Australia
UFES (Federal University of Espirito Santo)	Brazil	Vitoria, Brazil
UENF (University in the state of Sao Paulo)	Brazil	Vitoria, Brazil

Table 3: Third-party companies who gave presentations at project meetings

Meeting	Date	Location	Host
1	March 2007	Brussels, Belgium	worldsteel
2	June 2007	Duisburg, Germany	ThyssenKrupp Steel
3	Nov 2007	Shanghai, China	Baosteel
4	April 2008	Jamshedpur, India	Tata Steel
5	June 2008	Pittsburgh, USA	US Steel
6	Oct 2008	Vitoria, Brazil	ArcelorMittal
7	Feb 2009	Wollongong, Australia	BlueScope Steel
8	April 2009	Brussels, Belgium	worldsteel

Table 4: Meeting hosts

In addition to third-party presenters local by-product professionals were also invited to the meetings.

Methodology and approach

Confidentiality

Anonymity of the contributors to the survey was assured by the use of a numeric coding system, known only to worldsteel.

Definitions

The section below gives some of the acronyms used in this report. It is important to note that there are different legal definitions in different countries, and the terms below are specific to this study and do not necessarily reflect the legal definitions from any region or country.

Regions

In order to investigate any regional variation in the results, countries were grouped into general 'regions', based on geographical and cultural aspects (see Table 5). Note that this does not mean that we necessarily have an answer from each country.

The groupings were also adjusted when, for example, the number of answers received meant that confidentiality could potentially be breeched.

AD	Asia Developed (including Oceania): Japan, South Korea, Taiwan-China, Singapore and including Australia and New Zealand.
AO	Asia Other: China, India, Indonesia, Malaysia, Mongolia, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam.
CSI	Azerbaijan, Byelorussia, Kazakhstan, Moldova, Russia, Ukraine, Uzbekistan
EU	West European countries (EU15): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK
LSA	Latin and South America: Argentina, Brazil, Chile, Colombia, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Mexico, Peru, Trinidad and Tobago, Uruguay, Venezuela
MEA	Middle East, East Europe and Africa: Iran, Israel, Jordan, Quatar, Saudi Arabia, Syria, United Arab Emirates, Bulgaria, Czech Republic, Hungary, Latvia, Poland, Romania, Slovak Republic, Slovenia, Albania, Bosnia-Herzegovina, Croatia, Macedonia, Montenegro, Norway, Serbia and Montenegro, Switzerland, Turkey, Algeria, Egypte, Ghana, Kenya, Lybia, Morocco, Nigeria, South Africa, Tunisia, Uganda, Zaire
NA	North America: Canada, US

Table 5: Regional acronyms

BF	Blast furnace
BOF	Basic oxygen furnace
BP	Best performers
CC	Continuous casting
D&S	Dust and sludge
EAF	Electric arc furnace
ER	External recovery
ESP	Electrostatic precipitator
HBI/DRI	Hot briquetting and direct reduced iron
HM	Hot metal
HRM	Hot rolling mill
IR	Internal recovery
NWA	Non-weighted average
RHF	Rotary hearth furnace
SM	Secondary metallurgy
WA	Weighted average

Table 6: Technical acronyms

Data collection

The project was divided into two phases:

Phase 1 gathered objective information on the quantities and nature, i.e. tonnage and chemistry, of the by-products and determined where and how they were used or discarded.

Phase 2 examined why the best performers (identified from the results obtained in phase 1) were able to either reduce the quantity of by-products produced or maximise their level of utilisation. This part of the study was more subjective and sought information associated with the technology used, the managerment approach, the effect of regulation/legislation and whether marketing could influence performance.

Phase 1: general data and best performers

Within the given scope, the team chose a range of by-products to study more closely. In total, this consisted of 12 slag by-products and 30 dust and sludge by-products.

For dusts and sludges, separate categories called ‘other’ were also created for each process to enable plants to enter another by-product if they considered it of interest. ‘Other’ categories are different from primary, secondary and any other listed by-products. As this category may contain very different types of items, comparisons are generally not meaningful.

BF slag was also included in the study purely to update utilisation trends and to compare these trends with the earlier studies. There was no specific technical question about BF slag.

Initially, the project group considered including questions about the potential of reducing by-products at source. However, after significant debate it was decided that the factors influencing production were too numerous and complex, for example, improved gas cleaning technology, changes in coke quality, burden quality and blowing practices. In many instances it is also difficult to influence or alter generation rates without significant impact on the processes themselves. An open question was therefore included on possible factors contributing to production, and a relatively simple analysis of the responses was carried out.

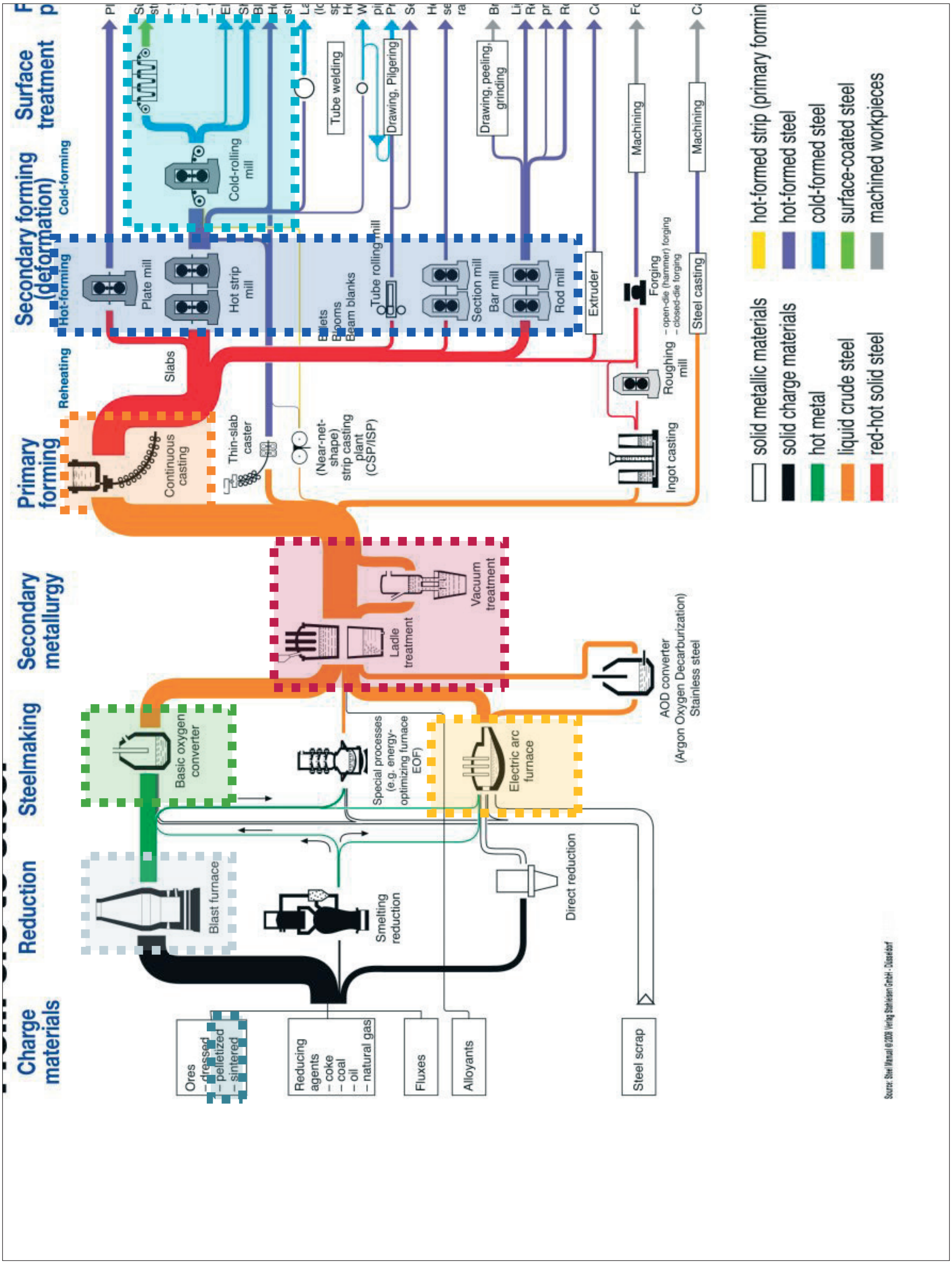
Information was also gathered from iron producers using alternative processes such as Corex and Midrex. These are considered 'minority' processes and their slag results were not statistically representative. Therefore, a summary was produced only for dusts and sludges associated with these particular processes.

Phase 1: By-products considered

The table below, in conjunction with Figure 2, shows the by-products investigated in this study and indicates the process areas from which they arise.

Pelletising Primary dust collection Secondary dust/handing Pelletising, sludge Pelletising, other	Sintering Primary dust collection Secondary dust/handling Sludge Other
Blast furnace Top gas cleaning D&S (primary/coarse) Top gas cleaning D&S (secondary/fine) Other D&S Granulated slag Pelletised slag Air-cooled slag	BOF D&S (primary/coarse) D&S (secondary/fine) Other D&S Steelmaking slag Desulphurisation pre-treatment slag Dephosphorisation pre-treatment slag Dosiliconisation pre-treatment slag
Other ironmaking process Top gas cleaning D&S (primary/coarse) Top gas cleaning D&S (secondary/fine) Other dust/sludge Slag	EAF Primary collection EAF, other D&S EAF, steelmaking slag
Continuous casting Scale (coarse, fine) Sludge Secondary metallurgy dust Continuous casting, other	Secondary steelmaking Slag from BOF Slag from EAF
Hot rolling Mill scale (coarse, fine) Hot rolling, mill sludge Hot rolling, other	Pickling/Cold rolling/Coating Sludge Iron oxide Other

Table 7: List of all by-products considered



Source: Verlag Stahleisen

Figure 2: Processes considered

Phase 1: Questions

Data collection

The project team decided to divide into two sub-groups, one focussing on slags and the other on dusts and sludges. Each sub-group devised its own list of questions which were then combined and then sent to all steel companies within the worldsteel membership. (For the phase 1 questionnaire, see the appendix.)

The questions covered topics ranging from the general strategy and approach taken to managing by-products to more specific technical questions.

For each by-product, questions were constructed on subjects such as:

- Generation (by-products and products)
- Basic treatments (initial treatments)
- Chemistry (all the main elements)
- Use (focused on destination within the broader categories of 'internal recovery', 'internal landfill', 'external landfill' and 'external recovery'). Information was also sought on examples of specific good practices, potential issues and problems, and examples of any projects or innovations which were being developed or had been implemented.

There was also a series of questions about the main routes by which by-products were either used or discarded. The final questions were aimed at understanding the main drivers (current and foreseen) that would increase the levels of by-product utilisation.

Analysis

Analysis of the questionnaire responses was carried out by the sub-groups. Project meetings ensured that there was regular communication between the sub-groups. This allowed any commonalities and linkages to be considered.

Elimination of outlying data

Initial analysis of the raw data suggested that it contained several 'outliers'. It was understood that these could potentially be real data or mistakes, for example, typographical errors. To account for these outliers the dust and sludge sub-group sought clarification directly from the questionnaire respondent. However, the slag sub-group discarded the outlying data.

Sub-group analysis and best performers evaluation

Two key performance indicators were used to identify best practice in management of by-products at the plant level. These were:

a. the recovery ratio (either internally or externally) and
b. specific generation rate, normalised against production (kg of by-product/t product).

As previously stated, consideration was given to the potential to influence the production process itself, by eliminating or reducing the quantities of by-products produced. The recovery ratio was chosen as the prime indicator to identify the 'better' performers.

Calculations

In general, averages reflect a weighted average. For example, in destinations data the tonnages of each destination in each plant are taken into account. However, for chemical analysis, an arithmetic average (giving a weight of one to each plant), was used. This was done to reflect differences between plants more accurately.

Timetable of phase 1

March 2007: project commenced

June, November 2007: meetings to finalise the questionnaire

December 2007: questionnaire sent to worldsteel membership

February 2008: deadline for response from worldsteel members

April, June and October 2008: meetings to analyse the responses to questionnaire

Results and representation of the data

Completed questionnaires were received from 24 companies (with operations at 60 sites in 25 countries). This represented approximately 200 million metric tons of crude steel production, of which approximately 25% was produced via the EAF route.

The 'regional' (see p. 9 for definitions of the regions) representation of the responses, for both the integrated and EAF steelmaking routes, is outlined in the charts below.

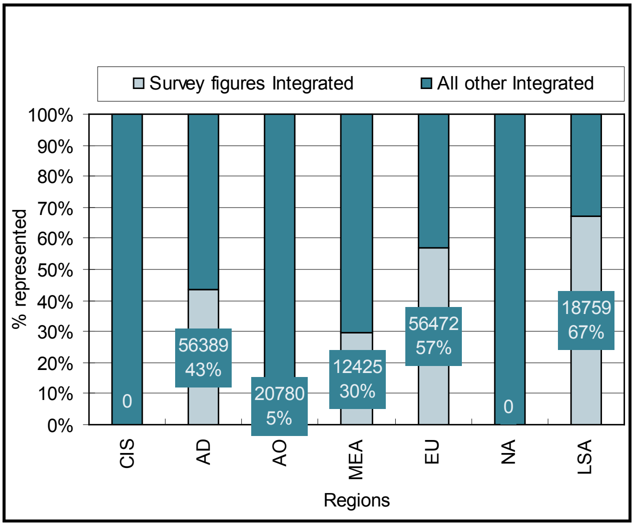


Figure 3: Comparison between survey and the world crude steel production for the integrated route

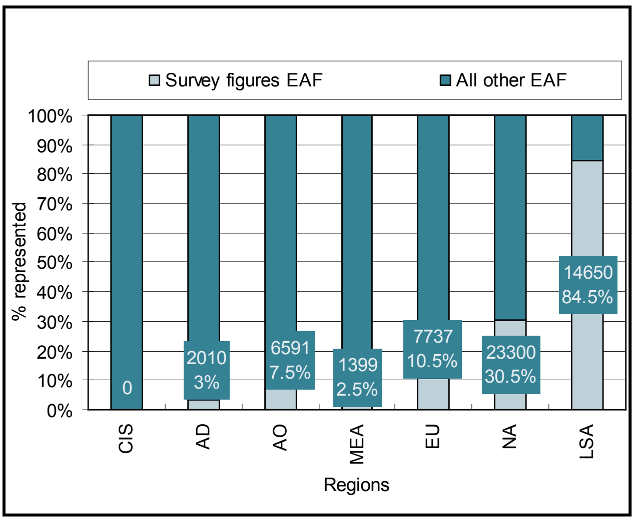


Figure 4: Comparison between survey and the world crude steel production for the EAF route

Phase 2: understanding the reasons behind the best performers

Based on the methodology for identifying companies with above average by-product management, a second questionnaire was designed and circulated. Its aim was to identify why some companies appeared to perform better than others.

Data collection

The second questionnaire targeted aspects such as:

- regulations relating to by-products
- common technology
- marketing strategies
- management strategies
- best performers' technology.

This questionnaire was subjective in design, seeking insight into the influential factors and explanations for the effective management of specific by-products.

Each company response was rated, to identify those plants consistently scoring higher for each of the various influences and to identify any correlation between these aspects and the degree of by-product utilisation.

Also, plants which were found to be best performers with respect to the recovery rate of a specific by-product (from the results of the phase 1 questionnaire), were targeted with a specific set of questions. These questions aimed to identify and provide details of any specific technologies developed and/or implemented to improve the utilisation of these materials.

Timetable of phase 2

June 2008, October 2008: meetings held to formulate the second questionnaire

November 2008: circulation of the phase 1 questionnaire results to worldsteel participants

January 2009: deadline for responses from phase 2 questionnaire

February, April 2009: analysis of phase 2 questionnaire responses.

Results and representation of the data

The phase 2 questionnaire was circulated to all plants that responded to the initial questionnaire Only 44 (of the 60 phase 1 respondents) plants responded.

Slags

Scope and focus

The following slags were included in the study:

- BF slag
- Other ironmaking slag
- BOF slag
- BOF secondary steelmaking slag
- EAF slag
- EAF secondary steelmaking slag
- Pre-treatment slag – de-siliconisation (de-Si), de-phosphorisation (de-P slag), de-sulphurisation (de-S slag).

Whilst BF slag was included in the study, this was only for comparison purposes with the 1994 by-products study, as there are no significant technical or commercial barriers to its recovery and use.

As the slags produced in greater tonnages are those associated with BOF and EAF steelmaking, these slags are examined in the greatest detail. Less data is available on secondary steelmaking slags, pre-treatment slags and alternative ironmaking slags. This report is therefore primarily focused on BOF and EAF slags. The conclusions of phase 2, regarding management of by-products, are on the whole common to these types of slags.

Methodological remarks

There were two main difficulties encountered in the analysis of the data from the survey.

1. Generated quantities

Slag quantities were requested in wet tonnes and dry tonnes, both before and after metal recovery – a total four data sets. Only a minority of plants provided information for all four data sets. Some gave only wet tonnes, others dry tonnes, some before metal recovery and others after. The data gaps were overcome by assuming a standard moisture rate of 5% and a standard metal recovery rate of 15%. Both were calculated using the mean of all the collected data.

2. Destinations

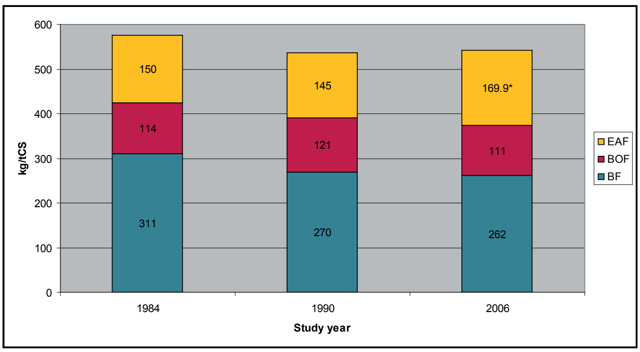
The questionnaire then sought information on the primary 'destinations' of the slags: internal or external recovery and landfill. More detailed information was then sought using a three-level 'tree' structure. These questions were on the whole comprehensively answered, although there were some inconsistencies.

For instance, the sums of tonnages in level three of the tree were not always consistent with the data entered in level two. In such cases, it was assumed that the higher level was correct and the difference between the two was considered 'non-specified'.

Another difficulty regarding destinations is the ambiguous and inconsistent definition of internal stockpiles. Internal stockpiling is sometimes necessary during the processing of steel slags and these stockpiles are assumed to be temporary. However, if material is stockpiled for a long time, it is difficult to differentiate these 'long-term stockpiles' from landfills. Therefore, recovery rates have been calculated without the data relating to stockpiles. It should be noted that the EU Landfill Directive lays down specific timescales after which stockpiles are legally redefined as landfills, but this is not the case globally.

Specific generation

The average specific slag generation rates, given in dry kg/tonne crude steel (or hot metal for BF slags) are detailed in the chart below.



* 111 with scrap only

Figure 5: Comparison of slag-specific tonnage (kg/t crude steel) by study

Whilst these figures are averages from the questionnaire responses it should be noted that there were significant geographical gaps in the data. Very few results were obtained from North America, the CIS and Asia. To say that the data set is representative of worldwide statistics may be too generous a claim.

Analysis of the data shown in Figure 5 gives rise to two major observations:

- There is no significant difference between the generation rates observed in the 1994 survey and this current one. Generation rates depend on raw materials, grades of steel produced and process optimisation. There is a well-established trend towards producing high-quality steel grades, which will lead to the production of more slag (and possibly more steel slag containing free lime). In spite of this unfavourable factor, the average specific generations are stable.

- There is a wide range of generation rates from the plants that responded to the questionnaire. The information from this study could enable plants to benchmark and improve their performance in slag management.

Recovery rates

Recovery rates for the different slags are outlined in the chart below. The data does not include internal stockpiles.

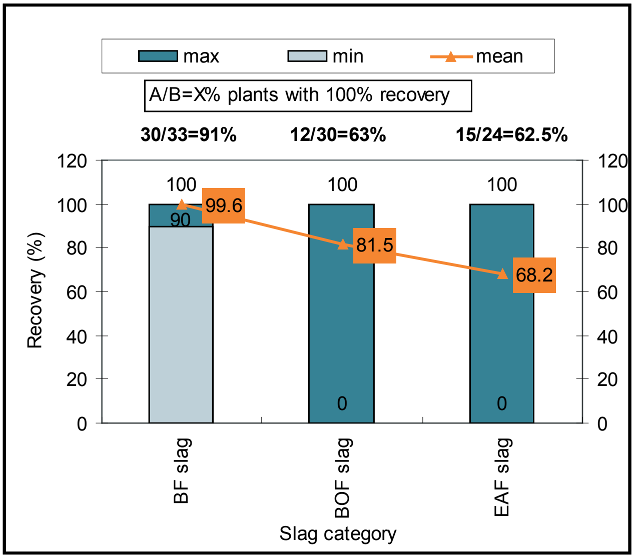


Figure 6: Recovery (external+internal) of slag by category for BF, BOF and EAF slags

Key comments:

- Almost 100% of BF slag is reportedly recovered, of which approximately 80% is granulated (compared to a 50% in the 1994 study). It is anticipated that this trend of increasing rates of granulation will continue.
- Plants are steadily increasing their rates of recovery of BOF slag (82% average today compared with an average of 78% in the 1994 study). Many plants reportedly recover 100% of their BOF slag and some even more than 100% from de-stocking.
- The levels of EAF slag recovery and use in the 1994 study and the current one are similar, with around 60% of the plants reporting 100% recovery.
- The average recovery rate of SM slags is approximately 60%, which is slightly higher than reported in the 1994 study.

Problems, solutions and trends

Blast furnace slag is now recovered as a matter of course. Close to 100% of it is granulated. This is due to the higher price that granulated slag attracts compared to air-cooled slag.

Steel slags pose more of a challenge in recovery and use because of their chemistry. The main issues are:

- stability concerns (or lack of stability due to expansivity) related to the free lime and MgO content
- leaching properties (with respect to Vanadium, Fluorine or their pH), especially if their use brings them into contact with water.

Another opportunity is the potential to increase the levels of iron recovery (metallic and non-metallic) from BOF and EAF slags. The current reported losses range between 15% and 20%.

Whereas results from the survey suggest that the chemistry of BF slag is quite consistent, this consistency is not apparent for steel slags as their chemistry varies depending on the steel grades which are produced. This poses issues for developing utilisation routes for these slags.

In some instances where plants have achieved 100% recovery, this could be due to the influence of drivers such as regulations banning them from landfill, or prohibitive costs, or space associated with landfilling. Other plants anticipate that the drivers for recovery will increase and as such are developing and implementing solutions and recovery routes ahead of these increases.

The questionnaire results indicate that the biggest challenge for steel slags is still their free lime content. Thus, major research and application development work has been directed towards seeking solutions to this issue (see the report section on BOF slag).

Main conclusions

The main recommendations arising from analysis of the free text answers to the questionnaire and information provided in various presentations made at the project meetings are:

- Where possible ensure different type of slags are segregated. Their different properties will mean that mixing may cause difficulties for quality control and end use.
- Develop a portfolio of slag applications.
- To maximise the value of the slag, select specific applications that takes into account local conditions, demand and markets.
- Where possible, market the slags as a product, with detailed physical and chemical specifications. Branding of such products may also prove beneficial.
- Whenever possible introduce stringent quality control systems, including traceability. If quality controls fail and 'unsuitable' slags are supplied, this could have significant negative impacts upon their continued use and the reputations of the companies concerned.
- Optimise internal recovery routes.
- A holistic approach to slag management should be considered. This is a combination of factors, including technical, marketing, commercial and environmental considerations.

Blast furnace slag

In this section of the report both wet and try tonnes of slag are considered.

The average moisture content was estimated to be 10%. This was derived from the available data.

Number of plants	33 out of 60
Tonnage represented	164 Mt hot metal (HM) (18% of world production) / 44 Mt BF slag (dry)
Regions	All regions except NA and CIS
BF slag ratio	(kg/t HM) (Min/Average/Max): 240/275/320
Recycling ratio	Close to 100%
Stockpiles	Generally small
Major destinations	Cement industry and construction; average granulation ratio: 80% (50% in 1980)
Good practices	Cement industry
Forecast at a glance	Maximising granulation ratio and economic value of GBFS, becoming a real product

Table 8: Summary of responses

Generation

Detailed information obtained from the results of the questionnaire, including regional variations are included in the appendix on BF slag. Information on granulation ration is also available on the appendix CD.

The option for respondents to answer questions related to the quantities produced in either ‘wet’ or ‘dry’ tonnes led to complications in analysing the data.

In general, the results obtained from the survey equate to a total annual production of approximately 44 Mt of blast furnace slag, with production from individual plants ranging from 240 kg/thm to 320 kg/thm, with an average production rate of 275 kg/thm.

Destination	Percentage of total generation (%)
External recovery	89.34
Internal recovery	10.25
Internal landfill	0.32
External landfill	0.09

Table 9: Main destinations of BF slag

Basic facts and figures on recovery of BF slag

It can be seen from the table above that 99.6% of BF slag is reported as being recovered, either internally or externally, with only a very small proportion not finding a useful outlet.

Examining the individual responses to the questionnaire, 20 out of the 33 respondents reportedly recover 100% of their arisings via external routes, with one plant (in Western Europe) actually reporting 100% internal recovery. Figure 7 demonstrates the ranges of external recovery which were exhibited.

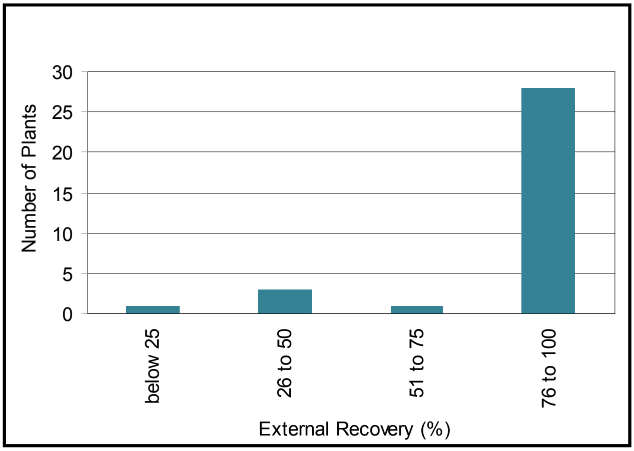


Figure 7: Distribution of external recovery of BF slag

Out of the 33 responses, 30 reported 100% recovery either internally, externally or combined. Two plants (sited in the 'Middle East, East Europe, Africa') reported landfilling 10% (internally) and 3% (externally). No other plants reported issues associated with using this particular slag.

Main applications (cement, construction, internal)

Figure 8 indicates the major routes for BF slag utilisation. A relatively small quantity (4.5%) is used internally as aggregates for roadmaking and engineered landfills.

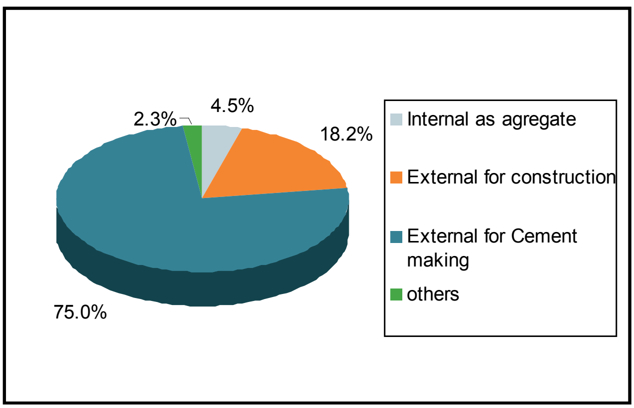


Figure 8: Destination for BF Slag by application

Further analysis of the responses indicates that of the total quantity of BF slag utilised by the cement industry, around 56% is used as a hydraulic binder, with the remaining 44% used as a raw material for clinker. This use in 'clinker' is reported by seven plants.

As shown in Figure 8, approximately 18% of the BF slag is used externally for construction. The recovery routes and proportions utilised in external construction are presented in Figure 9. About half the material used via this route is consumed as concrete aggregate whilst 43% is used in roadmaking and 5% BF slag is used in asphalt. Less than 1% is used in waterways constructions (dykes, banks, ports, marine uses), and these are mostly in the 'Asia Developed' region, and to a lesser extent in the 'West Europe' region.

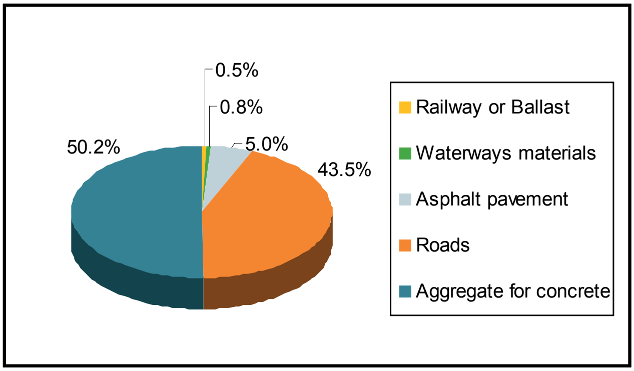


Figure 9: External recovery destinations of BF slag in construction

Figure 10 details the various uses of the proportion of BF slag that is used as internal aggregates (around 4.5% of total arisings).

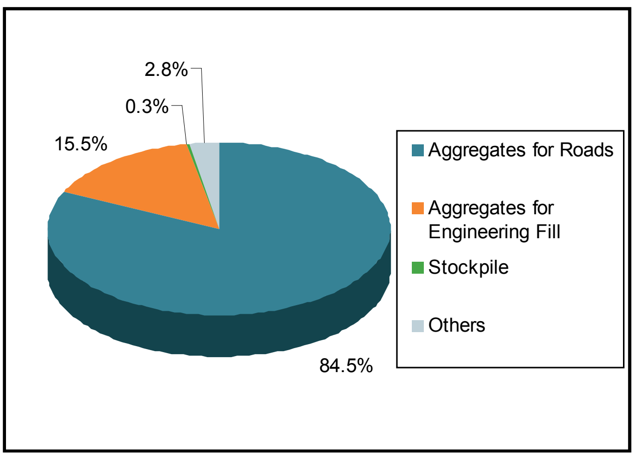


Figure 10: Internal recovery of BF slag as aggregates

Stockpiles and trends

For each slag type, information was sought to establish the current quantities of materials being stored in stockpiles and secondly to determine the rate of arising.

Granulated BF slag (GBFS)

The results, outlined in Figures 11 and 12, show that only one plant, in the region 'Middle East, Eastern Europe and Africa', has a significant stockpile of 500 to 1,000 kt, and an annual production rate of 500 kt. Nineteen plants reportedly have no stock or a stock less than 200 kt, which could be attributed to operational/logistical requirements or due to seasonal variations.

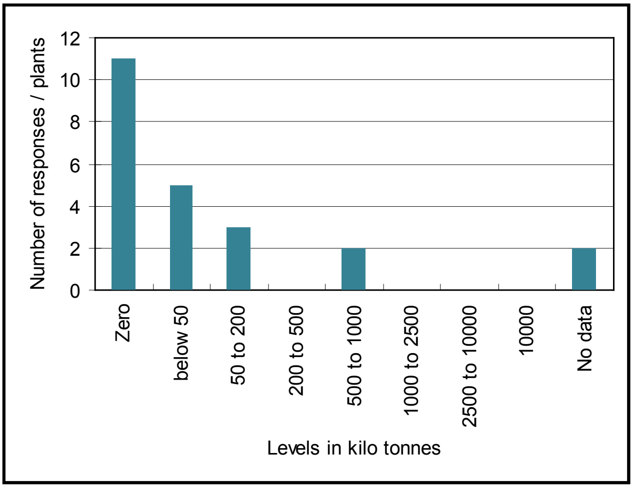


Figure 11: Stockpile level for GBFS

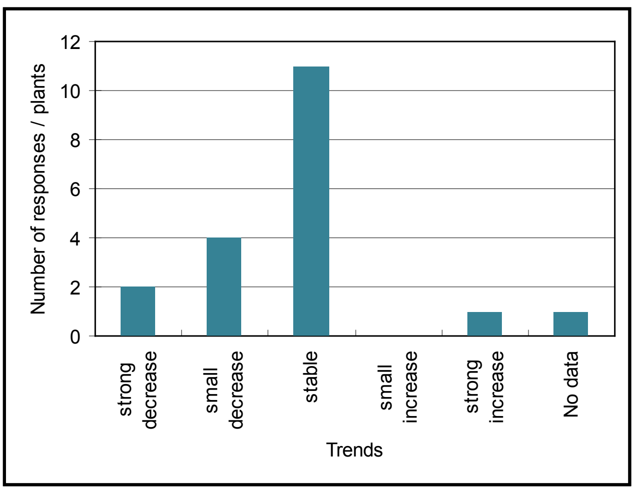


Figure 12: Evolution and trend of GBFS stockpile

It can therefore be concluded that sales of GBFS are good and improving with one exception, that is probably due to local market conditions. Today, market demand exceeds the yearly fresh production and therefore stockpiles can be decreased.

Pelletised slag

Of the six responses regarding the levels of pelletised slag that is currently stockpiled, five reported zero stock and the sixth had a stockpile less than 50 kt. The general conclusions regarding this particular slag are similar to that described earlier for GBFS.

Air-cooled BF slag

Only three sites of the 16 that responded reported stockpiles in excess of 500 kt, which equates to several years of production. All of these plants are located in the 'Asia Developed' region.

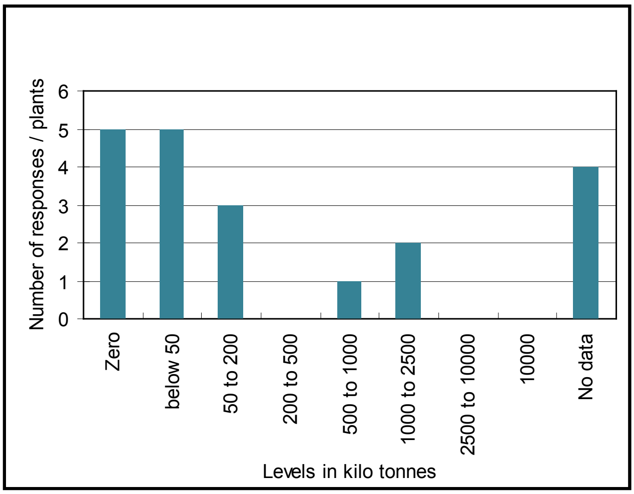


Figure 13: Stockpile level for air-cooled BFS

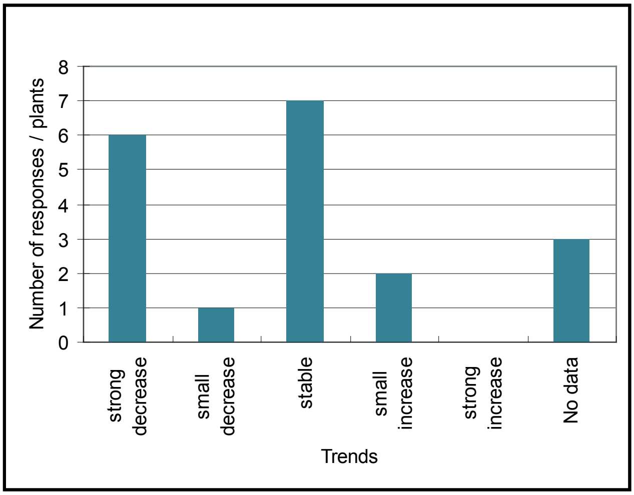


Figure 14: Evolution and trend for air-cooled BF slag stockpile

Only two reported a small increase, but their stockpiles are small, below 200 kt. All three sites with a big stockpile reported a strong decrease.

We can conclude that stockpiles of air-cooled BF slag are usually small or zero, with a general good trend of decrease, meaning that market demand is greater than fresh production. This may be explained by the shift to produce GBFS instead of air-cooled slag, reducing the fresh production of the latter, and inducing recovery from old stocks.

BF slag examples of applications and management practices

Treatments

This part of the study focuses on retrieving information associated with the various treatments directly related to the routes by which the slags were utilised.

Which treatments for which destinations? Main utilisation routes:

- cement (hydraulic binder), primarily through granulation or pelletising,
- raw material for clinker kilns (air-cooled slag), via various screening operations
- aggregates for construction, by various crushing and screening processes (air-cooled slag), but also as reported by two plants by granulation (granulated slag can sometimes be used in roads for bound layers).

Description of main treatments: one to create a glassy product and one to control Al_2O_3 and MgO, in the operation of the BF for secondary building material criteria.

Air-cooled slag is primarily processed through several series of crushers and screens to produce a material suitable as an aggregate or as a raw material for clinker or rockwool.

Good practices

Nine plants provided examples of what they deemed to be good practice in management of their slags. These are summarised below (see also the appendix on BF slag):

- Reaching close to 100% granulation ratio through new granulation facilities adjacent to the blast furnace. This is an improvement over the common practice (in Eastern Europe and CIS) of using remote granulation facilities associated with slag yards.
- Better logistics: transport of GBFS to a nearby cement plant by conveyor belt. The practice of locating grinding plants near steel plants is becoming more common. Most Western European integrated steel plants now have a GBFS grinding plant or several within a few kilometres, owned by customers. This has been a major change over the last 15 years.
- Better marketing: sales organisation, partnerships with cement makers, production and sales of ground GBFS. Plants reported improving marketing in several ways, from strengthening the sales department, to producing ground GBFS and marketing it. There is a trend towards more involvement of the steel industry downstream to reap the full value of GBFS as cement.
- Selling a blend of air-cooled BFS and BOF slag for roads to take advantage of the qualities of both slags.

Innovation projects

In the eight plants that provided data under 'BF Slags Project Innovation', the majority of BF slags are recycled (external recovery/cement industry) in granulated form. The other application is as construction material, such as a component for asphalt, pavements and road consolidation. This use has both environmental and financial benefits.

When asked for drivers for innovation, six plants selected 'Technical/Industrial', three plants selected 'Marketing Commercial and Management', one plant selected 'R&D' and one plant 'Quality Control'.

Moreover, in the responses, three projects were reported with the aim of increasing or maximising the granulation ratio, one project to optimise the sale of GBFS, and another to develop new shipment facilities to avoid large stocks at the plant.

We can conclude that there are currently no technical limitations to BF slag utilisation; GBFS is extensively used in the cement industry and construction material.

Comparison with previous survey (generation, granulation, recycling)

Item	1984 survey	1987 survey	1994 survey	2007-9 survey
BF Slag generation dry kg/t HM	311	About 300 to 400	270	275
BF Slag granulation %	50%	No data	No data	80%
BF Slag recycling %	84%	Nearly 100%	98%	99.6%

Table 10: Comparison of previous surveys

The recovery ratio was already close to 100% in the 1990s, but the granulation ratio, not mentioned in the 1987 and 1994 surveys was still probably far below 80%, maybe around 65%.

The major change is the move towards granulation as standard practice and cement as the destination, and towards a higher economic value: from by-product to product.

Forecasts

- GBFS will be used in external recovery, in particular in the cement industry; we expect change to be driven by market demand and marketing policy; and where relevant by industrial factors such as improving the granulation ratio or investing in granulation facilities.
- Pelletised BF slag production will drop as GBFS increases, due to cost and environmental issues.
- Air-cooled BF slag will increase in use as road material (internal recovery) and for the cement industry (external recovery), whilst use in construction applications will remain at current levels. The future may well see the reduction of air-cooled BF slag production, due to the rise of the granulation ratio. This will allow a focused use of air-cooled BF slag for higher value niche markets, where the chemical composition and consistency will be targeted.
- The results for "other ironmaking slag" in our survey are too limited to analyse.

For details, see the complete tables in the appendix on BF slag.

BOF or converter slag

We requested data on four different streams of BOF slag: wet and dry, before and after metal recovery. Due to incomplete answers to these questions, some approximations had to be made on moisture content (assumed to be 5%) and metal recovery ratio (assumed to be 150 kg/t slag).

<table>
<tr><td rowspan="3">Representation and production</td><td colspan="3">Number of plants: 29 out of 60</td></tr>
<tr><td colspan="3">Regions: all regions except CIS and NA (EU and AD represent 68.5% of total steel).</td></tr>
<tr><td colspan="3">Production: 165 Mt CS (20% of 824 Mt – 2006 world figure)</td></tr>
<tr><td rowspan="2">Generation</td><td colspan="3">18 Mt BOF slag (dry after metal recovery)
Min/Average/Max: 46/111/223 (kg/t CS).</td></tr>
<tr><td colspan="3">Metal recovery: average at 150 kg/t slag, (Min/Max=120/345)</td></tr>
<tr><td>Main issues</td><td colspan="3">Fe recovery and free lime</td></tr>
<tr><td rowspan="3">Destinations</td><td>Total recovery: 81.5%
(internal: 23.3,
external: 58.2)</td><td>Stockpiling: 7%</td><td>Landfill: 11.5% (all internal)</td></tr>
<tr><td colspan="3">External recovery (ER): construction (91.4% of ER or 53.1% of total), and particularly roads (53.6% of ER or 31.2% of total)</td></tr>
<tr><td colspan="3">Internal recovery (IR): process (71.8% of all IR or 16.7% of total) and particularly BOF (32.4% of IR or 7.5% of total)</td></tr>
<tr><td>Good practices and projects</td><td colspan="3">- Injection of SiO_2 and BSSF process
- Sorting of BOF slag with a model (chemistry prediction)
- Blending with inert aggregates
- Speed up weathering
- Use in marine applications
- Use of subcontractors
- Application for base and sub-base pavement
- Internal recovery for lime and iron content.

Orientations are: reduction in disposal, improvement of value in use, enhancement of environmental protection.</td></tr>
<tr><td>Forecast at a glance</td><td colspan="3">Traditional destinations such as cement, road and construction material and the known potentialities such as acid soil conditioner, steel slag hydrated matrix block and artificial stone (component for concrete) and rail road ballast will for sure exist simultaneously, in a portfolio of destinations.</td></tr>
</table>

Table 11: Summary of responses

Generation

A total of 29 plants provided data on BOF slag, covering all regions except the CIS and North America. This represented 165 Mt crude steel and a little over 18 Mt BOF slag (dry after metal recovery). For quantities of BOF slag generated and regional analysis, see the BOF appendix.

The regions 'West Europe' and 'Asia Developed' accounted for over 50 Mt of steel production each. Together, they represented 68.5% of the survey responses. The 'Asia Developed' region responses were for fewer, larger capacity sites.

The 'West Europe' region has a relatively low average specific generation of slag of 98 kg/t of crude steel, while the 'Middle East, East Europe and Africa' region has the highest rate of 133 kg/t.

The world average specific generation rate of BOF slag (estimated dry slag after metal recovery) is 111 kg/t of crude steel.

The range for specific generation of BOF slag (estimated dry slag after metal recovery) of individual plants varied from 46 kg/t to 223 kg/t of steel production (see Figure 15 below).

Compared to 1994 study (average of 121 kg/t steel), the average today is lower but not significantly different. However, far fewer plants in the current survey had a slag generation rate above 120 kg/t.

Plants selected as best performers (BPs) have a similar distribution to that of the whole set. Specific generation depends on many parameters (raw materials, steel grades produced), but is not linked to by-products management. In other words, a plant may have excellent by-product management practices, but a high slag specific generation rate.

Figure 15 shows that most plants (20 out of 29) operate within the slag generation rate range of 65 to 118 kg/t, and 11 out of these 20 operate in the range between 81 and 98 kg/t. However, several plants report substantially higher specific generation of slag. The highest reported rate was 223 kg/t, and the lowest was 46 kg/t. Further studies would be required to understand the reasons behind the lowest reported slag generation rates.

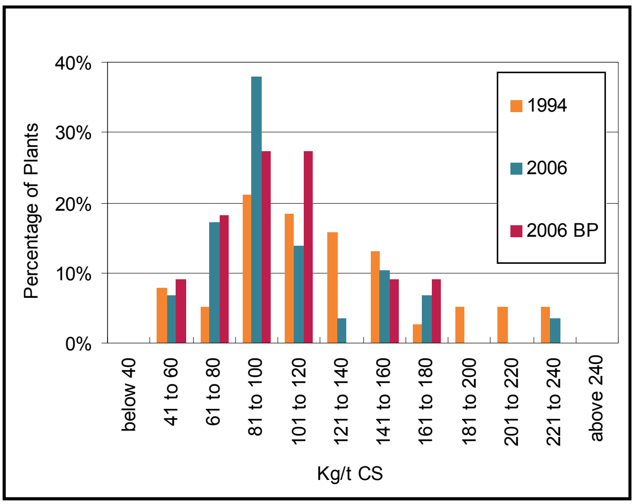


Figure 15: Specific generation distribution for BOF slag

Metal recovery

An average metal recovery rate was calculated based on nine plants that gave before and after recovery tonnage data (either dry or wet). Six of them recover 11 to 20% metal (to rebuild missing data we assumed an average of 15%). Only three plants indicated substantially higher values of metal recovery. These three plants were in the 'West Europe' region (see Table 12).

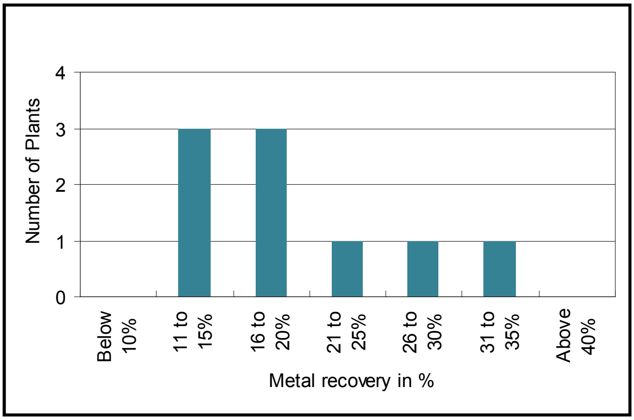


Figure 16: Metal recovery distribution for BOF slag

Abnormally high metal recovery may imply a high loss in crude steel yield. Since some plants must ensure absolutely slag-free tapping in view of their product mix, these plants may be compelled to allow more metal into the slag. It may be a good idea to examine this parameter in a future study.

Interestingly, plant number 362 reported the highest metal recovery of 34.6% and the lowest slag specific generation of 46 kg/t.

A scatter plot of slag-specific generation and percentage of metal recovery is presented in the in appendix. However, the correlation is not very clear. Further analysis of metal recovery as a percentage of crude steel is also available in the appendix.

Plants 280 and 137 perform at very low levels of metal recovery per kg of crude steel. This may imply that these plants are successful in keeping the liquid steel separate from slag. This may be worth examining further in another study.

Plant code	Steel production	Kg metal recovered per tonne of dry slag	Kg metal recovered per tonne of steel produced
280	5,274,058	119	12.5
340	2,650,798	130	17.7
348	1,968,631	140	18.4
137	2,925,523	152	13.0
153	4,178,000	166	17.5
242	2,666,400	183	19.9
210	3,699,000	220	38.0
437	3,182,077	258	30.8
362	4,153,000	346	24.2
Average		190	21.3

Table 12: Metal recovery from BOF slag

Three plants in 'West Europe' have much higher metal recovery ratios than the rest.

Chemistry

The following data analysis is available appendix:

- range and mean component composition for each element
- mean values by region
- free lime values.

Here we focus on the main issues including iron content, free lime content, phosphorus and chromium content.

Phosphorus

Phosphorus is the first limitation to internal recycling of BOF slag to the sinter plant or the BF. BOF slag has value in recycling for ironmaking, but phosphorus goes into the hot metal mostly and comes back in a loop to the converter, where it has to be removed by consuming more lime and generating more slag, which results in negative economic value for steelmaking. Therefore, this recycling is limited depending on the particular parameters of each plant (raw materials, steel grades, etc.).

According to the survey, the average phosphorus content in BOF slags is 1.1%. All values are below 2.5%. This range obviously affects recycling constraints. The reason for low phosphorus content is usually the iron ore chemistry. It appears that only plants in Asia have a de-phosphorisation pre-treatment.

Internal recovery in the process may be influenced by phosphorus content (see Figure 17, below). The observed variation in the recovery ratio may be due the type of steel produced (proportion of very low phosphorus steel), steel plant constraints on process or simply the will to recover the material. In many cases, it goes to landfill or storage.

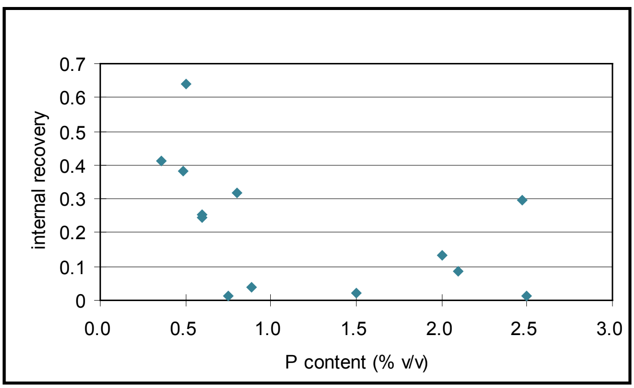


Figure 17: Influence of phosphorus content on the internal recovery in the process

Chromium

Chromium is significant because CrVI is hazardous to human health. As it is water soluble, it can leach out of solid materials and wastes. In the EU, a directive (2003/53/CE) sets a maximum level of 2 ppm soluble CrVI in cement. This is a real limitation to the use of steel slags in clinker kilns.

According to the survey, the average chromium content in BOF slags is 0.046% or 460 ppm. The maximum reported was 2,000 ppm, and the minimum was 0 ppm.

Chromium in slag is present as CrIII (Cr_2O_3), but after treatment in the clinker kiln, part of it is oxidised and becomes soluble CrVI. That is why the first limitation for this use in Europe is the chromium content, before the iron content.

Main issues

Loss in total Fe

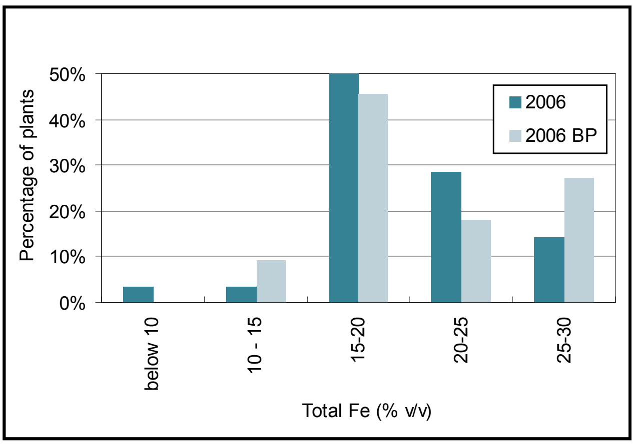


Figure 18: Distribution of total Fe in BOF slag

The average total iron composition is 19%, and ranges from 2.4% to 28%. Previous surveys did not include data for comparison. There is no significant difference in iron content for plants achieving 100% recovery with others. Globally, the total iron content of BOF slag represents a huge loss of about 21 kg/t steel on average.

The only simple way to recover this iron (metallic and oxide) is internal recycling to the sinter plant and BF, which should be the first route investigated in all plants. This route is limited by phosphorus content. There is a positive value in its use at the BF (iron and lime) but a negative one at the converter, because phosphorus comes back in a loop and builds up in concentration. The economic balance depends on the operating parameters of the steel plant, the steel grades, and the iron ores.

Free lime is problematic

- range from 2% to 10.5% (average for the plant): volume instability
- no distribution result in the 1994 survey: average was 7% in 1984
- no significant difference for plants selected as best performers (BPs)
- same reason as specific generation (other factors affect the free lime content).

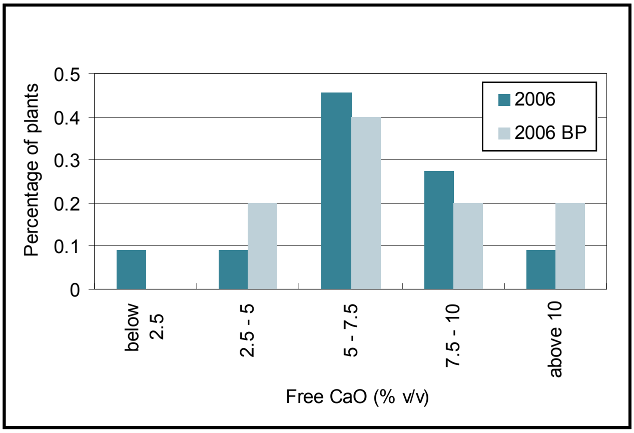


Figure 19: Distribution of free lime in BOF slag

(See also the appendix on free lime content by plant, chemical content by region and minimum, maximum and mean content.)

Free lime may hinder some applications by:

- volume instability (expansion) for construction
- high fines content
- high pH in water.

High free lime content is an issue for construction applications such as aggregate, but conversely can be beneficial in fertiliser and cement.

List of problems collected in the survey

1. Grain size over 150 mm: no value-added applications
2. Free lime problem from lime crystal nuggets due to high dolomite use
3. Increasing stocks due to less demand and free lime content impacting sale value
4. No application found, require storage
5. Looking for higher value application of BOF fines (fraction over 6 mm find some application into asphalt pavement)
6. Alternative use for fines, problem due to instability (humidity and expansion control)
7. Lack of external market due to free lime content.

Key issues

Apart from the two main problems of iron recovery and free lime, the other main problem is fine grain size. As a consequence, there is little or no external application. However, it must be stressed that these problems only occur for some applications in construction. Environmental problems are not mentioned, which means they are not perceived as major obstacles.

Destinations according to our five main categories

Below are the results from 27 plants. Three plants did not give satisfactory data on recovery.

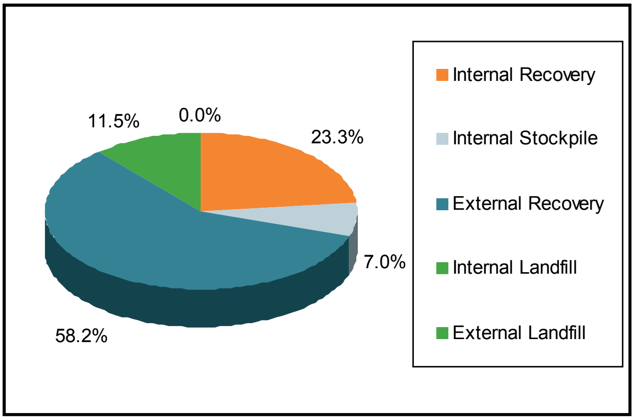


Figure 20: Main destinations for BOF slag

Globally, about 58% of BOF slag goes to external recovery and 23% is recovered internally. Internal landfill accounts for 11.5% of the total. There is no reported external landfill among the participating plants. Internal stockpile amounts to 7%, which is not considered landfill and cannot be considered recovery. Therefore, total recovery amounts to 81.5%.

Distribution of landfill

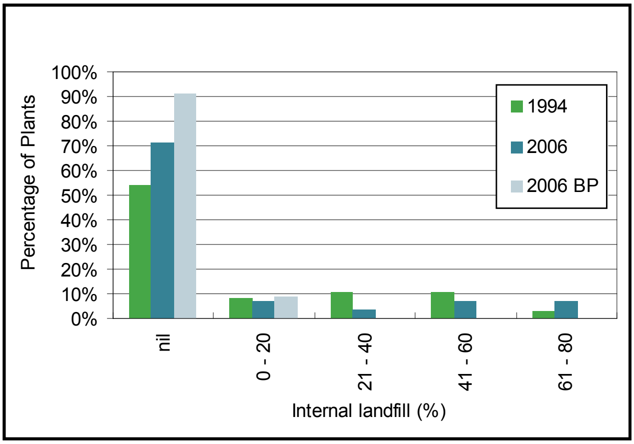


Figure 21: Landfill of BOF slag

All landfill is internal for this by-product, nothing is landfilled externally. In 2006, 70% of plants did not landfill any BOF slag. This is a substantial increase compared with 1994.

The recovery rate of BOF slag varied from 0% to 147% (recovery of stockpiled slag). This rate is very high, and may be due to the blurred distinction between internal stockpile and internal landfill. If stockpile figures are included in the internal landfill number, the recovery figure goes from 70% down to 45%. This is still a remarkable result, knowing that BOF slag is commonly described as the most “difficult” by-product. There are two points to note:

- The survey results probably show some bias because the participating plants are naturally more involved in by-products management
- The survey demonstrates that 100% recovery of BOF slags is possible and indeed is achieved by 13 plants in various continents.

External and internal recovery analysis

The trend since 1994 shows a progression:

- Internal recovery moved from below 20% towards 20-60%. Nevertheless, a significant number of plants still reported less than 20% internal recovery and 20% of all plants report 0%.
- External recovery: significant move from 0 to 20-40% and from 20-40% towards 40-60%. More than one-third of the plants even reported 81-100% external recovery and 14% reported 100% external recovery.
- The best performers of 2006 show the same trends, ahead of the move. However, a more detailed breakdown of destinations shows no difference between these plants and others.

On the whole, both internal and external recoveries are increasing, with external recovery showing the better improvement.

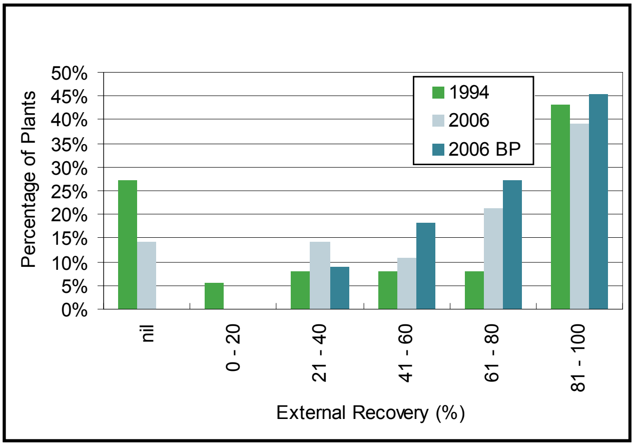


Figure 22: External recovery of BOF slag

See the appendix for the information in Figure 22 expressed in terms of numbers of plants rather than percentages.

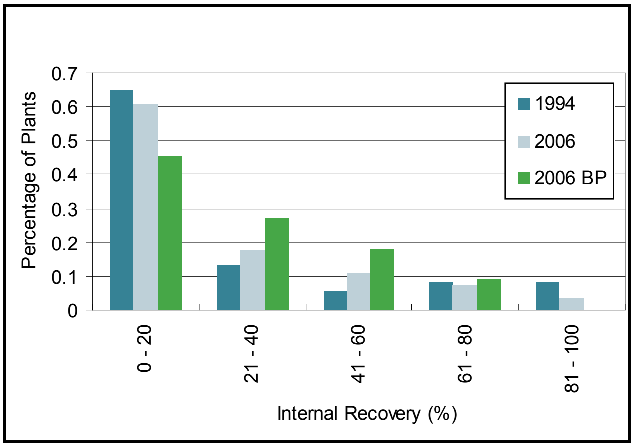


Figure 23: Internal recovery of BOF slag

Details of main recovery

Unambiguous data about the details of recovery were directly available for 12.3 Mt of BOF slag. It was also possible to use the data from 29 plants by applying some relevant calculations. The four major destinations, expressed as a percentage of the total of 19 Mt are shown in Figure 24.

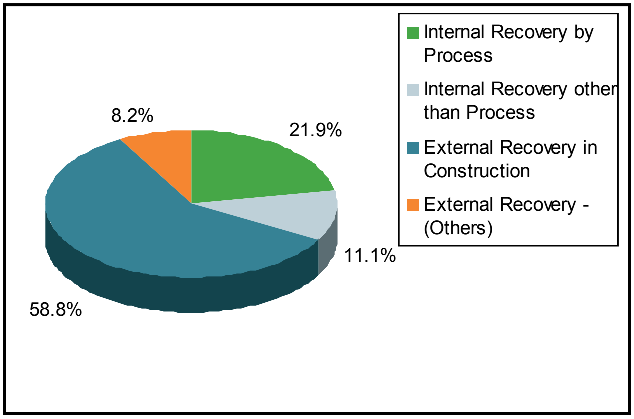


Figure 24: Main recovery destinations of BOF slag

Each of the above recovery routes is detailed below.

External recovery in construction (59%)

See also Figure 22. This outlet is clearly dominated by roadmaking (78% of total external recovery; including aggregates (71%) and asphalt pavement (7%)). The other major application in this category is railway ballast (over 20%). In this last category, close to 91% is from the 'Asia Developed' region (two plants). One plant in the 'Latin and South America' region supplies over 120,000 tonnes of BOF slag for railway ballast.

Internal process recycling (22%)

See also Figure 23. Over 58% of internal process recycling is consumed by the BOF. Plants in the 'Asia Developed' region are responsible for the majority of this figure (82%, within which one plant accounts for nearly 77% of this consumption). This is linked to the practice of hot metal pre-treatment (de-P treatment before conversion). In other regions, the recycling is done essentially to the sinter plant and the BF.

Internal recycling other than process (11%), as aggregates and for engineering landfill

See Figure 24. In the survey, 90% of this internal application as aggregates comes from just two plants in Asia, so the long-term sustainability of internal use is uncertain.

External recovery (Others) (8 %)

Two major external uses for BOF slag are in cement (as a component or extender, or a raw material for clinker kilns) and in agricultural fertilizer. See a more detailed version of Figure 24 in the appendix.

A number of minor or emerging applications for BOF slag also exist:

- cement component
- concrete blocks or other artefacts
- de-pollution of waste waters
- marine ecosystems enhancement
- agricultural soil improvement.

Use in cement accounts for close to 45% of this category, specifically as an ingredient to be mixed with the raw material for clinker-making. The use as a component of green mix for clinker was reported by four respondents. Use in agricultural applications accounts for a little below 25% of total external recovery in the 'Others' category. Five of the six plants that reported agricultural use of BOF slag are located in the 'West Europe' region; the other is in the 'Asia Developed' region.

It is noteworthy that no participant of this survey has indicated any use of BOF slag as aggregate for concrete or as a hydraulic binder component.

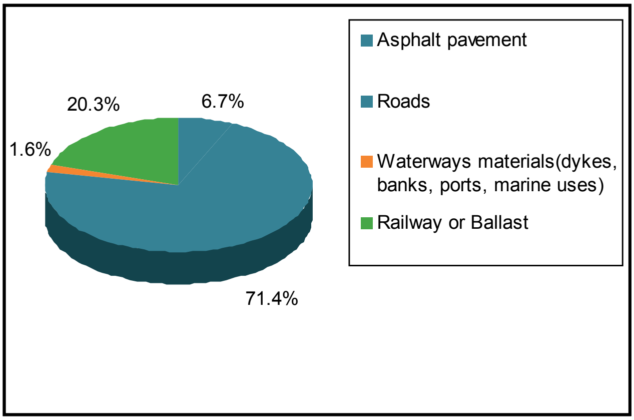


Figure 25: External recovery in construction for BOF slags

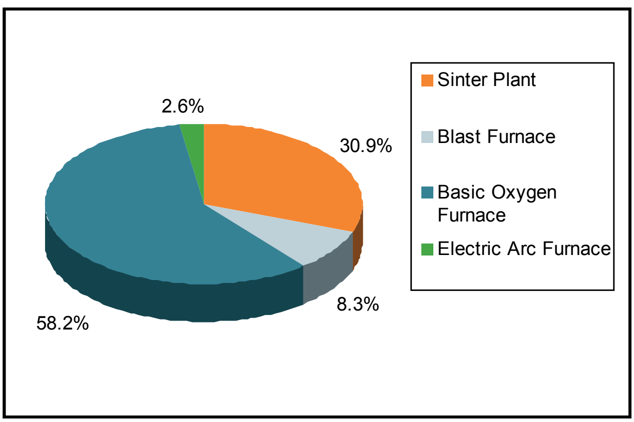


Figure 26: Internal recovery BOF converter slag by process

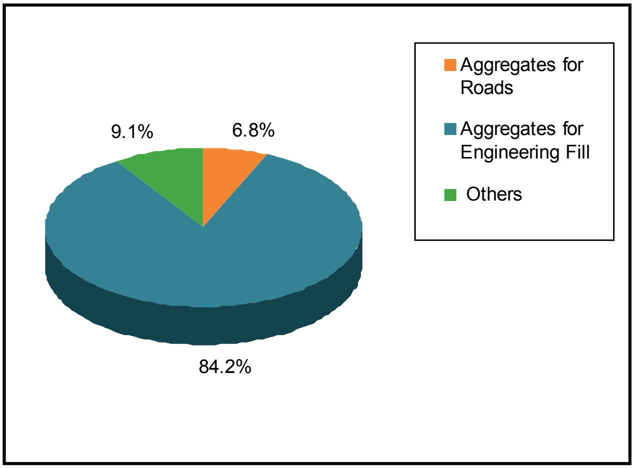


Figure 27: Internal recovery of BOF converter slag in other than process destinations

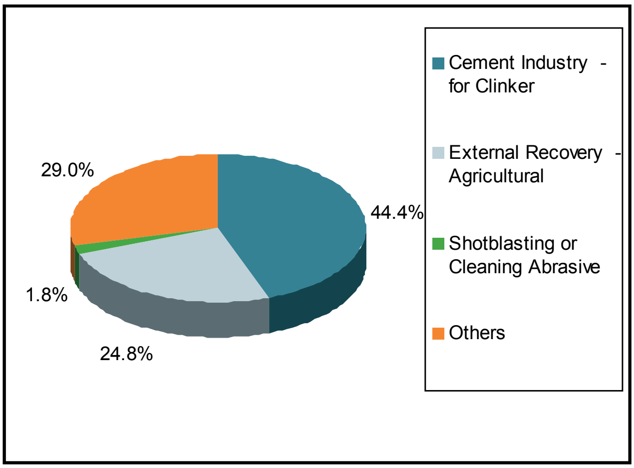


Figure 28: External recovery of BOF converter slag – Other destinations

Stockpiles

These stockpiles concern all types of steelmaking slags, including secondary and pre-treatment slags.

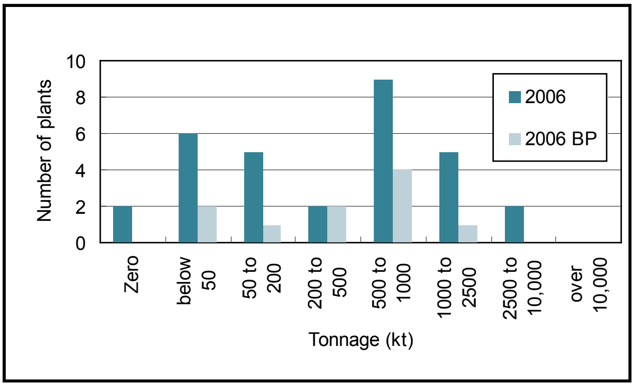


Figure 29: Stockpile level of steelmaking slags (number of plants)

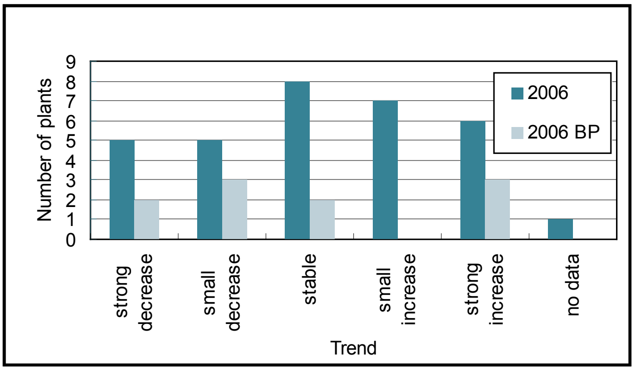


Figure 30: Stockpile evolution and trend for all steelmaking slags (number of plants)

- Stockpiles of steelmaking slags are a serious problem worldwide.
- Big plants state that the problem will worsen in the future. There is a need for effective technology and new end uses.
- One plant recycling 100% of its BOF slag has a stockpile above 1 Mt.
- Three other plants recycling 100% of their BOF slag foresee a strong increase, five a decrease, and two no change in stockpile size, which identifies limited market at this stage.

BOF slag examples of applications and management practices

Free-lime, problem number one

The problems caused by free lime are expansion, or volume instability, and production of fines. Magnesium oxide (MgO) causes the same problems, and dolomitic lime (high Mg) is used by more plants today in order to increase the lifetime of refractories in the converter, which increases the MgO content in the BOF slag to 6-10%.

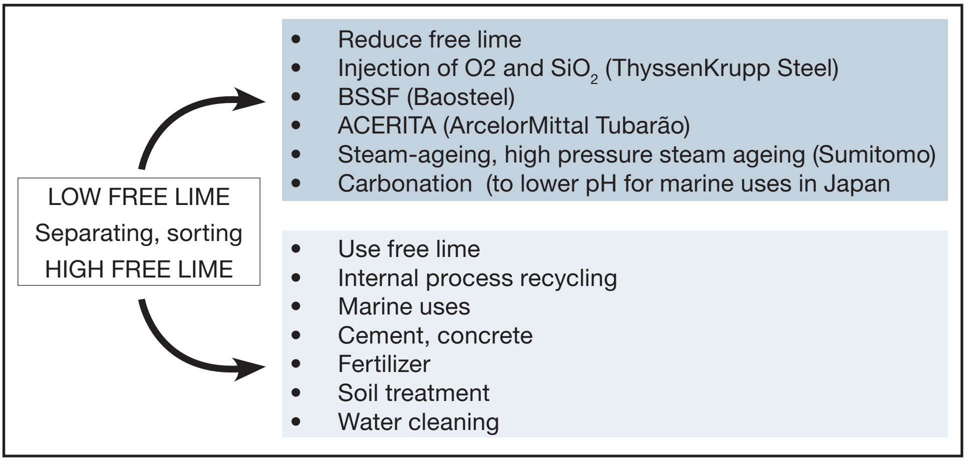


Figure 31: The two approaches to solving the free lime issue

The first step, which is also a good practice, is to separate the slag into several classes by the forecast free-lime content, using BOF data. This allows each type of slag to be processed differently according to destination.

In the first approach (see Figure 31), the aim is to minimise the free-lime content, thereby minimising expansion when used in aggregates, to meet local standards. The weathering or maturing process is not, in general, sufficient for BOF slags but can be sufficient if the free-lime content is below 3% (depending on MgO content and local requirements). Some processes have been developed and are used to accelerate and intensify the weathering:

- steam-aging in Japan: hydration of free lime by steam
- ACERITA in Brazil: hydration by water sprinkling and aeration (carbonation) by overturning the slag layer with a plough.

Another process, developed and used partially in one plant in Germany, is the treatment of liquid molten slag in the slag ladle by injection of O_2 and silica sand, in order to render the free lime inert by binding it with silica. The treated slag is then processed in the usual way (cooling in a pit, and metal recovery by crushing, screening and magnetic extraction).

The second approach is to use BOF slags in applications where free lime content is advantageous, or at least not problematic. One solution is internal process recycling, to the sinter plant, the BF, or the converter. External applications are diverse: fertilizer, soil conditioner, marine fertilizer, cement component, raw material for clinker or rock wool, filler for concrete, carbonated bricks or blocks, absorption of pollutants from waste waters.

In all cases, there is a CO_2 benefit, by CO_2 capture or substitution of other materials with their own CO_2 footprint. This field uses well-established mature applications as well as emerging ones. It is likely to grow for environmental reasons, to increase sustainability, reduce CO_2 emissions and add value by selling the product.

Basic treatments

In the survey, basic treatments were defined as treatments applied to all the BOF slag output, whatever the destination.

The traditional treatment used in most plants is: air-cooling in pits with some water sprinkling, then crushing, screening and recovering the metallic fraction from the slag by magnetic extraction. This process may be done after sorting the slag into several types according to their free lime content.

The other basic treatment is the BSSF process (Baosteel Short Flow) described later.

Good practices

The practices reported are the injection of SiO_2, sorting the slag before casting with a model, blending with BF slag, BSSF process, accelerated weathering by increasing the surface area of the stockpiles, use in marine applications (after toxicity assessment), use of subcontractors for treatment and sales, application for base and sub-base pavement, internal recovery for lime content.

See the appendix for lists of the good practices captured by the survey.

Projects and innovations

Among the 13 plants that provided data for BOF slags projects and innovation, 10 recycle their slags in the traditional way of external recovery/construction (including cement, railway ballast, road asphalt, landfill). Others use their slags in marine applications (artificial reef, active capping), on agricultural land, and as a soil conditioner.

It can be concluded that in the future, both traditional and more innovative uses of BOF slag shall co-exist. The drivers for innovation in BOF slags recovery are reduction in dumping and disposal, improvement of value in use, and enhancement of environmental protection.

Drivers of change for projects or innovations

Eleven plants selected R&D as the most important factor influencing BOF slags recovery. Other significant factors listed were: ‘Technical/industrial’, ‘Marketing’, ‘Commercial’, ‘Management’, ‘Legal/Compliances’ and even ‘Quality Control’. This is essentially because BOF slag composition, production and characteristics vary greatly depending on the ironmaking process, equipment and steel types, and plant location.

The biggest perceived technical limitations in BOF slags recovery are their instability due to high free lime content.

Examples of innovation

Most innovation projects aim at developing or improving an application without changing the basic process (e.g. cooling, metal recovery). These projects focus on the technical properties in the application (such as cement, concrete, fertilizer or water treatment), and the environmental impacts. The specific preparation of the slag starts after the initial metal recovery process. There is still considerable scope of development in this direction, which is market-driven.

Other innovation projects change the basic process by employing a completely different cooling process that also changes the metal recovery and crushing/screening process. However, fluidity constraints limit the application of this type of development.

1. The Ecomaister process is a Korean proprietary technology that blows air through a stream of liquid BOF slag to reduce it to regularly shaped granules or pellets, and eliminate the free lime expansion issue associated with BOF slag. It is a type of dry granulation. Several units are operated in Asia and one is starting in South Africa.

2. According to Baosteel, their BSSF (Baosteel Short Slag Flow) technology produces granulated slag from liquid steel slag in minutes. The end-product slag has low free lime content, high hardness, and the metal particles can be separated easily. Therefore, the granulated slag product can be widely utilised as construction material. BSSF is relatively mature and has been transferred to several plants in China and Asia.

Other innovations go even further by processing the liquid or molten slag, which is sometimes called slagmaking. One innovation has been adopted on an industrial scale: the stabilisation treatment by injection of oxygen and sand at ThyssenKrupp, Duisburg.

Another innovation was developed in a pilot plant in 2005 as part of a European project called Zero Waste involving ArcelorMittal. The BOF slag was treated in an EAF by adding fly ash, and coal or coke fines as reductant, to produce hot metal and a final slag similar to BF slag, to be used for cement. The technical results were good, but the process was considered too expensive for BOF slags.

Forecast and trends for the future

Trends for BOF slag recovery vary greatly depending on the ironmaking process, equipment, steel grades, etc. However, traditional destinations – such as cement, road and construction material – and the known potential alternative applications – such as acid soil conditioner, steel slag hydrated matrix block and artificial stone (component for concrete) and rail road ballast – will co-exist, providing a portfolio of destinations.

BOF slag forecast

The survey collected answers from 21 plants out of 50 dealing with BOF (see also the appendix).

There are many types of steel produced and therefore many types of BOF slag, leading to different types of recoveries. This makes it difficult to analyse common patterns for future trends.

Under 'internal recovery in the process', three plants declared they will recycle more using this route in the future and two plants declared increased internal use. Three plants predicted no increase and two predicted a reduction in the proportion of slag recovered internally.

The same conclusions can be made for recovery for aggregates, construction and the cement industry.

Nevertheless, BOF slag certainly has a role to play as a performance enhancer in many applications. This includes the cement industry, as an acid soil conditioner for agriculture, as a marine environment-improving material for ocean engineering and also as railroad ballast, in base and asphalt layer in road construction, as concrete aggregate, steel slag hydrated matrix block and artificial stone (component for concrete), and dredged clay improving material.

Estimated risks

Steelmaking with improved quality increases the slag production rate and free lime content. There are also forecasts of increasing BOF slag generation with increased steel production. There is, therefore, a risk that market consumption will not match this increased production.

More BOF slag recovery will depend on projects success and acceptance from technical authorities or legislation agencies, proper planning and social support.

Certain chemical components such as sulphur (S), phosphorus (P) and total chromium (Cr) might limit the use of some slag internally. Others, such as fluorine (F), chromium(Cr)6 might restrict the use of some slag externally because of stricter environmental legislation. As a consequence, there might be more landfill, and the associated higher costs.

Anticipated drivers of change in the future

Internal and external recovery of BOF slag is a serious and complex problem, requiring input from marketing, commercial, technical/industrial and R&D perspectives. Other drivers like quality control, management and promotion are still significant, but have less direct influence over BOF slag recovery.

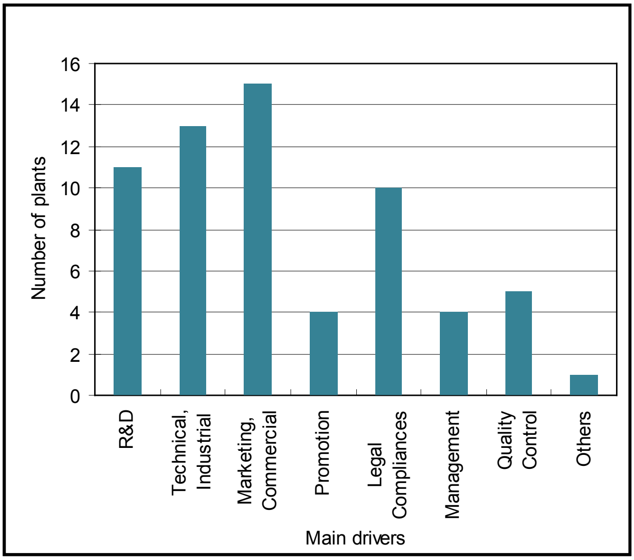


Figure 32: Main drivers of change for the future

Conclusions for BOF slag

- BOF slags are a difficult by-product to recover. It has the largest tonnage for an unrecovered by-product.
- Recycling 100% of BOF slag is possible today, and it is achieved in many plants all over the world.
- The main problem is free lime (volume stability, pH). Two approaches (dependent on end application) should be developed in parallel: stabilisation by rendering the free lime inert and exploiting the value of lime.
- The key is to manage slags and sell slags as products, meeting specifications of a standard, through a quality control system.
- However, markets and regulations change all the time. Increasing the value of slags is a strong objective and sustainability is a relatively new challenge.
- Therefore, innovation is needed to develop new and better applications and markets by selling products differentiated by specific chemical or mineral compositions or physical properties.

BOF secondary metallurgy (BOF SM) slag

In analysing the survey data, moisture content and metal recovery rate had to be approximated.

The data received were variable because of the different types of secondary metallurgy slag considered. See also the appendix.

Representation	Number of plants: 30 out of 60 have BOF operations, 19 gave data for BOF SM.		
	Regions: all regions except CIS and North America		
Generation	Min/Average/Max: 2.9/14.8/31.7 (kg/t CS) dry after metal recovery. Metal recovery: average estimated at 23 kg/t CS, (Min/Max=7.2/36.2) (dismissing abnormal values of 70!)		
Main issues	Lack of end use leading to landfill		
Destinations	Total recovery: 56.5% (internal: 27.6, external: 28.9)	Stockpiling: 4.6%	Landfill: 38.8% (internal: 33.5, external: 5.3)
	Internal recovery (IR): process with nearly 50% of IR (13.4% of total). Among the processes, BOF is the main recovery channel (16.45% of IR, 4.5% of total).		
	External recovery (ER): construction is by far the main destination with 96.6% of ER (27.9% of total), with roadmaking (61.8% of ER and 17.9% of total).		
Good practices and projects	- Reuse of SM slag in the BOF - Reuse in sinter plant: through proper sorting of different slags (LD/converter, SM/Secondary Metallurgy slag and de-S/de-Sulphurisation slag) - Raw material for calcium aluminates cement		

Table 13: Summary of responses

Generation

Representations of data

Sixty plants responded to the survey, of which 30 have a BOF operation. Nineteen plants provided information on secondary metallurgy slag. The responses cover every region except North America and the CIS.

Analysis of generation

The data was quite variable (see appendix). After removing the two highest (67.1 kg/t and 47.3 kg/t) and two lowest (2.9 kg/t and 10.9 kg/t) reported generation rates, the average generation rate for BOF SM slag (dry tonnes basis, after metal recovery) was 14.8 kg/t crude steel.

Chemistry

The following analysis can be found in the appendix.

- chart plotting Fe content versus Al_2O_3 content and by plant
- distribution of CaO, SiO_2 and CaO/SiO_2 in BOF SM slag.

On the whole, BOF SM slag chemistry (and other characteristics which affect final application) is quite different from BOF slag chemistry. Therefore, the slags should remain segregated. SM slags usually have a high Al_2O_3 content but a low iron content, which is valuable for some internal and external applications, and is conversely disadvantageous to some BOF slag applications. For example, Al_2O_3 may be undesirable for recovery at the sinter plant.

Main issues

The most common problem cited was the lack of end use applications, with the consequence that BOF SM slag is sent to landfill.

Destinations according to our five main categories

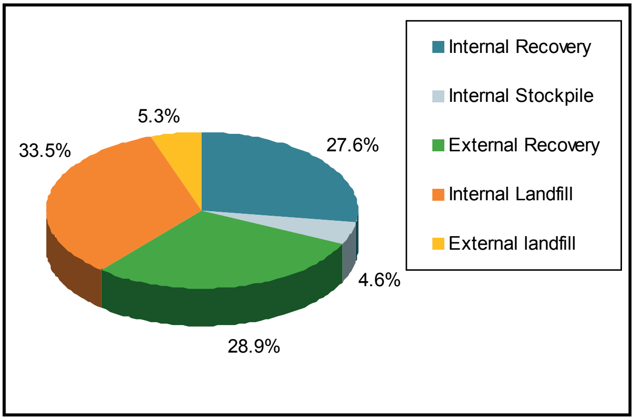
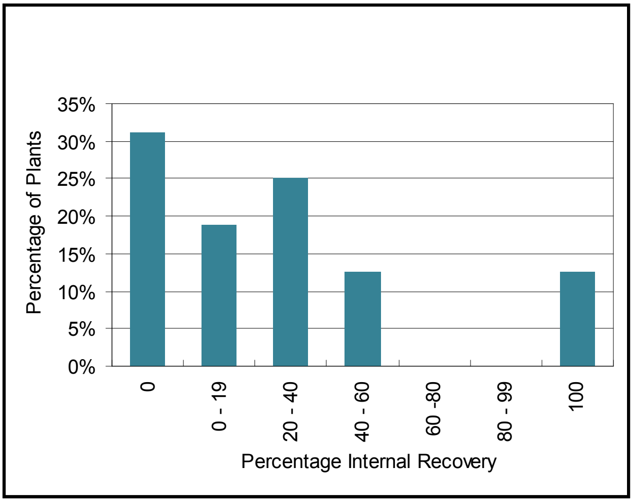


Figure 33: Main destinations

Internal and external recovery analysis



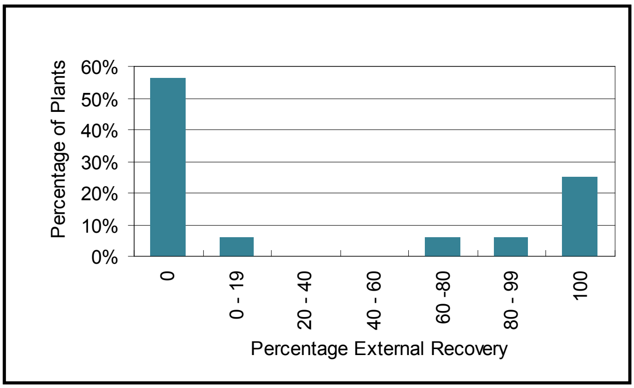


Figure 34 (a) and (b): Distribution of internal and external recovery for BOF SM slag (in %)

Unfortunately, earlier surveys did not include suitable data for comparison.

Main destinations

Steel company processes are the main destination for internal recovery, with nearly 50% of internal recovery (IR) (13.4% of total). BOF is the main recovery channel (16.45% of IR, 4.5% of the total).

Construction is by far the major external destination with 96.6% of all external recovery (ER) (27.9% of total) with essentially road making (61.8% of ER and 17.9% of total).

Ten plants responded regarding use in the process but only seven detailed the destinations.

The BOF plant accounted for approximately one-third of process recovery (three plants declared total process reuse in BOF, and one plant recovered 33% to the BOF, with the remainder to the EAF). The other process destinations include BF (one plant declared total use), or sinter plant (two plants declared total use). In fact, it is usually BF for large grain, and sinter for fine grain.

SM slag has a different chemical composition (lower iron content and higher alumina content) from BOF slag. This makes it potentially valuable in applications such as materials for calcium aluminate cements or rockwool. However, many applications are only financially viable when the slag customer is located close to the steelworks.

SM slags are not a particularly good material for internal recycling or as aggregates. The main problem is that it is processed together with BOF slags in many plants.

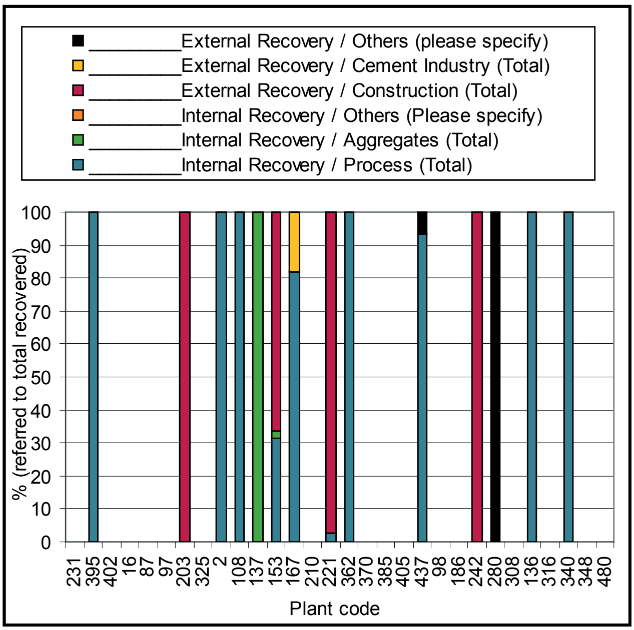


Figure 35: Detail of destinations by plant and by region

Fourteen plants answered in more detail. Plant 280's answer of 'Other' refers to donations for social projects.

BOF SM slag examples of applications and management practices

Basic treatments

The following treatments were reported:

- treatment of liquid (molten) slag by two plants - both 100% - one in the 'Asia Other' and the other in the 'West Europe' region
- air-cooling (100% in 12 out of 20 plants)
- water granulation by one plant - 100% - in the 'Asia Other' region
- metal recovery (screening, magnetic sorting) - 100% - in 15 out of 20 plants
- air granulation and steam aging was not reported by any plant covered in the study
- crushing/screening - 100% - in seven out of 20 plants.

Good practices

Two examples were given:

- Reuse of secondary metallurgy (SM) slag in the BOF: after sizing and cleaning, it is used as fluidiser due to its high alumina content; and also used as a replacement for lime due to its high CaO content.
- Reuse in the sinter plant: proper segregation of converter (LD), SM and de-sulphurisation slag, allowed improved slag handling and utilisation.

Projects and innovations

One company intends to replace a certain amount of burnt lime with SM slag.

Another plant will treat its SM slag with an in-house technology (details not provided).

BOF SM slag forecast

Only 13 plants provided data (see the appendix for details). It is not possible to predict future trends based on the small number of responses and the diverse range of solutions currently in use.

Estimated risk

Grain size (10 to 50 mm required), phosphorus and alumina contents all pose limitations on recovery.

Anticipated drivers of change in the future

Here again it is difficult to have a clear picture of the future due to the small number of responses. Nevertheless, from our results, the most likely future drivers of change may be 'Technical/ Industrial' (selected by 7 plants). Meanwhile, the drivers of 'Marketing' (3 plants), 'Quality Control' (1 plant), 'Management' (1 plant), 'R&D' (2 plants) and 'Promotion' (0 plants) were not considered by responding plants to be as important.

Conclusions for SM slag

BOF SM slag is quite different from BOF slag in chemistry. Therefore, the first and key good practice (not employed by all plants), is to separate the processing of SM slag and BOF slag. Otherwise, some BOF and SM slag applications cannot be applied.

Some plants manage to achieve 100% recycling of BOF SM slag, either internally or externally.

As SM slag normally has a low iron content, its internal process recycling value is lower than the value of BOF slag. Its particular value comes from its relatively high alumina content, which can be used in the steel shop as flux, or at the sinter plant or BF when bauxite is needed, depending on the chemistry of the main raw materials.

External applications include use in construction aggregates. However, better opportunities may be available if certain types of industries were located at an economical transport distance. Due to its high alumina and lime and low iron content, substituting bauxite and lime, SM slag is a good raw material for cement kilns, calcium aluminates and the cement and rockwool industries.

Desulphurisation (de-S) slag

The survey asked for figures before and after metal recovery and for wet or dry slag. We considered wet slag after metal recovery and calculated the missing data using an average moisture of 7.5% and an average metal recovery of 454 kg metal per tonne of slag.

Representation and production	Number of plants: 23 out of 60 A: 20 gave generation figures B: 18 gave destination figures Regions: all regions except CIS and North America		
	Production: 103 Mt (A) and 84 Mt (B) crude steel (about 10% of 824 Mt - world BOF steel production in 2006)		
Tonnage and generation	1.1 Mt de-S slag (wet after metal recovery) (estimated) (kg/t CS) (Min/Average/Max): 0.8 / 11.1 / 27.9 (wet after metal recovery) Metal recovery: average estimated at 454 kg/t slag, (Min/Max=154/700)		
Main issues	High sulphur, high alkali, high free lime		
Destinations	Total recovery: 77.9% (internal: 53.6, external: 24.3)	Stockpiling: 0.6%	Landfill: 22.1% (internal: 19.4, external: 2.7)
	Internal recovery (IR): process with nearly 50% of internal recovery (IR) (13.4% of total). Among the processes, BOF is the main recovery channel (16.45% of IR, 4.5% of total).		
	External recovery (ER): construction is by far the main destination with 96.6% of ER (27.9% of total), with roadmaking (61.8% of ER and 17.9% of total).		

Table 14: Summary of responses

Generation

Twenty plants provided data on de-S slag, covering all regions except CIS and North America, representing 103 Mt crude steel and about 1.1 Mt de-S slag (wet after metal recovery), considering the assumptions mentioned earlier.

As not all steel necessarily goes through a desulphurisation stage, the specific tonnage generation of de-S slag is unknown. Therefore, what is shown in Figure 36 and Table 15 below is an approximation, certainly under-estimated, derived by dividing the slag tonnage by total crude steel production.

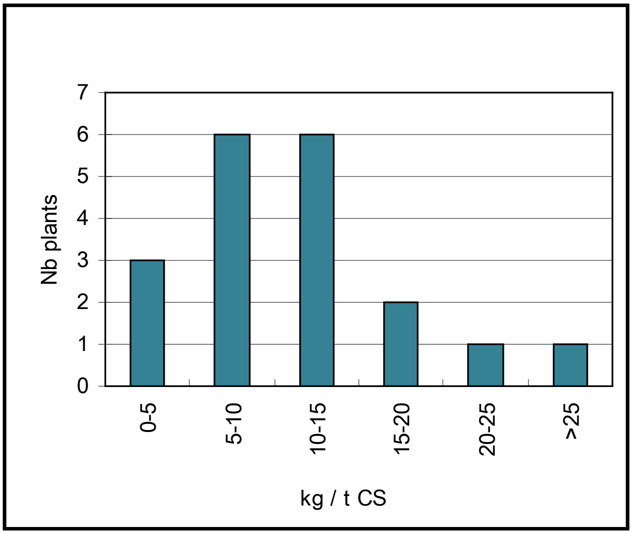


Figure 36: Distribution of de-S slag specific generation

Regions	Ratio kg slag/t steel	No. of plants
AO	2.2	2
AD	12.2	3
EU	11.6	10
LSA	7.0	2
MEA	20.7	3

Table 15: Specific generation by region for de-S slag

The differences in the results could be due to the treatment ratio and the steel grades which vary by company and by region.

Metal recovery

An average metal recovery rate was calculated from nine plants that gave slag tonnage data both before and after iron recovery (on either a dry or wet basis).

Six plants recovered 450 to 600 kg of metal per tonne of slag (to rebuild missing data we assumed an average of 454 kg/t of slag).

There was a considerable range in the reported percentage metal recovery, from 154 to 700 kg/t of slag, with geography having no apparent effect. More information on the type of de-sulphurisation process employed at each plant would be needed to explain the differences in the reported figures.

Chemistry and main issues

Only three plants reported free lime content (all around 2-3%). Other plants with high CaO/SiO_2 levels in their de-S slag will certainly also have a high free lime content.

Three other plants reported levels of fluoride and have low CaO/SiO_2 values, indicating use of CaF_2 as a desulphurisation agent. This practice may lead to other problems like fluoride leaching, which tends to be a country-specific problem.

High sulphur content is mentioned as a problem for reuse.

Plant code	Water / Moisture	CaO	Free lime	SiO_2	Al_2O_3	Total S	Total F	CaO/SiO_2
231		38.3	2.41	26.7	6.5	0.92		1.4
395		14.5		10	1.8			1.5
97	25	40	2	12	4	0.6		3.3
87	5	37.2	3	25.7	11.3	0.6	0.09	1.4
203		54		10.9	8	2.3		5.0
221		29.4		10.87	3		0.004	2.7
2		12			1	1.4		
405	6	37		9	3.4	2.9		4.1
437	6.5	32.7			3.6	0.3		
362		50		22	12.5	0.25		2.3
167	5.4	18.1		14.37	2.3	0.92	0.018	1.3
137	5	42		1.9	4.4			22.1
280	7	30.2		13	6.6	0.816		2.3
242		37		35	14	0.8		1.1
136		5.68		3.02	0.33	0.006		1.9

Table 16: Chemical elements for de-S slag

Below are the results from the 18 plants that provided data, in our five main categories.

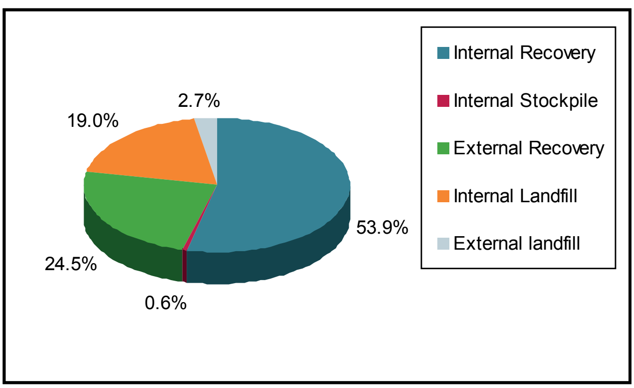


Figure 37: Main destinations for de-S slag

Compared with the data for BOF converter slag, the internal recovery ratio is higher and external recovery is much lower. The main reason for this is the high lime and low phosphorus contents, rendering this slag more amenable to recovery in the sinter process. Free lime, sulphur and sometimes fluoride limit the use of slag, therefore a greater proportion is sent to internal landfill.

External and internal recovery analysis

Internal recovery: 90% is recovered in the process (sinter plant or EAF – only two plants) and the rest is reused as aggregates for engineering landfill inside the plant (also two plants).

Half of all externally recovered de-S slag goes to construction uses such as roads (three plants gave construction as a response, of which one specified roads). The other 50% is recovered by external EAF plants (two plants gave this response).

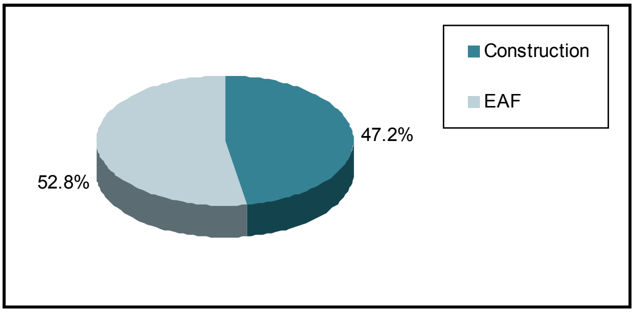


Figure 38: External recovery of de-S slag

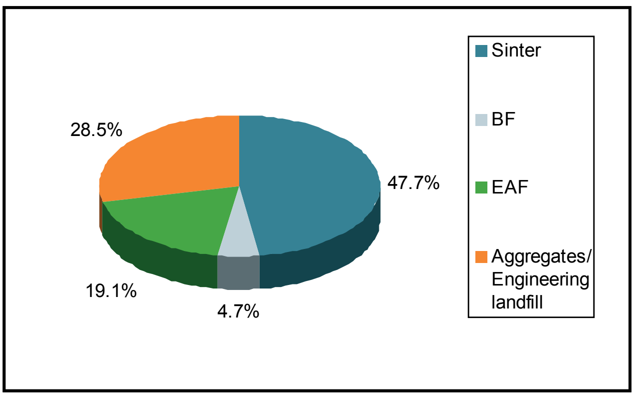


Figure 39: Internal recovery of de-S slag

Basic treatments

	Yes	No	No reply
AO	0	0	2
AD	2	2	0
EU	4	8	0
LSA	2	0	0
MEA	2	1	0
Total	10	11	2

Table 17: Primary sorting by region for de-S slag

The reasons given for primary sorting were metal recovery, segregation of high fluorine content slag and size segregation for feeding to the BF (coarse fraction) and sinter plant (fine fraction). The reasons given for not sorting were limitation of space and treatment of de-S slag together with converter and secondary metallurgy slag.

	NUMBER OF PLANT	TREATMENT OF LIQUID (molten) SLAG	AIR-COOLING	AIR GRANULATION	WATER GRANULATION	METAL RECOVERY (screening, magnetic sorting)	AGEING BY WEATHERING	STEAM AGEING	CRUSHING/SCREENING
AO	2	1	1	0	1	2	0	0	2
AD	3	0	3	0	0	3	1	0	1
EU	11	1	10	0	0	11	4	0	5
LSA	2	0	0	0	0	2	0	0	0
MEA	3	0	3	0	0	1	0	0	0
Total	21	2	17	0	1	19	5	0	8

Table 18: Basic treatments by region for de-S slag

The most commonly employed processes are air cooling and metal recovery. One plant uses both a liquid slag treatment and water granulation. Other treatments mentioned include water sprays for fume control, balling and oxycutting.

Conclusions for de-S slag

- de-S slags are more difficult to recover than converter slag because of their lime, sulphur and sometimes fluoride contents.
- Half of the plants that responded recovered 100%.
- It is mainly internally recovered.
- Internal recovery is mostly done through the sinter, EAF and also internal engineering landfill.
- External recovery is half done through construction and half through EAF in other steel plants.
- Primary sorting is done by about half of the plants. The rest either have space limitations or first mix it with the other steelmaking slags.
- The most commonly employed treatment processes are air cooling and metal recovery.

EAF primary slag

<table>
<tr><td rowspan="2">Representation and production</td><td colspan="3">Number of plants: 30 out of 60, 24 retained for analysis
Regions: all regions except the CIS and ‘Asia Developed’.</td></tr>
<tr><td colspan="3">Production: 30 Mt EAF crude steel (CS) (15% of 195 Mt total crude steel collected)</td></tr>
<tr><td>Generation</td><td colspan="3">4.5 Mt EAF slag (wet, after metal recovery)
(kg/t CS) (Min/Average/Max): Scrap only: 65/111/141, Midrex: 142/199/342, RHF: 168/229/272
Metal recovery: average calculated at 6 kg/t, (Min/Max=4.4/13.4)</td></tr>
<tr><td>Main issues</td><td colspan="3">Legal and marketing issues (government and market restrictions), technical (material deterioration and sinter plant limitations)</td></tr>
<tr><td rowspan="3">Destinations</td><td>Total recovery: 68.2%
(internal: 7.6, external: 61)</td><td>Stockpiling: 4.8%</td><td>Landfill: 27.1%
(internal: 25.3, external: 1.8 – 1 plant only)</td></tr>
<tr><td colspan="3">External recovery (ER): construction (98% of ER or 59.3% of total), and particularly roads (59% of ER or 35.7% of total)</td></tr>
<tr><td colspan="3">Internal recovery (IR): process (43% of all IR or 3.3% of total) and particularly sinter (31% of IR or 2.4% of total)</td></tr>
<tr><td>Good practices</td><td colspan="3">Replacement for mined limestone, aggregate in civil construction with special attention for legal requirements. Improve management of this by-product and find new ways for recovery.</td></tr>
<tr><td>Forecast at a glance</td><td colspan="3">Go more into construction uses (cement), developing more treatment technologies and quality control to ensure stable and sound mechanical and environmental properties.</td></tr>
</table>

Table 19: Summary of responses

To include as much of the data provided as possible in the analysis, assumptions have been made on the levels of metal recovery achieved (estimated average of 6 kg/t of slag) and also moisture levels contained therein (1% on average).

Representation of data

Replies to the questionnaire were received from 60 sites, of which 30 stated they were operating EAFs. After screening the data received 24 of these sites were included in the final analysis. They included three from ‘Asia Other’, seven from ‘West Europe (EU)’, 10 from ‘Latin and South America (LSA)’, three from ‘Middle East, East Europe and Africa (MEA)’ and one from ‘North America (NA)’. ‘CIS (Russia)’ and ‘Asia Developed’ were the only regions not represented.

These 24 sites represent around 30 Mt of steel produced a year using the EAF route, with an average annual steel production of 1.25 Mt. The largest producer manufactured 3.4 Mt a year.

Analysis of generation

The quantity of wet slag produced after metal recovery operations was considered a key factor in this section in terms of identifying the best performers. The report appendix gives geographical information.

The average specific generation rate was calculated to be 151 kg of slag/tonne of crude steel.

The type of reduced iron processes used (Midrex, RHF) seems to have an influence on specific generation (rather than geography).

The statistics from plants only operating EAFs (charging 100% scrap) results in a calculated average slag generation rate of 111 kg of slag/tonne of crude steel (this is 'wet' post metal recovery operations). The 1987 study indicated these levels were between 100 – 160 kg of slag/tonne of crude steel, and the 1994 study levels were 116 kg of slag/tonne of crude steel. It appears therefore, that the slag generation rates have not changed significantly over time.

Those plants reporting the use of DRI as a charge material (between 25%-100% DRI) also appear to have much higher levels of slag production. For instance, those operating with 100% DRI produce on average 250 kg of slag/tonne of crude steel, more than double that of those using 100% scrap sources. Lack of data meant that it was not possible to correlate the proportion of DRI charged with the slag production ratio.

Metal recovery

On average, metal recovery rates were calculated to be 62 kg/tonne of slag with a minimum and maximum rate of 44 and 135 respectively.

Chemistry

Two main observations were noted in relation to the slag chemistry:

- Metallic iron is not a parameter that is routinely monitored. It is suggested that this is because the most common use of EAF slag is in construction (mainly in roads) an as such this element is not a limiting factor to this particular use.
- 'Asia Other' and 'Middle East, East Europe and Africa' monitor and analyse more parameters than the other regions, whilst in South America the analysis of trace elements is not so detailed. There was no data from North America.

Results

%	Max	Min	Mean	Stdev	No. values
Moisture	2	0.13	0.98	0.8	4
CaO	47.38	6.4	29	8.4	23
Free lime	1.14	0.1	0.36	0.5	5
MgO	11.83	1.3	6.68	2.5	21
MnO	7.5	0.1	4.24	2.3	22
Total Fe	55	13.61	29.2	9.8	22
Metal Fe	11.4	0.8	4.07	4.4	5
SiO_2	20	0.07	13.1	5.2	22
Al_2O_3	13.9	0.6	5.24	3.0	22
TiO_2	0.82	0.08	0.51	0.3	10
Total S	1	0.05	0.21	0.2	16
Total P	0.59	0.079	0.32	0.2	13
Total F	0.4	0.03	0.18	0.2	3
Total Cr	2.52	0.01	1.03	0.8	14
Total Ni	0.01	0.0024	0.0045	0.004	4
Total Cd	0.002	0.002	0.002		1
Total V	0.1	0.01	0.06	0.04	5

Table 20: EAF slag basic components: Min, Max and Mean

%	All plants	No DRI (scrap only)	Midrex	RHF
Moisture	1	1.3	0.6	0.13
CaO	29	30.8	28	24.9
Free lime	0.36	0.36	0	no data
MgO	6.7	6.9	5.9	7.1
MnO	4.2	5.5	2.6	1.86
Total Fe	29.2	27.2	30.4	34.4
Metal Fe	4.1	1	11.4	3.5
SiO_2	13.1	13.7	15.1	8.9
Al_2O_3	5.2	5.17	4.1	7.1
TiO_2	0.51	0.60	0.6	0.29
Total S	0.21	0.26	0.075	0.16
Total P	0.32	0.39	0.21	0.15
Total F	0.18	0.22	0.055	no data
Total Cr	1.03	1.47	0.21	0.4
Total Ni	0.004	0.005	0.001	0
Total Cd	0.002	no data	0.0007	no data
Total V	0.063	0.09	0.02	0.01

Table 21: EAF slag components: Mean values for all, no DRI (scrap only), Midrex and RHF

As shown in Tables 20 and 21, there is significant chemical variation. Whilst this could be attributed to the analytical methods used, it could also be the type of feed to the EAF. In other words, there may be a relationship between slag chemistry and the specific charge materials. In plants charging 100% scrap it was found that in general:

- Total Fe and metal Fe content of the slag is lower than those with mixed charge feed types.
- The levels of CaO in the slag appear higher, as does the S, P, F and 'heavy metals' content.

The chromium content of these slags is considered important because any CrVI therein is hazardous. It is soluble and leachable. In the EU, a directive sets a maximum of 2 ppm soluble Cr_6 in cement since January 2005. This is a real limitation to the use of steel slags in clinker kilns.

Results indicate the slags contain an average Cr content of 0.103% with a minimum and maximum of 0.252% and 0% respectively.

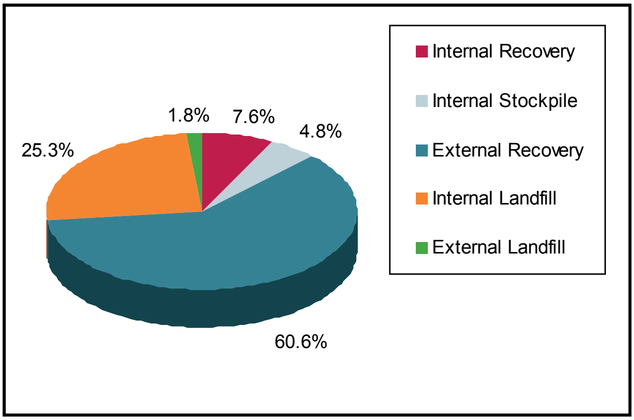
In the clinker kiln, part of this Cr (present as Cr_2O_3) may potentially oxidise to soluble CrVI. As in the EU (and possibly wider afield) this particular form of chrome is classified as a Category 2 carcinogen and is also classed as ecotoxic, there are specific limits to the levels allowed in its use.

Main issues of concern

Respondents reported several issues of concern in their responses to the questionnaire, including:

- Legal issues: recovery activities frequently require specific approval from Legal and Regulatory Authorities.
- Technical issues: the mechanical and/or chemical characteristics of the slags may limit their levels of internal and external utilisation.
- Marketing issues: the lack of external customers/contractors reduces the potential to recover and utilise these slags.

Destinations according to our five main categories



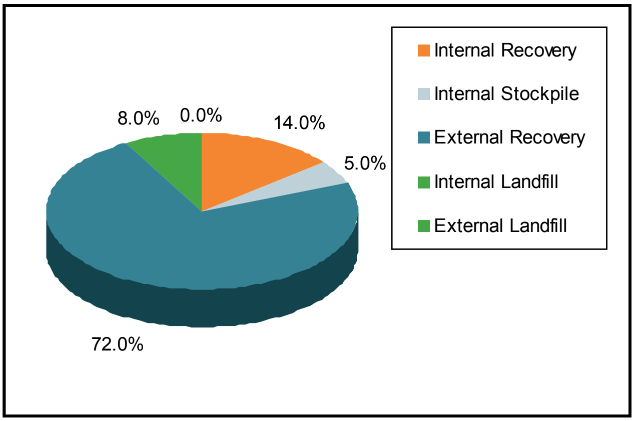


Figure 40: Main destinations of EAF slag, all plants (a) and best performers (b) in %

Most plants, 22 out of the 24 that responded, report having internal stockpiles of this particular slag. The majority, however (18 of the 22), reported that the levels 'in stock' were less than 30% of their total annual production.

Many of the plants reported that by using a combination of internal and external recovery routes, they could use all of their arisings, and that landfill is usually a last resort. For more details, see the appendix.

Distribution of internal landfill

Landfill seems to be more common in 'Middle East, Eastern Europe and Africa'. Two out of three plants landfill some material. There is insufficient data for precise trends.

It would also appear that having a DRI plant at the same site as the EAF plant increases the prevalence of sending some of this slag to landfill (especially internal landfill) rather than recovering it. The reasons may be associated with market and regulatory aspects rather than the specific chemical factors, as landfill is the cheapest and most simple solution.

Since the 1994 study there has been a significant decrease in the number of plants actually landfilling this material.

External and internal recovery analysis

External recovery is more common, in particular in 'West Europe', 'Asia Other' and 'North America', while internal recovery for uses other than process is a little more common in 'South America'.

It may be that in South America EAF plants are still increasing their activities and changing their lay-out so that it is easier to find internal destination for EAF slag. In the EU, 'Asia Other' and North America there is probably less need for slag for internal activities and the obligation to acquire authorisation for internal use makes it easier to find external destinations already approved. Unfortunately, the open answers provided by plants do not give enough information to confirm this hypothesis.

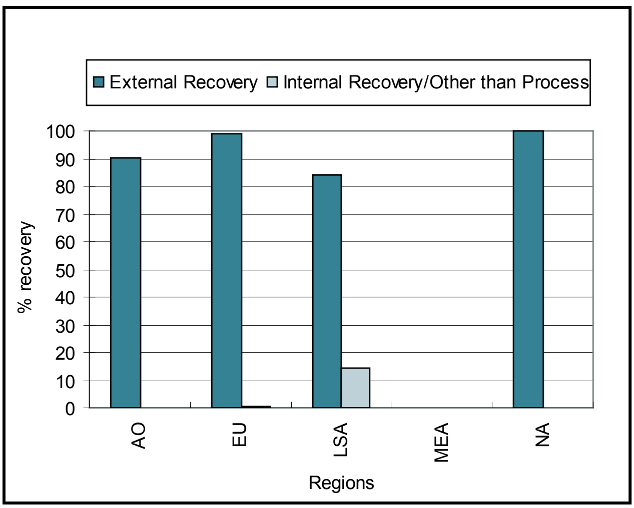


Figure 41: Recovery by region

Study year	Total recovery rate in %
1984	63 (max)
1990	77 (average)
2006	68 (average, 73 with internal stockpile)

Table 22: Earlier studies recovery results

Table 22 indicates that the levels of slag recovered has not changed significantly.

Road construction appears to be the main utilisation route. The best performers (those who achieved 100% recovery) have managed to develop more diversified recovery routes, for instance via ballast, concrete, clinker, waterways.

Table 23 highlights the different recovery routes and proportion of slag recovered via those routes for the best performers and for all plants.

	All plants	**Best performers (recovering 100% EAF slag)**
External recovery (ER)	60.6% of total	72% of total
Construction	98% of ER	95% of ER
Construction/Road	59% of ER	61% of ER
Construction/Asphalt pavement	6.3% of ER, 3.8% of total (2 answers)	0%
Waterways	1.5% of ER (1 answer)	3.2% of ER
Railway/Ballast	4.5% of ER (3 answers)	3.1% of ER (1 answer)
Aggregate for concrete	2.1% of ER (1 answer)	4.7% of ER (1 answer)
Cement/Raw material for clicker kiln	2.1% of ER (1 answer)	4.7% of ER (1 answer)
Internal recovery (IR)	7.6% of total	14% of total
Process	43% of IR	61% of IR
Process/Sinter	31.3% of IR	47% of IR

Table 23: Destinations for all plants and for best performers

The results above indicate that the best performers recover more material via the sinter plant and through the process itself.

The table also lists the main ways slags are used, again enabling comparisons to be made between the best performing plants and the average plant.

Details of main recovery

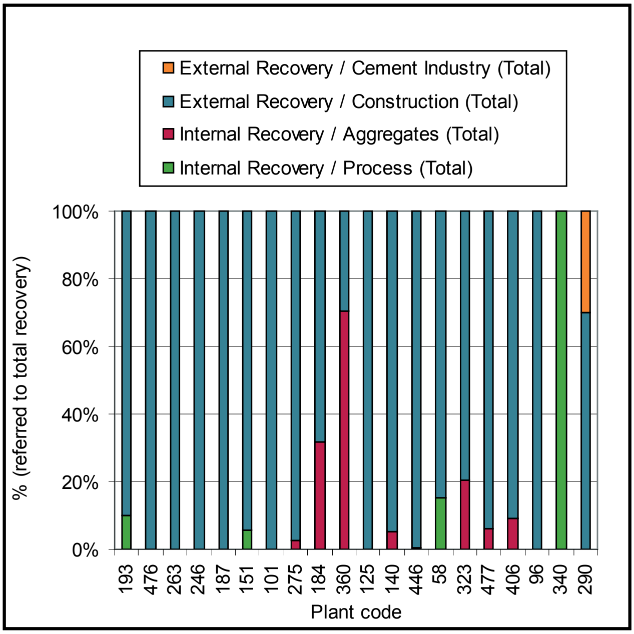


Figure 42: Details of internal and external recovery for EAF slags

BP = 231, 193, 263, 187, 275, 360, 58, 340, 290

- External recovery – Construction is the most common destination for EAF slag. Road construction is the main activity and in 'West Europe' and 'Asia Other' it represents more than 90% of recovery.
- Internal recovery – Aggregates are common too. They represent the same destination the previous except that the destination is developed internally.
- Reuse in internal process is chosen sometimes. In particular, when there is a sinter plant on the site, EAF slag is recovered in the sinter. Some plants (151, 58, 340) declared that they reuse a little part of their EAF slag (5-15 % corresponding to 7,000-20,000 tonnes/a) in the same EAF. It could be useful to have more information about this kind of recovery, to understand if there is something that limits reuse of EAF slag in the EAF.
- Reuse in the cement industry is rare. It is done by one of the plants in the survey. Unfortunately, no data on chemical composition is available for this slag so it is not possible to check if it has any particular (and reproducible) characteristics that allows this type of recovery.

Steel slag, from the EAF and BOF processes, is used as a raw material in clinker kilns in North America and Asia. The quantity is limited by the iron content of the slag (total Fe). In Europe an EU directive sets a limit of 2 ppm of soluble Cr_6 in cement.

Stockpile tonnage and trends

Stockpiling is practiced by a few plants. In the questionnaire, it was considered as temporary storage to be recovered. We analysed stockpile trends and amounts but no global trend was seen, as stockpile is probably dependant on land availability and on local environmental regulations.

EAF slag examples of applications and management practices

Basic treatments

Crushing and screening operations, in combination with metal recovery techniques, are used to make material suitable for road construction and asphalt (especially within Europe). Some sites report 'aging' slags, again primarily in Europe and possibly due to the more stringent requirements associated with preventing problems from expansion of the material in situ.

One plant suggested that they treat the molten slag. Indeed, in some EAF plants there are additions of borates to the molten slag to minimise fine dust after cooling.

The information provided by the respondents suggests that air cooling of EAF slag is more prevalent in Western Europe, 'Middle East, East Europe, Africa' and North America, whilst water-based cooling is used more often in 'Asia Other', and Latin and South America.

Air cooling systems do not include any 'air granulation', while water cooling accelerates the cooling which reduces the grain size.

Good practices

Some recent examples of practices and processes include:

- Use of EAF slag in clinker as a replacement for mined limestone
- Use of EAF slag as an aggregate in civil construction.

Several plants suggested that the 'drivers' for the implementation of these practices are principally the introduction of new legislation, as well as the opportunity to develop new recovery routes.

Projects and innovations

Seven plants provided data on projects and innovations in EAF and LF slag management.

Two projects aimed at EAF slag were:

- increase the potential to reuse slag directly in hot metal production processes;
- define standard quality parameters to increase the acceptance of EAF slag as a suitable material for construction (roads, civil construction etc.).

All the quoted projects are under development and have not yet been fully implemented.

Forecast and trends for the future

It is forecast that treatment technologies will continue to be developed, to recover more EAF slag.

EAF slag forecast

In general, the majority of plants responding to the questions in this section agreed that there is potential to increase the levels of EAF slag used in cement production. Greater use in roads and civil construction was, however, more contentious. Some saw potential but others thought this would be limited or difficult to achieve.

Respondents suggested that the adoption of treatment technologies (cooling systems and crushing systems) and quality control processes that could guarantee stability and consistent mechanical and environmental properties would help improve the use of EAF slag in construction activities, especially in asphalt. The appendix provides more details.

Anticipated drivers of change in the future

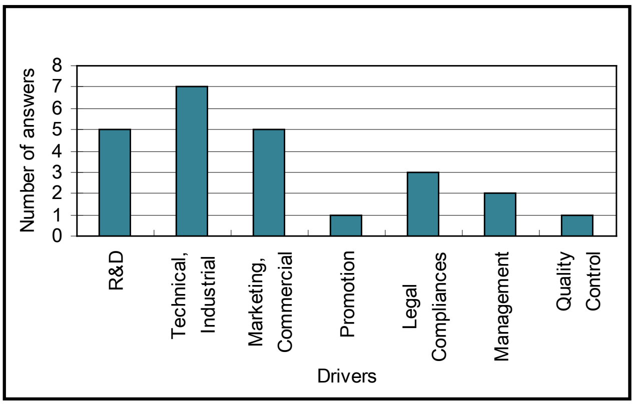


Figure 43: Driving factors in future EAF slag management evolution

Conclusions for EAF slag

- The generation rate of EAF slag appears to be directly related to the charge material, with plants using DRI producing, on average, greater relative quantities of slag.
- Crushing, screening and metal recovery are commonly used as a means of processing the slag.
- The main constituents of EAF slag are CaO and Total Fe which normally represent more than 50% of the slag; the content of free lime is generally low in comparison with BOSF slag. Other minor constituents include magnesium, manganese, silicium and aluminium with their individual content ranging from 5-10%. Sulphur, phosphorus and fluorine contents are approximately 0.5% respectively, whilst vanadium and chromium are also present to some degree.
- Many plants reportedly recover and utilise 100% of the slag through a combination of internal and external routes, with its major use being in road construction.
- Environmental and economic drivers are pushing plants to developing new processes and practices to further enhance recovery rates.

EAF secondary metallurgy slag

<table>
<tr><td>Representation and production</td><td colspan="3">Number of plants: 30 out of 60 for EAF, 24 retained for the analysis of EAF slag and 16 for EAF SM slag
Regions: all regions except CIS and 'Asia Developed'</td></tr>
<tr><td></td><td colspan="3">Production: 20 Mt crude steel (66% of all EAF slag and 10% of total crude steel collected in the survey)</td></tr>
<tr><td>Generation</td><td colspan="3">370 kt EAF SM slag (wet, after metal recovery)
(kg/t CS) (Min/Average/Max): 6.7/18.6/63.2
Metal recovery: calculated at 25kg/t on average (Min/Max: 1/60)</td></tr>
<tr><td>Main issues</td><td colspan="3">Legal, technical and marketing issues</td></tr>
<tr><td>Destinations</td><td>Total recovery: 36.2% (internal: 18.8, external:17.4)</td><td>Stockpiling: 6.1%</td><td>Landfill: 57.7% (internal: 33.7, external: 24)</td></tr>
<tr><td></td><td colspan="3">External recovery (ER): construction (64% of ER and particularly roads and aggregates for concrete 7% and 10% of ER; 3 sites) and cement industry (36% of ER for hydraulic binder or cement; 2 sites)</td></tr>
<tr><td></td><td colspan="3">Internal recovery (IR): process (100% of all IR) and particularly sinter and EAF (81% and 19% of IR but 1 plant only for each)</td></tr>
<tr><td>Good practices</td><td colspan="3">Projects on SM slag are focused on the possibility to reuse SM slag directly in EAF process to replace a certain amount of burnt lime.</td></tr>
<tr><td>Forecast at a glance</td><td colspan="3">Go more into construction uses (cement), developing more treatment technologies and quality control to ensure stable and sound mechanical and environmental properties.</td></tr>
</table>

Table 24: Summary of responses

Representation of data

Replies to the questionnaire were received from 60 sites, of which 30 stated they were operating EAFs. After screening the information, data from 16 of these sites was used in the final analysis. They included two from 'Asia Other', seven from 'West Europe (EU)', four from 'Latin and South America (LSA)', two from 'Middle East, East Europe and Africa (MEA)' and one from 'North America (NA)'. 'CIS (Russia)' and 'Asia Developed' were the only regions not represented.

These 16 sites represent around 20 Mt of steel produced a year via the EAF route.

Analysis of generation

As the following figures underline, SM slag-specific production varies significantly between plants even though the EAF steelmaking process is similar.

The average quantity of SM slag produced was found to be approximately 20 kg of slag/tonne of crude steel, with a maximum and minimum production of 60 kg and 40 kg of slag/tonne crude steel respectively.

Unlike EAF slag, there does not appear to be a correlation between the quantities of SM slag produced and the type of feed material to the EAF, although the lack of reported data makes this an observation rather than a statistic.

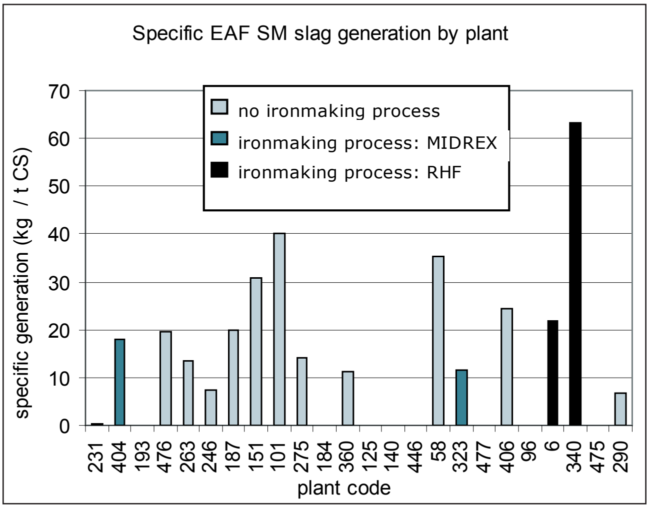


Figure 44: Specific EAF SM slag generation by plant and region and influence of DRI

	EAF SM slag (Kg/t), wet and after metal recovery		
	Max	Mean	Min
None	40.2	19	0.17
Midrex	17.8	15	11
RHF	63.2	42	22

Table 25: Specific generation according to DRI

Metal recovery

Plant	Metal recovery (kg/t slag)
231	600.0
151	286.0
101	150.0
58	10.0
340	200.0

Table 26: Metal recovery in the study for EAF SM slag

Only five plants provided data relating to pre- and post-metal recovery operations.

Although there appear to be two rather extreme values, the others that were reported are in fact similar in magnitude.

Chemistry

Two main observations were noted in relation to the slag chemistry:

- Metallic iron is not a parameter that is routinely monitored. This is probably because the majority of this slag is landfilled and it is unlikely that the Fe content matters.
- 'Asia Other' appears to routinely analyse more parameters than the other regions, whilst in South America the analysis of trace elements is not so detailed. North America did not provide any data.

Results

%	Min	Max	Mean	No.
Water/Moisture	0.34	8.1	2.41	6
CaO	6.4	60.85	46.04	14
Free Lime	0.05	30	15.03	2
MgO	3.6	19.9	9.56	14
MnO	0.51	6	1.92	13
Total Fe	0.5	55.55	9.29	13
Metal Fe	1.85	4	2.62	3
SiO_2	0.04	30.65	17.53	14
Al_2O_3	1.12	32.24	11.55	14
TiO2	0.08	1.28	0.44	6
Total S	0.02	1.53	0.68	11
Total P	0.02	0.34	0.12	8
Total F	0.01	5.45	2.02	5
Total Cr	0.01	0.896	0.15	10
Total Ni	0.01	0.029	0.02	2
Total Cd			0.01	1
Total V			0.01	1
Total B				0
Total Se				0

Table 27: Chemical compositions

The main constituent of SM slag appears to be CaO which normally represents close to 50% of the slag. The free lime content of this particular slag was also reported to be reasonably high, averaging 15%, therefore making it unsuitable for use in construction. Other major components include SiO_2, Al_2O_3 , MgO, and Fe, each ranging from 10-20%.

The presence of SiO_2 , MgO, and Fe at about 10% each probably means that some EAF slag is poured into the steel ladle together with steel.

S, P, F represent approximately 0.1-1% each. Cr and Ti are also present.

As shown in Figure 45, there is a significant degree of chemical variation. Whilst this could be attributed to the analytical methods used to determine the analysis, it could also be due to the type of feed to the EAF.

Although there is limited data available, it can be observed that the presence of a DRI plant appears to have no significant influence on SM slag composition.

Main issues

List of problems collected

In general, and due to the issues outlined earlier on slag chemistry and more specifically the free lime content, the use of EAF slag is more challenging than some of the other slags. Thus, the importance of ensuring that EAF and SM slag are segregated is recognised by many plants.

However, the chemistry of SM slag does sometimes lead to increased use in internal processes such as a flux in steelmaking or as a raw material for cement kilns or filler in concrete.

Destinations according to our four main categories

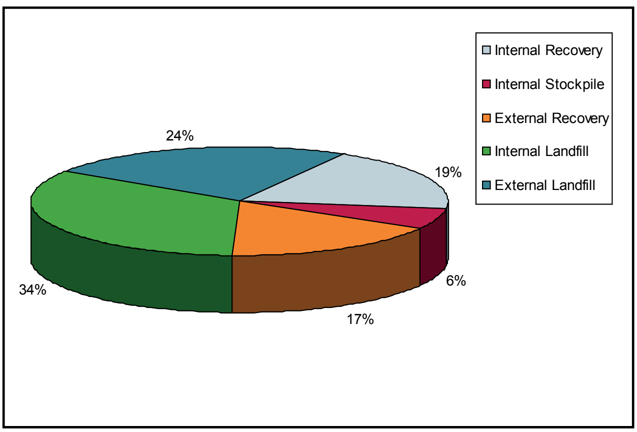
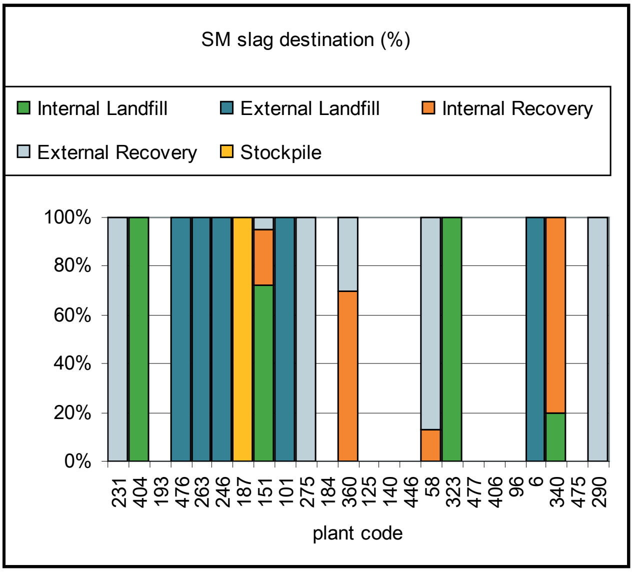


Figure 45: Main destination of EAF SM slag

The figure above outlines the various routes by which SM slag is either recovered or disposed of. It should be noted that due to uncertainties regarding the definition of a stockpile and the period over which material may be stockpiled, material originally reported as being internally recovered via stockpile has been included as 'internal stockpile'.



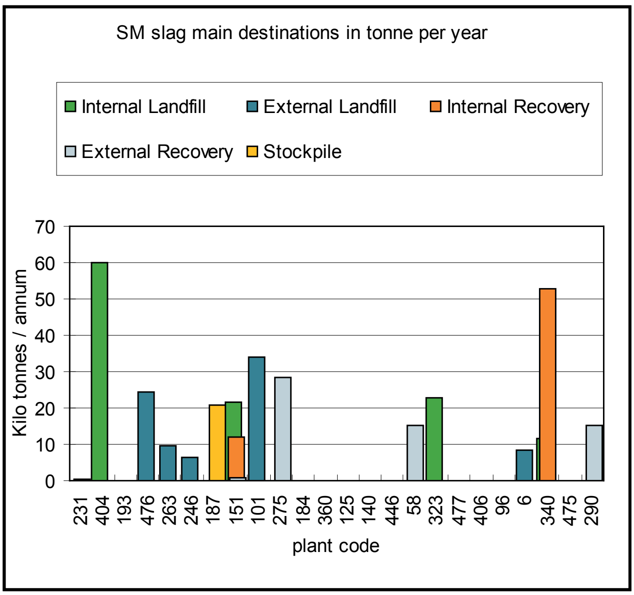


Figure 46 (a) and (b): EAF SM slag main destinations by plant (% and tonnage of generated slag)

Only five plants out of the 16 reported using 100% of the material for a combination of internal and external routes. Seven plants reported that they landfill 100% of the SM slag.

A degree of landfilling appears to be required regardless of geographical location, and this route appears to be more prevalent within Europe where five out of seven plants landfill the majority of this material.

The use of external landfills is also preferred to the alternative of using internal landfills, again this is more evident within Europe.

The responses from plants indicated that the requirement to landfill was not related to the nature of the slag. No plant reported that it was considered 'hazardous' or 'toxic'. The primary reason for landfilling was reportedly that it was difficult to determine a sustainable and acceptable route or use for the slag. Some companies have initiated research on this specific material.

External and Internal recovery analysis

It appears that there is more success in recovering this material in both North and South America, although details on how and where the material is recovered are sparse. Some plants recover a small proportion of the material via the sinter plant and some of it goes out for use in construction and cement.

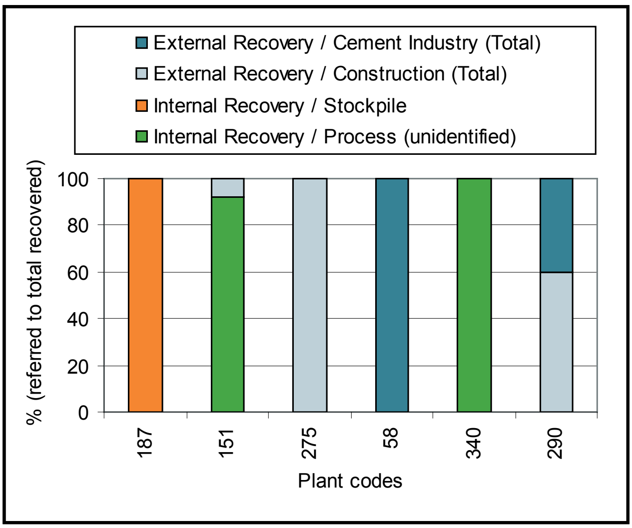


Figure 47: Details of internal and external recovery for EAF SM slags

EAF SM slag examples of applications and management practices

Basic treatments

Few plants provided data indicating the exact quantities being treated by the different processing methods. Hence, it was decided to group the answers into the following categories:

1. Treatment or sorting of liquid slag (primary sorting and treatment of molten slag)
2. EAF slag cooling (air cooling, air granulation, water cooling, water granulation)
3. EAF slag ageing (weather ageing, steam ageing)
4. Metal recovery
5. Crushing/screening.

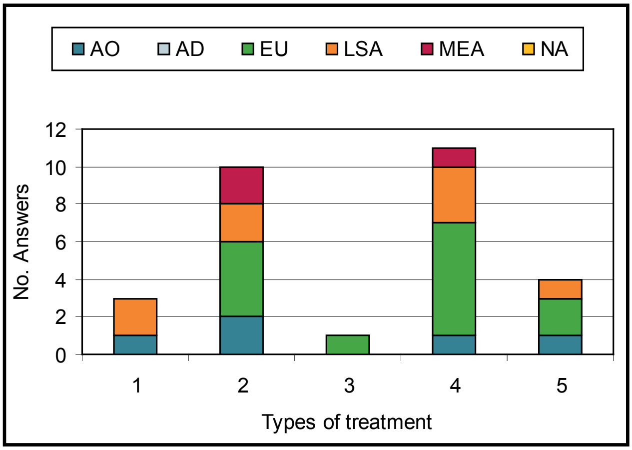


Figure 48: Number of answers for EAF SM slag basic treatments

Once again, the main processing techniques by which this slag is processed was crushing, screening and metal recovery. However, the relative quantities processed via these routes are not as high as those reported for EAF slag. This may be related to the fact that a large proportion of this slag is destined for landfill and its processing is not a pre-requisite for this.

Treatment of liquid slag and primary sorting are only implemented in 'Latin and South America' and 'Asia Other', although there is limited information on this subject. Once again, the use of air cooling is preferred to water cooling especially in 'West Europe' and 'Middle East, East Europe and Africa' where air cooling systems do not include air granulation.

Projects and innovations

Development projects appear to focus primarily on the use of SM slag directly in the EAF as a replacement material for burnt lime.

Forecast and trends for the future

The survey responses consistently indicated that more of this slag could be used in the cement industry in the future, although similar clarity and agreement was not evident on its use in roads or civil construction projects. Several plants indicated that this route into roads and civil projects will develop further over the next five year, whilst others forecasted that there will still be challenges to overcome.

Conclusions for EAF SM slag

There appears to be a significant variation in the generation rate of EAF SM slag, the reasons for which require further analysis.

The total recovery rate for this particular slag is the lowest when compared with the other slags reported in this study.

The chemical (free lime) and physical (fines) characteristics make this slag very difficult to valorise as aggregates in construction. However, some plants do achieve 100% recovery.

EAF SM slag must be totally separated from EAF slag in processing as EAF slag is a very good aggregate and should not become polluted.

Some plants have developed good practices for the cooling process, to prevent fine dust formation.

Dusts and sludges

The following types of dusts and sludges were included in the study:

- sinter dust and sludge
- BF dust and sludge
- alternative ironmaking dust and sludge
- BOF dust and sludge
- EAF dust and sludge
- continuous casting (CC) dust and sludge
- hot rolling mill (HRM) dust and sludge
- cold rolling, pickling, annealing, galvanising dust and sludge.

Sinter dust and sludge

This section of the questionnaire reviews the by-products from the sintering process (traditionally associated with the integrated iron and steelmaking route: BF/BOF).

Sinter dust and sludge was divided into four categories:

- 'Primary collection'
- 'Secondary/handling'
- 'Sludge'
- 'Other'.

See the appendices for details of the 'Other' sinter plant by-products category.

Table 28 below provides a summary of the survey responses.

<table>
<tr><td rowspan="2">Representation and production</td><td colspan="3">Number of plants: 28 out of the 60 respondents have sinter operations. (Group A)
21 answered on dust and sludge generation and their respective destinations. (Group B)
Regions: all regions except CIS and North America.</td></tr>
<tr><td colspan="3">Production:
Group A: 179 Mt sinter
Group B: 156 Mt sinter/3.7 Mt BF dust and sludge</td></tr>
<tr><td>Generation</td><td colspan="3">Primary dust and sludge (kg/t sinter) (Min/Average/Max): 0.08/0.6/24
Secondary dust and sludge (kg/t sinter) (Min/Average/Max): 0.11/10/32
Sludge (kg/t sinter) (Min/Average/Max): 3.3/24.7/54
Others (kg/t sinter) (Min/Average/Max): 0.5/1/2.1</td></tr>
<tr><td>Main issues</td><td colspan="3">The most commonly cited issues were: Alkali content in sinter flue dust causing plants to landfill this by-product and the efficiency of ESP filter.
According to the data poor efficiency of ESP (due to high specific resistivity of flue gas dust) was a significant issue.</td></tr>
<tr><td rowspan="7">Destinations</td><td>Total recovery: 97% (internal: 92.9%, external: 4.1%)</td><td>Stockpile: 0.7% (Included in internal landfill)</td><td>Internal landfill: 2.6%, External landfill: 0.4%.</td></tr>
<tr><td>Primary: Recovery = 97% (internal: 94%, external: 3%)</td><td>Stockpiling = 1.3% (1 plant)</td><td>Internal landfill: 2%, External landfill: 1%</td></tr>
<tr><td>Secondary: Recovery = 99.7% (internal: 99.4%, external: 0.3%)</td><td>Stockpiling: 0</td><td>Landfill = 0.3% (internal)</td></tr>
<tr><td>Sludge: Recovery = 86.4% (internal: 64.1%, external: 22.3%)</td><td>Stockpiling: 0</td><td>Landfill = 13.6% (all Internal)</td></tr>
<tr><td colspan="3">Main destinations for primary dust and sludge: (21 plants responded)
‘Process’ was the main destination for internal recovery (IR) with nearly 99% of IR (and 92% of total). The majority of this by-product is returned to the sinter plant. No specific destination information was provided for external recoveries.</td></tr>
<tr><td colspan="3">Main destinations for secondary dust and sludge: (13 plants responded)
‘Process’ was the main destination for IR with 93% (and 89% of total). Among the processes, the sinter plant and BF are the main recovery routes (43% and 15% of IR, 41 and 14% of total) and 6.7% sent to RHF (1 plant).
External recovery was all sent to other sinter plants (0.3% of total).</td></tr>
<tr><td colspan="3">Main destinations for remaining dust and sludge (4 plants replied)
All internal recovery was via the ‘Process’ (38% of the total), mainly via the EAF and sinter plant routes (63% and 30% of IR, 24 and 11% of total).
All external recovery (12% of total) was via the cement industry.</td></tr>
<tr><td>Good practices and projects</td><td colspan="3">Best practices are often common practices. All the materials which were chemically and physically suitable for sintering were fed back to steelmaking processes via the sinter plant.

In some cases BF and/or BOF slurries were separated (via hydrocyclone) into fine and coarse fractions. The Zn content in the fine fraction limits internal recovery, the coarse material is typically returned directly to the sinter plant.</td></tr>
<tr><td>Forecast at a glance</td><td colspan="3">Increased recovery rate of certain dusts and sludges by accurate on-line knowledge of sinter feed.

Increased recovery rate of secondary raw materials of steel making processes, avoiding disposal (i.e. landfilling).</td></tr>
</table>

Table 28: Summary of responses

Production

From a total of 60 respondents to the questionnaire, 28 plants had a sinter plant. The sinter production ranged from 1.2 Mt/a to 18 Mt/a (one answer was 39 Mt for multiple plants). The average production was 7 Mt/a and the total annual sinter output was almost 200 Mt/a.

All regions were represented, with the exception of North America and CIS.

See the appendix for information on regional distribution and plant specific production.

Generation and main issues

As shown in Figures 49 and 50 (below), the range of dust and sludge generation varied greatly and there appeared to be no direct correlation between annual sinter production and specific dust and sludge generation/collection (see also the appendix for more details).

Primary flue gas dust emissions were collected by dry abatement systems such as electrostatic precipitators (ESPs) or less commonly, wet abatement systems such as airfines. Results indicated that these particular by-products were the most difficult materials to effectively utilise, either internally or externally. This was mainly due to the relatively high level of alkali chlorides contained therein (see Figure 51). In some cases the lead, sulphur and fluorine content of the dusts and sludges were also highlighted as being of concern (refer to zinc and lead content in Figure 52 and 53, below).

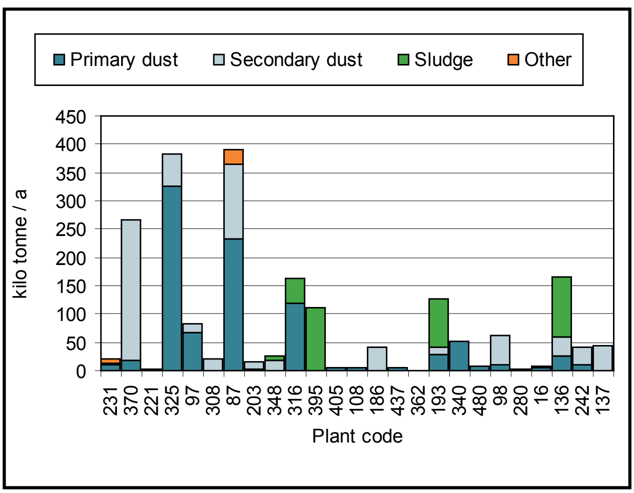


Figure 49: Dust and sludge generation (t/a) in sintering process by facilities

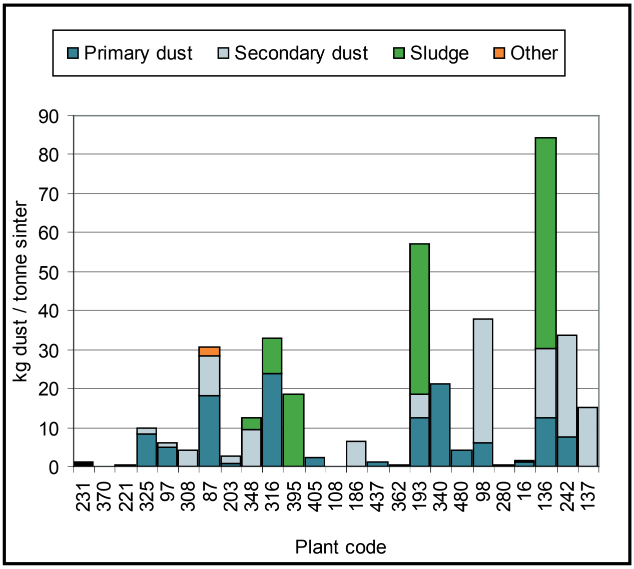


Figure 50: Specific dust and sludge generation (kg dust and sludge/t sinter) in sintering process by facilities

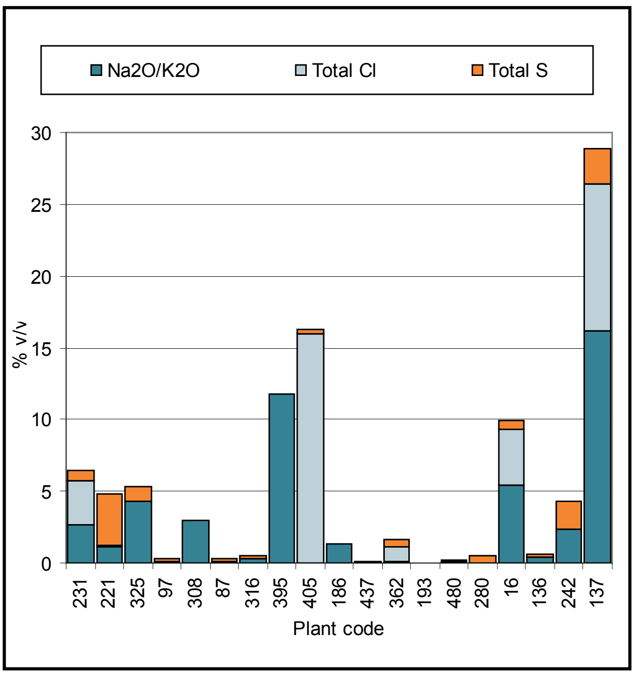


Figure 51: Total Sulphur (S), Total Chloride (Cl) and Sodium/Potassium Oxide (Na_2O/K_2O) content for primary dust and sludge by plant

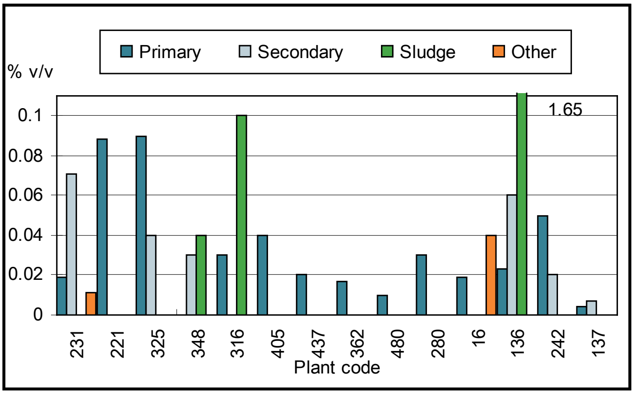


Figure 52: Zinc content by plant

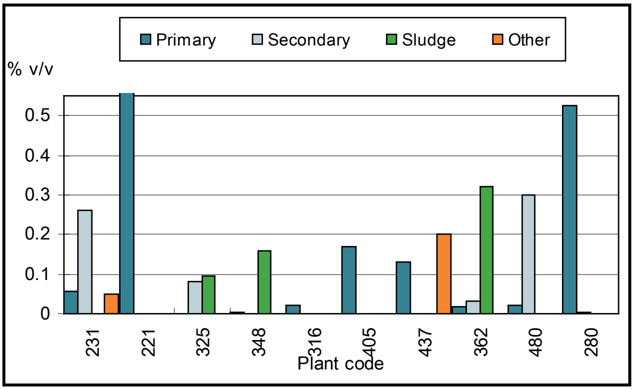


Figure 53: Lead content by plant

Utilisation

Not all of the primary dust and sludge generated was used. A proportion was recovered internally via the sinter plant (19 out of 28 plants reported fully recovering this material), whilst the remainder, driven largely by environmental regulation and process limitations, was disposed of via landfill.

Detailed chemical analyses of the dusts and sludges associated with the sinter plant are shown in Figures 54 and 55 below.

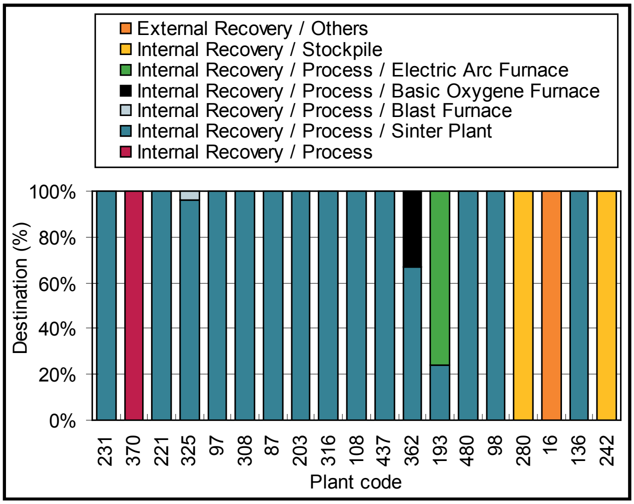


Figure 54: Sinter plant primary dust recovery rate

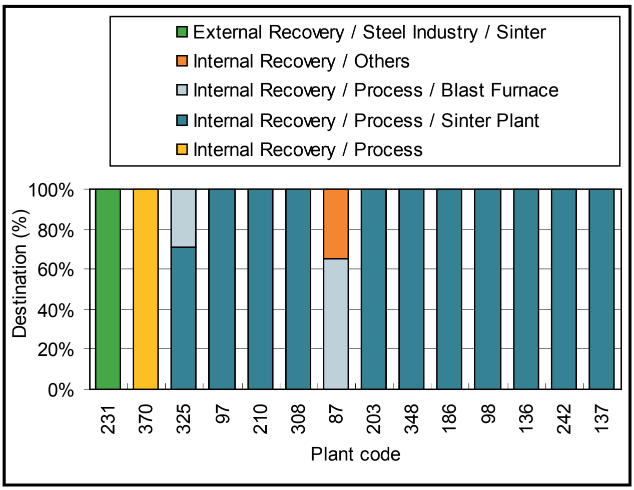


Figure 55: Sinter plant secondary dust recovery rate

One plant reported that they were able to reduce the alkali chloride content of their ESP dust by washing. This makes the material eminently more recyclable and, according to the respondent, has the additional benefit of improving the ESP performance, thereby reducing the emissions to air from the sinter plant stack.

The results suggest that sinter plants reuse nearly all of the by-products generated from the sintering process, with the exception of the ESP/airfine dust/sludge.

Sintering itself was generally considered to be a versatile process for recovering a high proportion of the by-products arising from many of the other iron and steelmaking processes, although some limitations, associated with concentrations of zinc, lead and several other compounds, remain.

BF dust and sludge

The study focussed on three categories of dust and sludge from BF operations:

- Top Gas Cleaning Primary/Coarse
- Top Gas Cleaning Secondary/Fine
- Top Gas Cleaning Others (Bag House, etc.)

Table 29 below provides a summary of the survey responses.

<table>
<tr><td rowspan="2">Representation and production</td><td colspan="3">Number of plants: 32 out of the 60 respondents have BF operations. (Group A)
28 answered on dust and sludge generation. (Group B)
26 answered on BF dust and sludge destinations. (Group C)
Regions: all regions except CIS and North America.</td></tr>
<tr><td colspan="3">Production:
Group A: 163 Mt hot metal (HM)
Group B: 152 Mt HM/3.7Mt BF dust and sludge
Group C: 145 Mt HM</td></tr>
<tr><td>Generation</td><td colspan="3">Primary (kg/t HM) (Min/Average/Max): 8/21/46 kg per tonne HM
Secondary (kg/t HM) (Min/Average/Max): 2.4/8.9/25.6 kg per tonne HM
Others (kg/t HM) (Min/Average/Max): 0.17/4.1/14.6 kg per tonne HM</td></tr>
<tr><td>Main issues</td><td colspan="3">Investigating alternatives to sinter plant for secondary dust and sludge (fines) containing Zn; alternative to hydrocyclone for BF secondary dust and sludge in case of failure; flue dust, gas cleaning plant and DRI dust to sinter.</td></tr>
<tr><td rowspan="7">Destinations</td><td>Total recovery: 91.2%
(internal: 74.2%,
external: 17%)</td><td>Stockpile: 1.7%</td><td>Internal landfill: 4.5%,
External landfill: 2.6%.</td></tr>
<tr><td>Primary: Recovery = 97.5%
(internal: 96.2%,
external: 1.3%)</td><td>Stockpiling = 1% (1 plant)</td><td>Internal landfill: 1.9%,
External landfill: 0.6%</td></tr>
<tr><td>Secondary: Recovery =
80.2% (internal: 46.7%,
external: 33.5%)</td><td>Stockpiling: 3.8% (2 plants)</td><td>Internal landfill: 9.7%
External landfill: 6.3%</td></tr>
<tr><td>Others: Recovery = 95.9%
(internal: 60.5%,
external: 35.4%)</td><td>Stockpiling: 0</td><td>Internal landfill: 2.9%
External landfill: 1.2%</td></tr>
<tr><td colspan="3">Main destinations for primary dust and sludge:
- ‘Process’ was the main destination for internal recovery (IR) with 99% of IR (and 98% of total). Among processes, the BF and sinter plant were the main recovery routes (44% and 36% of IR or of total).
- The cement and ceramics industries were the only external recovery (ER) with 63% and 37% of ER (approximately 1% of total).</td></tr>
<tr><td colspan="3">Main destinations for secondary dust and sludge:
- ‘Process’ was the main destination for internal recovery (90% of IR or 50% of total). The sinter plant was the main recovery route, followed by the BF and BOF, respectively (46%, 20% and 19% of IR and 26%, 11% and 10.5% of total).

For external recovery, the BF was the main recovery route (50% of ER, 16% of total, only 2 plants), followed by the cement and ceramics industries, respectively (33% and 10% of ER, 11% and 3% of total).</td></tr>
<tr><td colspan="3">Main destinations for remaining dust and sludge:
- Process is the main destination for internal recovery with 94% of IR; more than 54% of the total. This was predominantly via the BF (56% of IR and 32% of total).

The cement industry accounts for approximately 60% of the total external recovery (34% of total, the majority from 1 plant).</td></tr>
<tr><td>Good practices and projects</td><td colspan="3">Recovery of BF secondary dust and sludge after hydrocyclone, via the sinter plant.
Increased recovery of sludges: via reduced Zn concentration, filter-press before sending to cement, internal sludge basin, pelletising of fines.

Recovery of flue dust.</td></tr>
</table>

Table 29: Summary of responses

Representations of data

In total 32 plants responded, representing a pig iron output of 163 Mt (approximately 20% of the global volume in 2006). For more details, see the appendix on production and generation.

Plant responses were equally divided among three regions: 'West Europe', 'Asia Developed', and other countries (North America, Latin and South America and Asia Other). Pig iron production ranged between 0.6 Mt and 27 Mt (the larger tonnages arising from multiple sites within the same company).

Analysis of generation

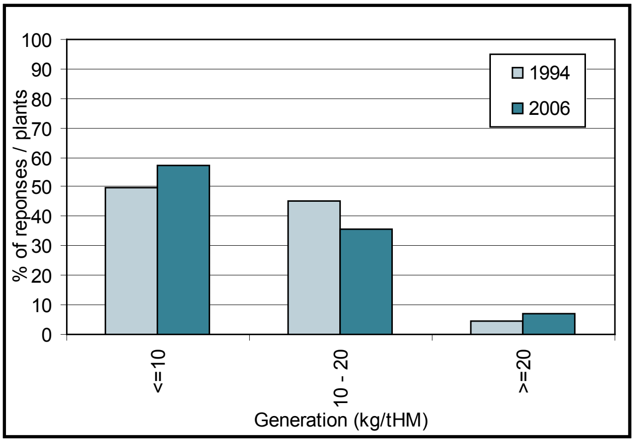


Figure 56: BF top gas primary dust and sludge generation

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary	kg/t HM	5	31	17.7	3.7	33.2	11.4

Table 30: BF top gas primary dust and sludge generation

Table 30 (above) indicates that although the minimum and maximum generation/collection rates were similar, in both the current and previous survey, there appears to have been a significant reduction in the mean generation/collection rate, from 17.7 kg/t HM in 1994 to 11.4 kg/t HM in the current study.

A similar reduction was observed for the BF top gas cleaning secondary dust and sludge (see Table 31 below).

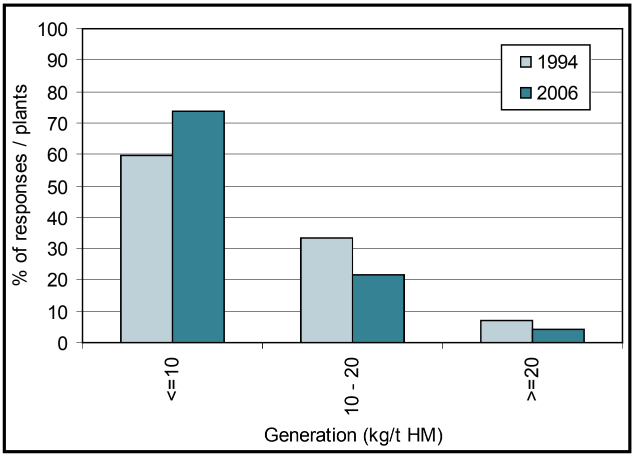


Figure 57: BF top gas secondary dust and sludge generation

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary	kg/t HM	1	37	14.6	2.4	25.6	8.9

Table 31: BF secondary sludge generation in kg/tonne hot metal

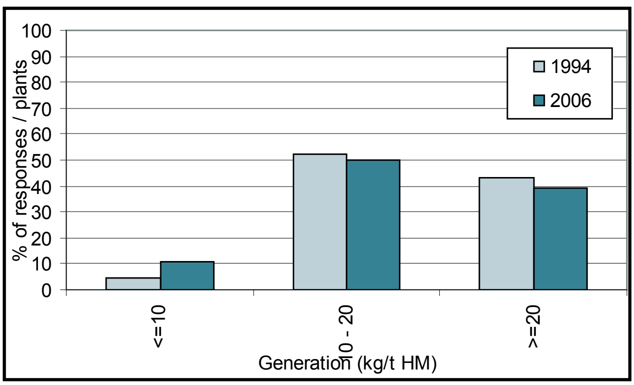


Figure 58: BF top gas primary and secondary dust and sludge generation

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary	kg/t HM	7	56	32.3			20.3

Table 32: BF top gas primary and secondary dust and sludge generation

The observed reduction in production rates of the BF top gas cleaning dust and sludge may be related to improvements in the coke and sinter properties and also improvements in process control of the blast furnace.

These materials are formed by the attrition of the burden materials as they flow down through the blast furnace, and the elutriation of these particles into the gas phase and thus out of the top of the furnace itself. Therefore, anything related to reducing the attrition (improved physical properties of the burden, reduced slippage etc.), leads to less material being produced, and therefore captured by the primary (i.e. dustcatcher) and secondary (i.e. Bischoff scrubber) gas cleaning systems.

The detailed chemical analyses of the dusts and sludges are given in the appendix.

The main difference between primary and secondary materials was related to the zinc and lead content, with higher concentrations of these elements evident in the secondary materials (see Figures 60 and 61 below). The total iron and carbon contents were found to range from 20-70% and 10-50%, respectively.

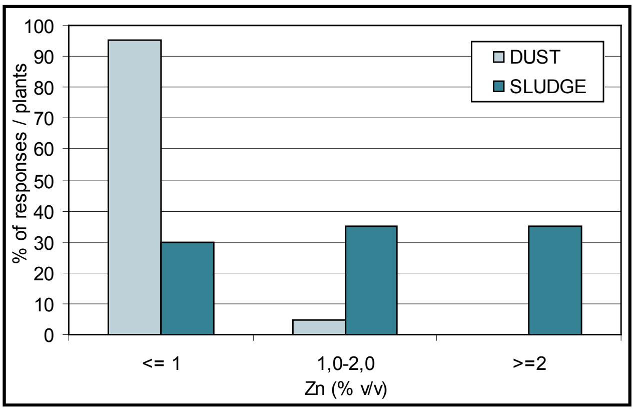


Figure 59: BF top gas cleaning primary and secondary dust and sludge Zn content

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary	%				0.01	1.2	0.2
Secondary	%				0.01	2.7	1.5
Primary + Secondary	%	0.1	7				0.8

Table 33: Combined BF primary and secondary dust and sludge Zn content in % v/v

Zinc and lead concentrations in the secondary dust/sludge were generally higher than those contained in the primary dusts. This may be attributable to the smaller size range of the secondary particles, which have a greater surface area to volume ratio, allowing more of these elements to condense on the surface of the material.

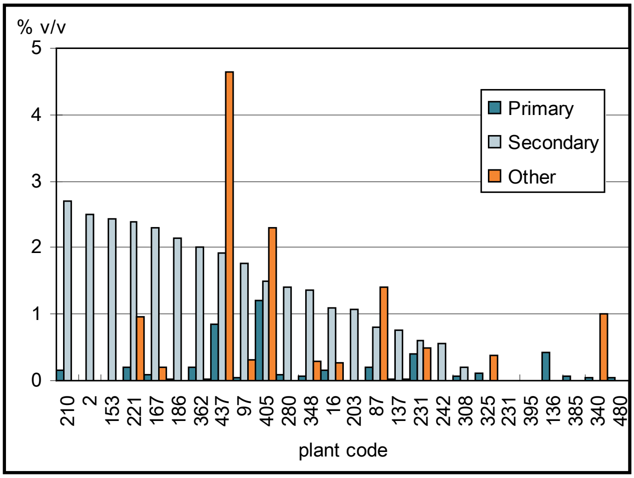


Figure 60: Zinc content by plant

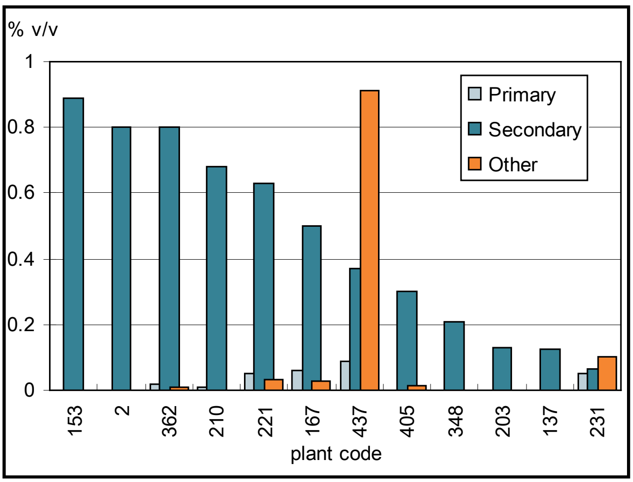


Figure 61: Lead content by plant

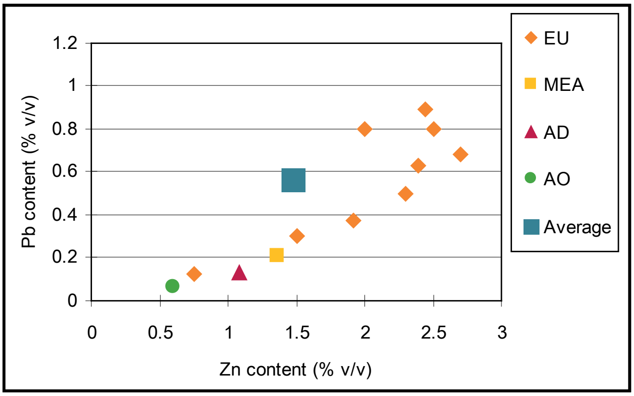


Figure 62: Pb/Zn correlation for BF secondary dust and sludge

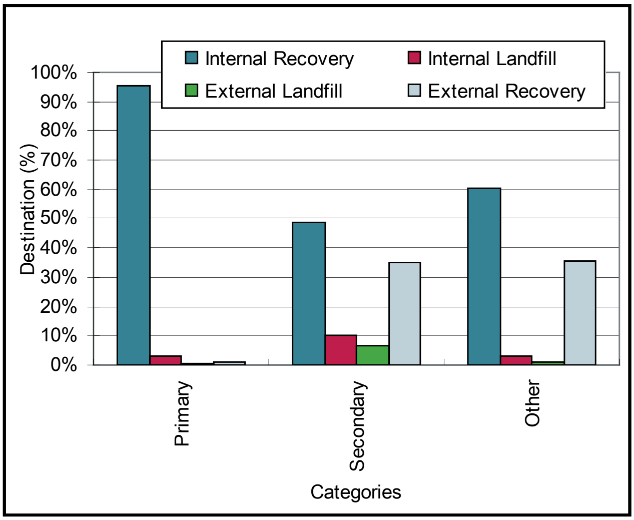


Figure 63: Comparison of BF primary, secondary and other dust and sludge recovery

Over 95% of the primary dust was recovered (either internally or externally) with the favoured internal route being the sinter plant. Out of the 25 plants considered in the study, 21 recover 100% of the material internally. Only two plants reported that they were not able to recover 100% of this particular material. This suggests that there are no significant barriers to recovery.

Approximately 83% of the secondary dust and sludges were reportedly recovered and used via the internal recycling route. This route accounted for approximately 50% of the total material recovered. Of those plants that reported, only 11 of 22 plants recover 100% of this material (internally and externally) whilst four plants dispose of all of the material in landfill.

In total, 11 out of 26 integrated steelworks reportedly recover 100% of all BF dust and sludge.

For detailed figures on main destinations and detailed destinations by plant see the appendix.

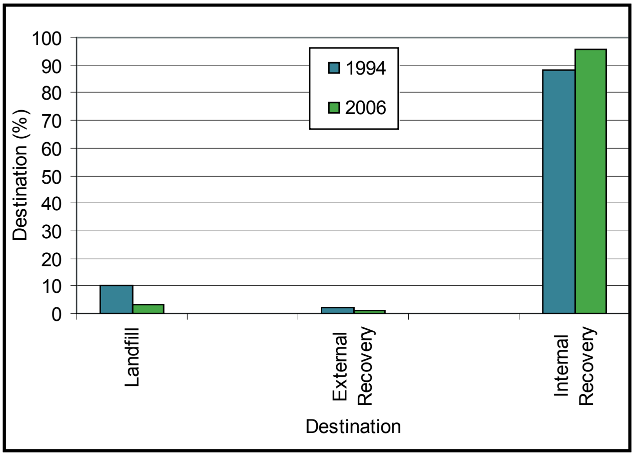


Figure 64: Comparison of BF primary dust and sludge utilisation in 2006 with 1994 study

Figure 64 depicts a marginal reduction in BF dust sent to landfill and an increase in internal recovery when compared with the 1994 results.

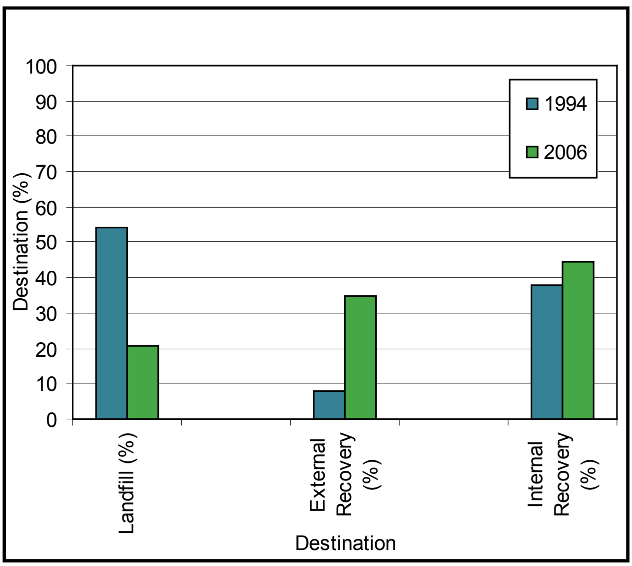


Figure 65: Comparison of BF secondary dust and sludge utilisation in 2006 with 1994 study

The graph above shows a significant reduction in material going to landfill and a marginal increase in material sent for external recovery when compared with results reported in 1994.

Several plants reported using hydrocyclones (a technique highlighted in the 1994 report) to classify their secondary material and enable a proportion to be recovered via the sinter plant. The prime external recovery route for this particular material is reported to be the cement industry. One respondent direct the material to the ceramics industry.

Some responses suggested there is an outstanding issue, associated with the zinc content of the secondary material, which restricted the levels of recovery. This may be partially attributed to a lack of awareness, or implementation, of the hydrocyclone technology highlighted in the 1994 study.

Projects and innovations

List received from the members:

- recovery of BF flue dust
- pelletising fines for internal recovery
- internal recycling sludge basin (BF and BOF sludges) for further internal recovery via sinter plant
- filter-press of BF sludge for external recovery in cement industry
- reduction of zinc in BF sludges, improving recovery in sinter plant
- concentration of BF sludge for sinter plant internal recovery.

Drivers of change for projects and innovations

Respondents indicated that 'Technical industry' and 'R&D' were future priorities, indicating that technical constraints remain an issue to increased primary, and in particular, secondary dust and sludge recovery.

Conclusions for BF dust and sludge

Significant progress has been made since the 1994 study was conducted. Whilst secondary dust and sludge remains an issue for a number of companies, historical issues associated with the recovery of primary dust and sludge appear to have largely been addressed.

From the results, companies were focussed on two main research activities: the first aimed at reducing the concentration of Zn and facilitating increased recovery via the sinter plant, and the second aimed at developing alternative markets, such as cement or ceramics.

Alternative ironmaking processes

Although the majority of iron and steel is produced through the BF/BOF and EAF routes, the present study included non-traditional ironmaking routes.

<table>
<tr><td rowspan="2">Representation and production</td><td colspan="2">Number of plants: 13 out of 60 respondents had 'alternative' ironmaking operations (e.g. Finex, Corex, Midrex, RHF) (Group A)
7 answered on dust and sludge generation (Group B)
6 answered on dust and sludge destinations (Group C)
Regions: all regions except West Europe and North America</td></tr>
<tr><td colspan="2">Production:
Group A: 18 Mt HM
Group B: 9 Mt HM / 0.4 Mt Alternative ironmaking dust and sludge
Group C: 8.5 Mt HM</td></tr>
<tr><td>Generation</td><td colspan="2">Group A: 18 Mt HM
Group B: 9 Mt HM/0.4 Mt alternative ironmaking dust and sludge
Group C: 8.5 Mt HM
Primary (kg/t HM) (Min/Average/Max): 1/16/46
Secondary (kg/t HM) (Min/Average/Max): 1/22/45
Others (Kg/t HM) (Min/Average/Max): 22/42/66</td></tr>
<tr><td>Main issues</td><td colspan="2">- DRI dust (micro fines) had an adverse effect on bed permeability of the sintering process.
- Improving the quality of dust and sludge and develop new techniques to increase utilisation.</td></tr>
<tr><td rowspan="7">Destinations</td><td>Total Recovery: 91% (internal: 13%, external: 78%)</td><td>Total landfill : 9% (external)</td></tr>
<tr><td colspan="2">Primary: Recovery = 100% (internal: 2%, external: 98%)</td></tr>
<tr><td colspan="2">Secondary: Recovery = 100% (internal: 32%, external: 68%)</td></tr>
<tr><td>Others: Recovery = 86% (internal: 82%, external: 78%)</td><td>Landfill = 14% (external)</td></tr>
<tr><td colspan="2">Main destinations for primary recovery:
- The sinter plant was the main destination for internal recovery, with 100% of IR (less than 2% of total)
- The steel industry (sinter plant) is the main destination for external recovery, with nearly 79% of ER (78% of total). Cement industry and others (unspecified) were the only external destinations reported with 11% and 10% of ER, respectively (11%, 10% of total).</td></tr>
<tr><td colspan="2">Main destinations for secondary recovery:
- 'Process' was the main destination for internal recovery with 100% of IR (and 32% of total). The sinter plant and blast furnace were the only reported internal destinations, with 54% and 46% of IR, respectively.
- Steel industry (EAF) was the main destination for external recovery with approximately 72% of ER (49% of total). The cement industry was the only external destination, with 28% of ER (19% of total).</td></tr>
<tr><td colspan="2">Main destinations for 'Other' recovery:
- The blast furnace was the main destination for internal recovery with 100% of IR (and 8% of total).
- The cement and steel industries, the latter via the sinter plant, are the only external destinations with 36% and 64% of ER, respectively (28%, 49% of total). The remaining material was sent to external landfill (14% of total).</td></tr>
<tr><td>Good practices and projects</td><td colspan="2">Reduction pellets used directly by BF.
Utilised as a fuel source in the clay brick industry.</td></tr>
</table>

Table 34: Summary of responses

Alternative ironmaking production dust and sludge

Sixty facilities responded and of those, 13 reported having an alternative ironmaking process. Production at these 13 facilities ranged from 0.1 Mt/a to 3.4 Mt/a. Mean production was 1.4 Mt/a, and the total annual output was approximately 18 Mt/a. Production statistics are shown in the appendix.

Generation

A total 0.4 Mt of dust and sludge was reported. Total dust and sludge generation ranged from 1,500 t/a to 125,000 t/a, and averaging 60,000 tonnes across the 13 respondents. No direct correlation between annual production and the specific dust generation was identified.

The specific generation of dust and sludge, from the respondents with alternative ironmaking processes, ranged from 2 to 125 kg/t pig iron with an average of 49 kg/t pig iron.

Destinations and uses according to our four main categories

Of the 13 plants, five facilities were able to recover 100% of dusts and sludges generated by returning the material to the ironmaking process. One plant reported disposing of all dusts and sludges, via external landfill.

In total, 91% of the generated dust and sludge generated from the 'alternative' ironmaking processes was utilised, either internally or externally, the remaining 9% of material was disposed of via external landfill.

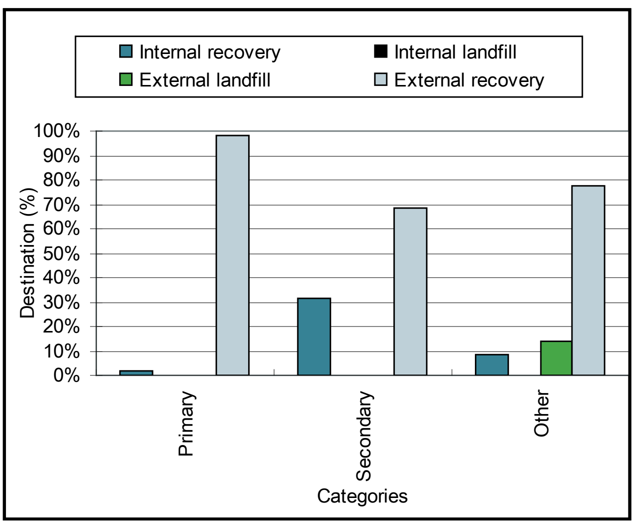


Figure 66: Comparison of primary, secondary and Other dust and sludge recoveries

Of the total primary dusts and sludges reported from alternative ironmaking processes, 98% were recovered internally and the remaining 2% recovered externally. However, it should be noted that only two of the 13 respondents provided information.

Eleven plants did not answer this specific question, and as such the information and resultant conclusions may not be representative.

In terms of secondary dust and sludge, only four out of the 13 plants provided information on use. From those that responded, 68% of the material was recovered externally and 32% of the material recovered internally. Again, as in the example above, these results may not be representative. Taking into account the limited number of responses, it could be tentatively concluded that there appeared to be no significant barriers to recovering either the primary or secondary dusts and sludges from alternative ironmaking processes.

Details of main destinations

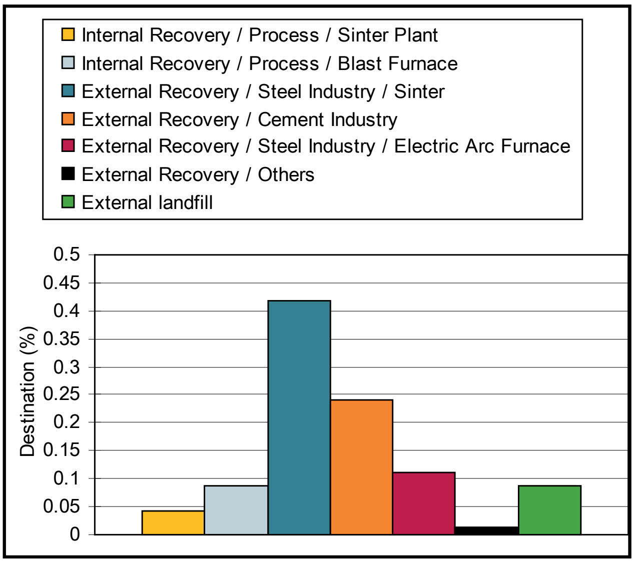


Figure 67: Detailed destinations for all dust and sludge

Figure 67 shows the process and routes by which alternative ironmaking dust and sludge were used.

Alternative ironmaking dust and sludge examples of applications and management practices: main issues

Respondents to the alternative ironmaking survey indicated that, typically, the particle size of the by-products is “very small”, and as such can adversely affect bed permeability when recovered via the traditional iron ore sintering process. As a result, some plants were reportedly investigating other applications for recovery, such as use as a fuel source in the clay/brick industry.

Some respondents also indicated these materials were recovered via pelletising plants.

BOF dust and sludge

This section of the study relates to the management of BOF dust and sludge. Its aim is to provide information on problematic by-products and potential recovery mechanisms.

BOF dust and sludges were divided into three categories:

- Dust and sludge (primary/coarse): recovery of the coarse dust and sludge from the converters primary fume exhaust (de-dusting)
- Dust and sludge (secondary/fine): recovery of the fine dust and sludge from the converters primary fume exhaust (de-dusting)
- Other dust and sludge: recovery of materials from secondary and auxiliary extraction systems.

Table 33 below provides a summary of the survey responses.

<table>
<tr><td rowspan="2">Representation and production</td><td colspan="3">Number of plants: 31 out of 60 respondents had BOF operations (Group A)
29 answered on dust and sludge generation destinations (Group B)
Regions: all regions except CIS and North America</td></tr>
<tr><td colspan="3">Production:
Group A: 165 Mt crude steel (CS)
Group B: 158 Mt CS/3.6 Mt BOF dust-sludge</td></tr>
<tr><td>Generation</td><td colspan="3">Primary (kg/t CS) (Min/Average/Max): 1.2/8.9/28.4
Secondary (kg/t CS) (Min/Average/Max): 0.6/14.8/30
Other (kg/t CS) (Min/Average/Max): 0.2/ 2.3/14.3</td></tr>
<tr><td>Main issues</td><td colspan="3">Fines and high levels of zinc</td></tr>
<tr><td rowspan="7">Destinations</td><td>Total: Recovery: 88% (internal: 58.5%, external: 29.2%)</td><td>Stockpile: 6.4%</td><td>Landfill: 12.2% (internal: 11.9%, external: 0.3%)</td></tr>
<tr><td>Primary: Recovery = 91% (internal: 78%, external: 13.5%)</td><td>Stockpile: 6.7% (78% of all landfills)</td><td>Landfill: 8.6% (internal: 8.6%)</td></tr>
<tr><td>Secondary: Recovery = 87.3% (internal: 49.8%, external: 37.5%)</td><td>Stockpile: 6.1% (50% of all landfills)</td><td>Landfill: 12.7% (internal: 12.4%, external: 0.3%)</td></tr>
<tr><td>Other: Recovery = 88.8% (internal: 56%, external: 32.8%)</td><td>Stockpile: 2.5% (25% of all landfills)</td><td>Landfill: 11.1% (internal: 9.8%, external: 1.3%)</td></tr>
<tr><td colspan="3">Main destinations for primary recovery:
- ‘Process’ was the main destination for internal recovery with nearly 100% (70% of total). Sinter plant and BOF are the main recovery routes with 52% and 37% of IR, respectively.
- The cement industry was the main external destination with 50% of ER (external recovery) (7% of total).</td></tr>
<tr><td colspan="3">Main destinations for secondary recovery:
- ‘Process’ was the main destination for internal recovery with 83% (31% of total). Sinter and BOF were the main recovery routes with 43% and 32% of IR, respectively.
- 30% of ER was recovered in other steel sites and nearly 60% of ER was via the cement industry (21% of total).</td></tr>
<tr><td colspan="3">Main destinations for ‘Other’ recovery:
- ‘Process’ was the main destination for internal recovery (31% of total). The sinter plant and BOF were the main recovery routes with 30% and 70% of IR, respectively.
- One plant accounted for 95% of ER, with the remainder recovered via other steel sites and the cement t industry.</td></tr>
<tr><td>Good practices</td><td colspan="3">Briquetting, flux unit recovery and hydrocyclone</td></tr>
<tr><td>Forecast at a glance</td><td colspan="3">Internal recycling appears likely to increase, with the potential to recycle BOF Secondary and ‘Others’ by-products externally via the cement industry.</td></tr>
</table>

Table 35: Summary of responses

Generation

Thirty-one of the 60 facilities that responded to the questionnaire have a BOF plant. These 31 plants represent a total production of 165 Mt crude steel a year.

See the appendix for more information on production and generation.

Dust and sludge specific generation

The average of specific generation BOF dust and sludge (combined) was 22 kg/tonne of crude steel, with a maximum of 40 kg/t CS and minimum of 10 kg/t CS. The highest rate of specific generation was from the secondary/fine collection systems (15 kg/t crude steel on average).

Specific generation	Minimum	Maximum	Average (weighted)	No. of answers
Primary/coarse	1.2	28.4	8.9	28
Secondary/fine	0.6	30.0	14.8	23
Other	0.2	14.3	2.3	22

Table 36: BOF dust and sludge specific generation

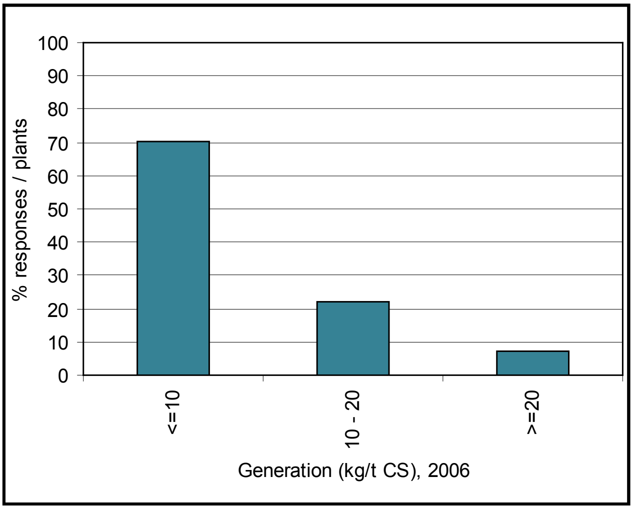


Figure 68: Specific generation of BOF primary/coarse dust and sludge

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary/Coarse	kg/t CS	-	-	-	1.2	28.4	8.9

Table 37: Specific generation of BOF primary/coarse dust and sludge

Approximately 70% of the sites that responded to the questionnaire produce < 10 kg/t CS of the primary/coarse dust.

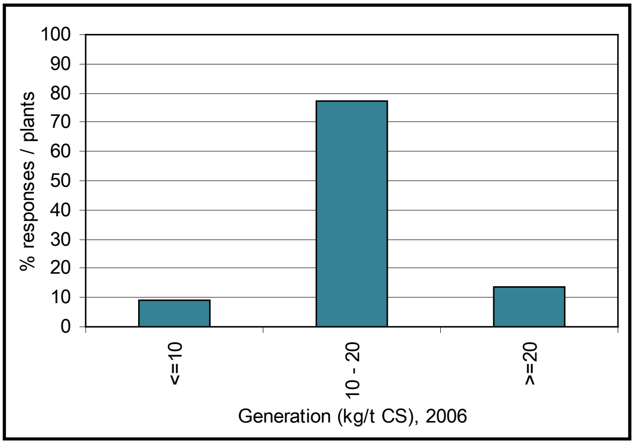


Figure 69: Specific generation of BOF secondary/fine dust and sludge

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Secondary/Fine	kg/t CS	-	-	-	0.6	30.0	14.8

Table 38: Specific generation of BOF secondary/fine dust and sludge

The majority of respondents reported secondary/fine sludge generation within the range of 10-20 kg/t CS (see Figure 36 above).

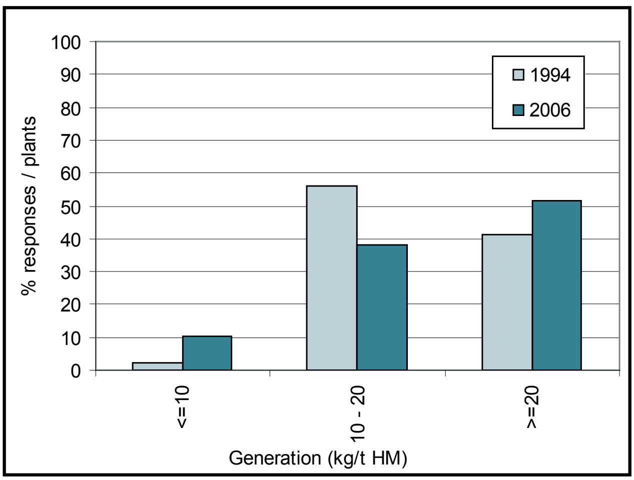


Figure 70: Specific generation of BOF primary and secondary dust and sludge

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary and Secondary	kg/t CS	-	-	18	3.9	36	20.4

Table 39: Specific generation of BOF primary and secondary dust and sludge

The overall generation/collection of BOF dust and sludge (primary/secondary combined) is marginally higher now than in 1994 (see 'mean' in Table 39 above). Whilst beyond the scope of this study, the reasons for this increase may be explained by factors such as:

- improvements in extraction (gas cleaning) systems, resulting in more material being collected rather than exiting into the atmosphere via exhaust stacks
- changed process conditions leading to increased levels of generation i.e. blowing rates, slag practices, bath additions, bath agitation, etc.

Additional research would be required to determine the factors influencing BF, BOF and EAF by-product generation.

Chemistry

The primary (coarse) and secondary (fine) dusts and sludges predominantly consist of iron particles ejected from the BOF (which then oxidises within the gas cleaning system). The extent of the oxidisation depends on the type of extraction system. Detailed chemical analyses of the dusts and sludges are outlined in the appendix.

The ranges of iron content in each of the dust/sludge categories are shown below in Table 40. Similarly, the metallic iron contents are shown in Table 41. Due to the high temperatures involved and the mechanism of formation (compared with the BF), the levels of carbon associated with these dusts and sludges are low (see Table 42).

Total iron	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	47.6	92	73.7	25
Secondary/fine	39.9	82	60.5	20
Other	30	60.4	43.5	15

Table 40: Total Fe content in BOF dust and sludge

Metallic iron	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	1.9	79.4	44.1	12
Secondary/fine	2.1	25	12.9	13
Other	1.3	18.6	5.4	6

Table 41: Metallic Fe content in BOF dust and sludge

Carbon	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.1	2.2	0.9	17
Secondary/fine	0.1	5.9	1.9	15
Other	0.5	15	4.6	14

Table 42: Carbon content in BOF dust and sludge

Zinc	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.01	1.7	0.3	22
Secondary/fine	0.05	8	1.6	19
Other	0.26	8.5	2.7	15

Table 43: Zn content in BOF dust and sludge

Lead	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.0016	0.1	0.06	9
Secondary/fine	0.01	0.3	0.1	11
Other	0.005	2.7	0.7	8

Table 44: Pb content in BOF dust and sludge

The iron and metallic iron contents of these particular dusts and sludges make recovery and use a priority. One issue limiting the use internally, via the sinter plant/blast furnace route, is the concentration of zinc and lead (see Tables 43 and 44 above). The results are consistent with the findings of the 1994 study (see Figure 71 below).

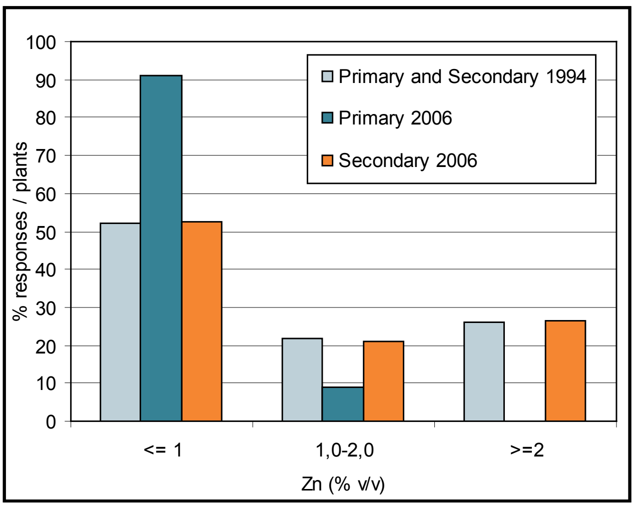


Figure 71: Comparison of BOF dust and sludge Zn content with 1994 study

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary	%	-	-	-	0.0	1.7	0.3
Secondary	%	0.1	7	-	0.05	8	1.6
Primary and Secondary	%	0.03	7.8	1.8			1.1

Table 45: Comparison of BOF dust and sludge Zn content with 1994 study

Destinations and uses

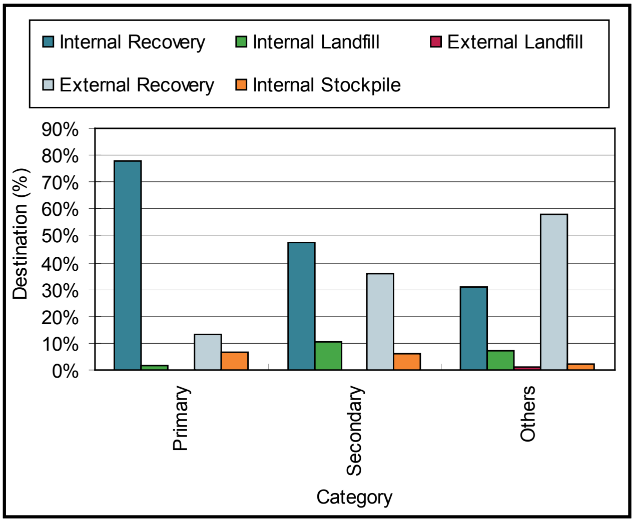


Figure 72: BOF dust and sludge main destinations by category

Respondents to the questionnaires indicated that, providing the zinc content was sufficiently low, some material can be recycled internally via the sinter plant/blast furnace route. This supposition appears to be confirmed by the higher levels of the primary dusts/sludge which were recovered internally.

Where the zinc content prevents such recycling via the sinter plant/BF route, some plants elected to blend the materials and produce briquettes/pellets which were then charged back to the BOF vessels. A small volume was also stockpiled, an interim solution until a cost and environmentally-effective solution could be identified. A significant percentage was recovered externally, mainly via the cement industry.

Some plants use 'alternative ironmaking' techniques such as RHF to process these wastes (blended with other by-products/materials) to produce a HBI/DRI product which was then charged to the BF/BOF or EAF (destination driven by quality/chemistry of the by-product).

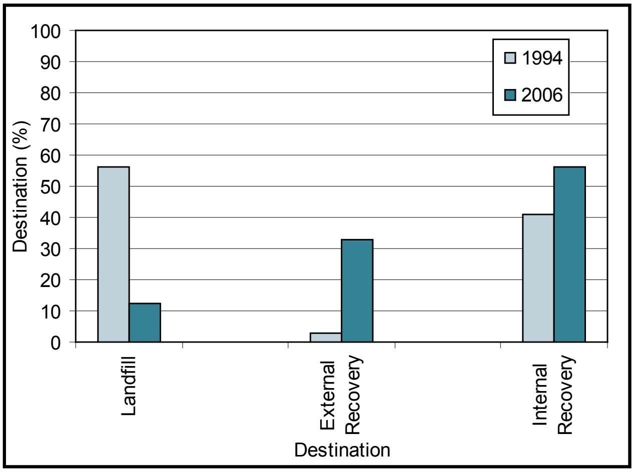


Figure 73: BOF primary and secondary dust and sludge main destination

Note: Figure 73 outlines information relating to the primary and secondary dusts combined, so these results cannot be directly compared with those reported in Figure 72.

In comparison with the 1994 study, the current study indicates that significantly less material was disposed of via landfill. This was potentially driven by increasingly stringent environmental legislation (particularly pertaining to the landfill of by-products and waste) and an increased focus on waste minimisation and a more sustainable use of resources. See the appendix for more details on BOF recovery.

Basic treatments

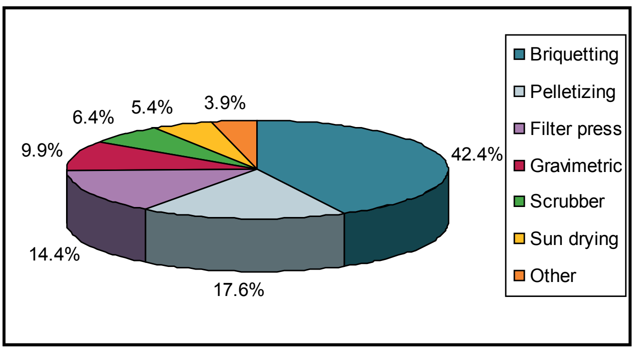


Figure 74: BOF dust and sludge main treatments by category

Figure 74 outlines the techniques used to treat BOF dust and sludge. Some of these were used to reduce the volume and improve the handling of these materials.

The responses provided showed that reducing the zinc content of these materials was not common practice. Management of the scrap steel entering the process (utilising clean, un-galvanised scrap) could reduce the zinc levels enough to enable increased usage within the sinter plant. However, in addition to limited scrap availability there may also be significant cost constraints.

EAF dust and sludge

This section of the study relates to the management of EAF dust and sludge. Its aim was to provide information on problematic by-products and potential recovery mechanisms.

EAF dust and sludge was divided into two categories:

- EAF primary collection: first stage of gas cleaning (typically a baghouse).
- Others: all other dust and sludge collected from the EAF process (See the appendix for additional information on 'Others').

<table>
<tr><td rowspan="2">Representation and production</td><td colspan="3">Number of plants: 28 out of 60 respondents had EAF operations. (Group A)
24 plants provided dust and sludge generation information and the main destinations. (Group B)
15 plants provided detail on destinations. (Group C)
Regions: all regions except CIS</td></tr>
<tr><td colspan="3">Production:
Group A: 56 Mt crude steel (CS) (14% of the world's EAF CS)
Group B: 28 Mt CS/450 kt EAF dust and sludge
Group C: 18 Mt CS/230 kt EAF dust and sludge</td></tr>
<tr><td>Generation</td><td colspan="3">Primary (kg/t CS) (Min/Average/Max): 1.4/11.3/25.2
Other (kg/t CS) (Min/Average/Max): 2/10/21</td></tr>
<tr><td rowspan="5">Destinations</td><td>Total: Recovery = 72.8% (internal: 9.8%, external: 63%)</td><td>Stockpile: 3.8% (15% of all Internal landfill)</td><td>Landfill: 23.4% (internal landfill: 18%, external landfill: 5.4%).</td></tr>
<tr><td>Primary: Recovery = 63.6% (internal: 0.8%, external: 62.8%)</td><td>Stockpile: 6% (17% of internal landfills)</td><td>Landfill: 36.4% (internal: 28.6%, external landfill: 7.8%).</td></tr>
<tr><td>Other: Recovery = 88.6% (internal: 25.4%, external: 63.2%)</td><td>Stockpile: 0</td><td>Landfill: 11.4% (internal landfill: 10.2%, external landfill: 1.2%).</td></tr>
<tr><td colspan="3">Main destinations for primary recovery:
Recovery of Zn is the main recovery route with 50% of all going either directly to the Zn industry (36%) or to a Waeltz Kiln (10%)</td></tr>
<tr><td colspan="3">Main destinations for 'Other' recovery:
Zn recovery was the most significant destination with 24.3% of total</td></tr>
<tr><td>Good practices</td><td colspan="3">Briquetting, flux unit recovery and hydrocyclone</td></tr>
<tr><td>Forecast at a glance</td><td colspan="3">Generation increasing as a result of stricter legislation and more efficient dust catching systems. Recovery was predominantly via the zinc industry.</td></tr>
</table>

Table 46: Summary of responses

Generation

Sixty facilities responded to the initial questionnaire, and of those, 28 reported having an EAF plant. EAF production output ranged from 27,000 t/a to 21 Mt of crude steel per annum (1 company reported multiple plants in aggregate, the largest individual plant output was 4.1 Mt/a). Mean production was 2 Mt/a and the total combined annual crude steel output was 55.7 Mt/a. Additional production and generation details are in the appendix.

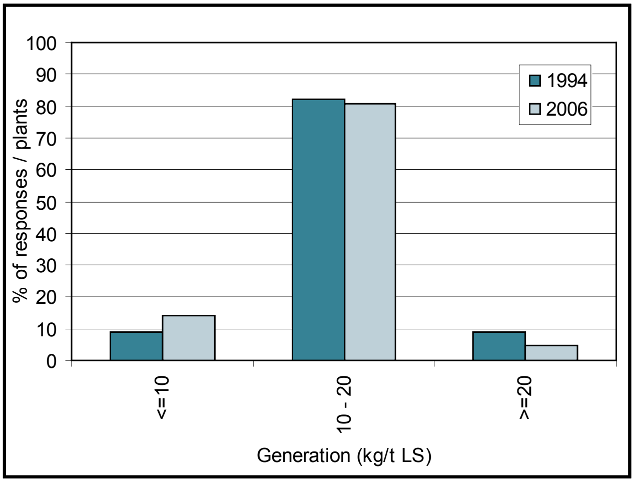


Figure 75: Generation of primary dust and sludge by EAF, comparison to 1994 study

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Primary	kg/t CS	4	32	16	1.4	25.2	11.3

Table 47: Generation of primary dust and sludge by EAF, comparison to 1994 study

Compared with the 1994 report, there appears to have been a slight reduction in the generation/collection of EAF dust. Potential explanations for this include an increase in the number of plants injecting carbon and oxygen through sidewall tuyeres to produce foaming slags. Whilst oxygen injection will undoubtedly increase the amount of dust generation, the foaming slag will tend to trap it within the furnace. Improved levels of scrap preparation and increasing amounts of dust recycling back to the EAF may also account for some of the reduction in the generation figures that have been reported.

Specific generation analysis and chemistry

The specific generation of dust and sludge shows an average of 14.2 kg/tonne crude steel reaching maximum values of 25 kg/tonne crude steel and minimum 3.4 kg/tonne crude steel. The primary system is the biggest generator (12.7 kg/tonne crude steel on average).

A more detailed indication of the chemical analysis results is given in the appendix.

Specific generation	Minimum	Maximum	Average (weighted)
Primary	1.4	25.2	11.3
Other	2.0	20.9	10.0

Table 48: EAF dust and sludge specific generation in kg/t

Total iron	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	16	60.8	35.1	17
Other	16	54.54	38.9	7

Table 49: EAF dust and sludge total iron (% v/v)

Metallic iron	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.19	9.2	3.5	5
Other			0.55	1

Table 50: EAF dust and sludge metallic iron content (% v/v)

Carbon	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.94	4.1	1.8	13
Other	0.55	1.0	0.8	5

Table 51: EAF dust and sludge carbon content (% v/v)

Zinc	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.03	37	14.6	17
Other	1.5	13.6	6.57	5

Table 52: EAF dust and sludge zinc content (% v/v)

Lead	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.05	21.5	3.1	15
Other	1	43	15.2	3

Table 53: EAF dust and sludge lead content (% v/v)

Moisture	Minimum	Maximum	Average (non-weighted)	No. of answers
Primary	0.1	3.7	1.4	9
Other	0.013	4	1.5	3

Table 54: EAF dust and sludge moisture content (% v/v)

The carbon content of the dusts from the EAF had relatively low carbon contents (1.8% on average, see appendix). This is similar to the carbon content of BOF primary and secondary dusts and sludges, suggesting that the carbon was largely driven off during the EAF steelmaking process.

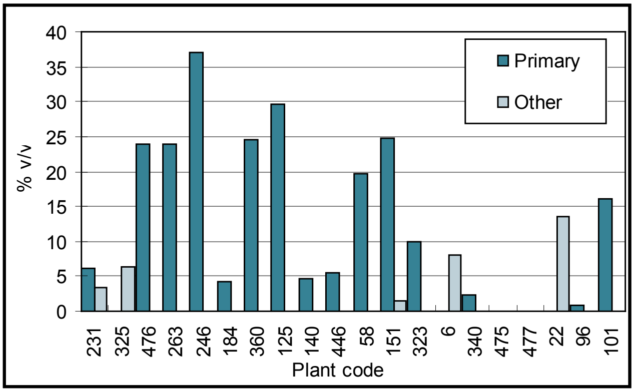


Figure 76: EAF dust and sludge zinc content by plant

As shown in Figure 76, the zinc content of the primary dust varied greatly from plant to plant. This may be reflective of the zinc content of the scrap used, the grades of steel being produced, and subsequently, the composition and utilisation of internally-generated scrap.

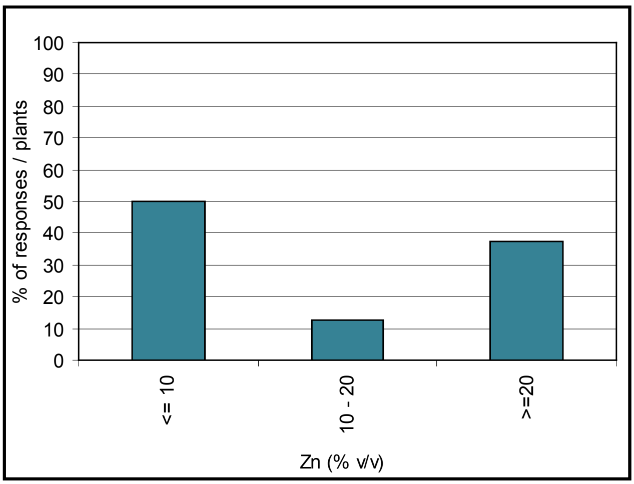


Figure 77: EAF primary dust and sludge zinc content, 2006

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Zinc in primary	%	10	36		0.03	37	14.6

Table 55: EAF primary dust and sludge zinc content

Zinc levels were influenced by the types of steel produced, galvanised scrap consumption, etc. The maximum zinc content of this material was consistent in both the present sutdy and the 1994 study. There was a significant difference in the minimum zinc content observed, possibly due to more stringent scrap quality criteria in some plants.

Similar variations were reported with respect to lead (Pb).

Destinations by category

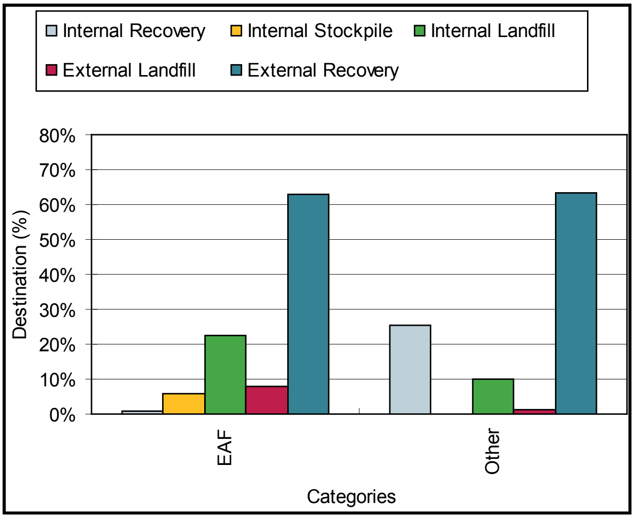


Figure 78: Main destinations by category

63.6% of primary EAF dust and sludge produced were recovered and 36.4% were sent to landfill (including stockpile).

In the 'Other' category, a total of 86.6% was recovered, and 11.4% landfilled (one plant used it for land engineering which greatly influenced the global recovery figures).

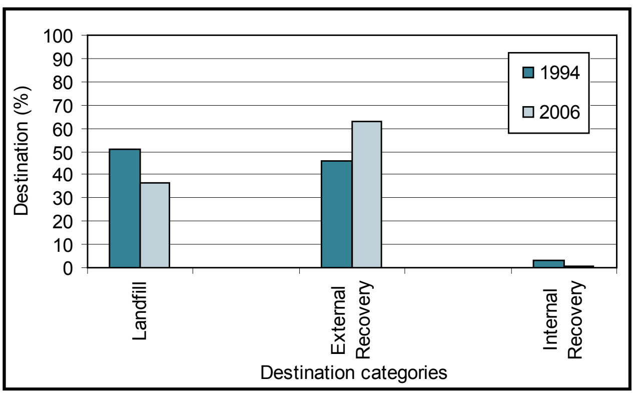


Figure 79: EAF primary dust and sludge utilisation comparison with 1994 data

Since 1994, there appears to have been a reduction in the relative quantity of EAF dust being disposed of via landfill, with more material recovered by external recovery methods.

Recovery and treatment methods included the use of Waelz kilns. Some material was agglomerated and returned to the EAF (possibly to increase the concentration of the zinc and hence its value when processed through the Waelz kiln route), and some was stabilised prior to landfilling.

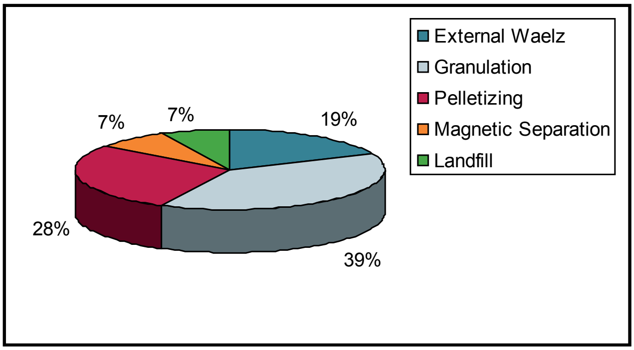


Figure 80: Basic treatments for 'Other' EAF dust and sludge

Continuous casting dust and sludge

This section of the study relates to the management of continuous casting (CC) by-products. The aim of this section of the study was to provide information on problematic by-products and potential recovery mechanisms.

CC by-products were divided into four categories:

- scale (coarse, fine)
- sludge
- secondary metallurgy dust
- Other.

The following is a summary table for this by-product. See the appendix for more information.

Representation	29 plants provided data. Regions: all regions except CIS and North America.
Tonnage and generation	143 Mt/a crude steel (CS)/1.1 Mt/a dust and sludge. Specific generation in kg/t CS: Scale (Min/Average/Max): 0.03/5.1/22.6 Sludge (Min/Average/Max): 0.014/0.4/1.3 SM dust (Min/Average/Max): 0.078/4.2/26.3 Other (Min/Average/Max): 0.325/1/2.1
Main issues	Mill Scale: oil content too high to return to sinter plant Sludge: oil too high for sinter plant, iron (Fe) content too low and material too fine for some other applications. Classified as hazardous by some regions, landfill difficult/expensive.
Destinations	Total: Recovery: 98.1% (internal: 88.6, external: 9.5); Stockpile: 0.7% Landfill: 1.2% (internal landfill: 0.2%, external landfill: 1%). Scale: Recovery = 100% (internal: 94%, external: 5.9%); Stockpile: 0% Sludge: Recovery = 57% (internal: 9%, external: 48%) Stockpile: 21% Landfill: 22% (internal landfill: 6.8%, external landfill: 15.3%). SM dust: Recovery = 73.3% (internal: 6.1%, external: 67.2%) Stockpile: 7.7% Landfill: 19% (internal landfill: 1.8%, external landfill: 17.2%). Main destinations for scale recovery: - 'Process' was the main destination for internal recovery (44% of total). The sinter plant and BF were the main recovery routes accounting for 25 and 18% of total, respectively. - An additional 3% of total was sent to external sinter plants. Main destinations for sludge: - Main recovery was via the cement industry (44% of total, 1 plant); another external recovery was via the ceramic industry (5% of total). - 6% was recovered internally in the BOF (1 plant) SM dust is completely recovered in the process and mainly in the sinter plant

Table 56: Summary of responses

Generation

Twenty-nine plants provided continuous casting by-product data. The majority of the total by-product generation is from continuous casting was in the scale (coarse, fine) category.

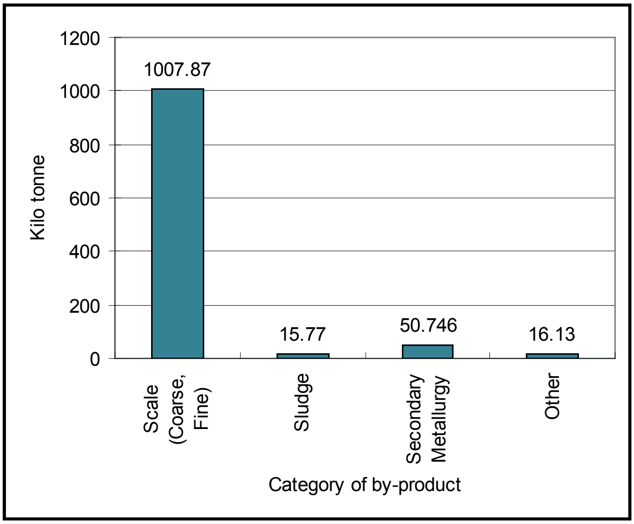


Figure 81: Continuous casting by-product generation (kt)

Specific generation analysis

Plant code	Scale	Sludge	Secondary metallurgy	Other
231	2.15			
221	0.03	0.01	0.08	
2	3.20			
325	22.59	0.31		
210	11.27			
476	13.76		26.26	
308	17.46			
263	4.07		0.24	
246	5.59		9.71	
87	4.24			
399	0.72			
395	1.87			
385	2.13	1.33		
186	2.73			
437	0.04	0.59		
362	2.47	0.25	0.36	
153	0.52	0.12		2.14
151	2.65		0.39	
323	4.07	0.53	2.62	
193	1.44			0.48
340	1.19			0.33
480	0.85			
477	8.00		1.51	
98	0.21		0.72	
167	3.71			
16	4.72	0.28		
136	17.33			
242	3.24		0.46	

Table 57: Continuous casting specific by-product generation (kg by-product/t crude steel) rates

Chemistry

Ranges of values found by element

The secondary metallurgy dust and 'Other' category were not included in this section due to a lack of chemical data in the responses.

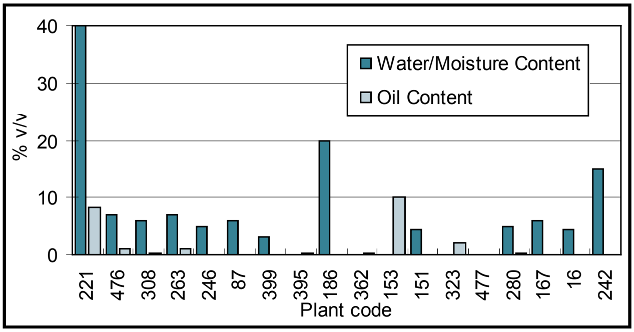


Figure 82: Scale (coarse, fine) moisture and oil content by plant

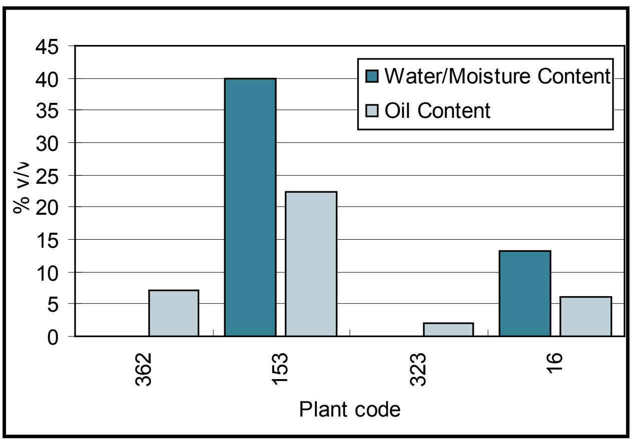


Figure 83: Sludge moisture and oil content by plant

Conclusion

In terms of quantity of by-products arising from the continuous casting process, scale (coarse/fine) was by far the most significant (1.01 Mt from a total of 1.09 Mt). However, the results of this study indicate all of this material is used via processes such as the sinter plant. On the other hand, sludge, whilst making up a comparatively small proportion of the overall by-products generated, was shown to be problematic and was either disposed of via landfill or sent to internal stockpile.

Hot rolling mill (HRM) by-products

This section of the study relates to the management of HRM by-products. Its aim was to provide information on problematic by-products and potential recovery mechanisms. HRM by-products were divided into three categories:

HRM scale (coarse/fine)

Scale is the result of oxidation of the metal surface during the heating and hot working of steel. The chemical compounds formed are the iron oxides FeO, Fe_2O_3 (and therefore Fe_3O_4). The rate of the oxide formation depends on the temperature, composition and physical characteristics of the steel, and is also influenced by the temperature and flow conditions in the atmosphere surrounding the hot metal. Also, the degree to which scale forms is a function of the length of time the steel is exposed to oxidising conditions, the types of steel products being manufactured (i.e. surface area), and whether direct or hot charging (i.e. rolling of steel immediately after it is cast) is practiced.

HRM sludge

The smaller particles of mill scale, which are referred to as HRM sludge, are generated during hot rolling operations and are generally collected in process water treatment units close to the rolling mill. The sludge can be the underflow from a clarifier, thickener, or backwash from a sand filtration unit. In some plants, however, all of the process waters from the rolling mills are piped to a central treatment plant where mill process waters are treated with acidic and other chemical wastes from other parts of the plant to form a sludge that contains 30-70% iron and 2-25% oil.

Other

The following rolling processes were considered (for more details, see the appendix):

- hot strip mill
- plate mill
- bar/rod mill
- shape mill
- pipe mill.

Representation and production	Number of plants: 48 out of total of 60 respondents reported tonnage against, at least one, rolling operation. (Group A) 40 answered on by-product generation and destinations. (Group B) Regions: all regions except CIS and North America.		
	Production: Group A: 142 Mt rolled steel. Group B: 128 Mt rolled steel / 2.25 Mt HRM by-products.		
Generation	Specific generation in kg/t rolled steel: Scale (Min/Average/Max): 2.2/18.5/54 Sludge (Min/Average/Max): 0.07/3.5/8.7 Other (Min/Average/Max): 0.06/1/2.9		
Main issues	Mill scale: oil content too high to return to sinter plant. Sludge: oil too high for sinter, Fe content too low and particle size too fine for some other applications. Generally difficult to landfill. In some regions it is classified as hazardous waste.		
Destinations	Total: Recovery = 98.2% Internal: 75.4%, External: 22.8%	Stockpile: 0.1%.	Landfill: 1.6% Internal landfill: 1.2%, External landfill: 0.4%
	Scale: Recovery = 99.9% Internal: 78.4%, External: 21.5%	Stockpile: 0%	Landfill: 0.1% Mostly Internal: 0.08%
	Sludge: Recovery = 85.8% Internal: 52.2%, External: 33.6%	Stockpile: 1%	Landfill: 13.1% Internal landfill: 9.8%, External landfill: 3.3%
	Other: Recovery = 77.4% All internal	Stockpile: 7.3%	Landfill: 15.2% Internal landfill: 8.4%, External landfill: 6.8%
	Main destinations for scale: - 72% of the total scale generated was recovered internally recovered, The majority recovered via the sinter plant (54% of total). - An additional 7% was sent to external sinter plants, 5% to cement industry, 6% to both petro-chemical and magnetic materials		
	Main destinations for sludge: - Internal recovery accounted for 55% of total generation, the majority recovered via the sinter plant (30%) and BF (18%) routes. - External recovery was principally via the cement industry (12% of total) and external steel process (5% of total).		
	Main destinations for 'Other': 100% recovered internally via the sinter plant.		
Good practices	For coarse/fine mill scale internal recovery via the sinter plant was the most common technique. Oily mill scale sludge was most often used as iron source in cement production, in some cases blended with other iron bearing materials or dried and screened before use. Other recovery options seem to be of minor relevance and heavily dependent on local conditions.		
Forecast at a glance	Oily mill scale sludge was generally recovered externally, however, many different processes for de-oiling, blending and briquetting to subsequently enable use in internal production facilities were being both developed and implemented.		

Table 58: Summary of responses

Production basic statistics

Out of the 60 respondents, 48 provided production data (representing 142 Mt steel) and 40 plants provided all the data (representing 128 Mt steel). Among the 142 Mt of hot rolled materials, 92.3 Mt were rolled in hot strip mills (65%), 22.2 Mt (16%) were rolled in plate mills, 19 Mt (13%) in bar and rod mills, 4.4 Mt (3%) were produced in shape mills and an additional 4.1 Mt (3%) in pipe mills. For more details, see the appendix.

Generation

Analysis of by-product generation is shown in Figure 84. The by-products were categorised into 'HRM scale (coarse/fine)', 'HRM sludge' and 'HRM Other'. The total amount of all HRM by-products reported was 2.6 Mt a year. The majority was generated as HRM scale (coarse/ fine), which accounts for 2.27 Mt a year or 88% of the total. The amount of HRM sludge was approximately 0.30 Mt (11.6%) and the category HRM 'Other' accounted for just 12,500 tonnes.

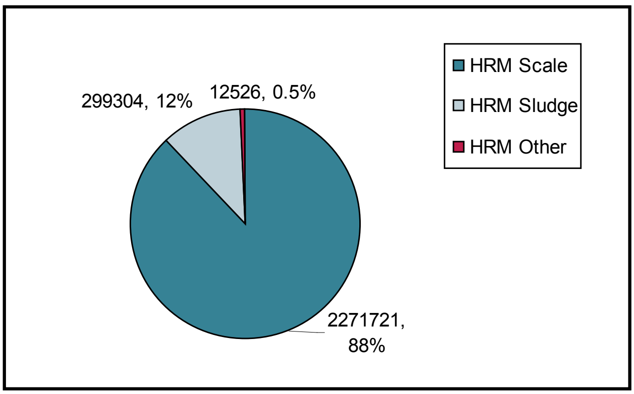


Figure 84: Generation of HRM by-product in tonnes per annum by category

The largest proportion of by-products produced from HRM facilities was coarse and fine mill scale, which was generated at an average rate of 18.5 kg/t of hot rolled steel. HRM sludge was generated at an average rate of 3.5 kg/t of hot rolled steel and HRM 'Others' at 1 kg/t of hot rolled steel.

According to the respondents, HRM sludge was the most difficult to recover (or landfill). Figure 85 shows a comparison of hot rolling mill by-product generation from 1994 to 2006.

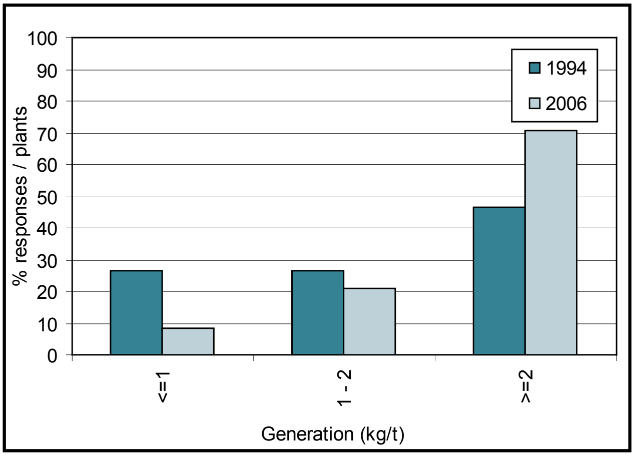


Figure 85: Specific sludge generation in 1994 and 2006

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Sludge	kg/t	0	28	5	0.1	8.8	3.5

Table 59: Specific sludge generation in 1994 and 2006

Overall generation has reduced since the 1994 study. This reduction may be attributed to improved maintenance/operations or improved reheating furnace controls (resulting in reduced scale formation). See the appendix for more details on specific generation by plant.

Chemistry

Scale	Minimum	Maximum	Mean
Moisture	1.8	20	6.1
Oil	0.01	15	1.5
Sludge	**Minimum**	**Maximum**	**Mean**
Moisture	7	55	22.9
Oil	0.2	16	4.1

Table 60: Scale and sludge moisture and oil content in % v/v

See the appendix for more composition information and moisture and oil breakdown by plant.

Main issues

The main issue raised by respondents was the level of oil in the material. Elevated oil levels and the associated safety and process issues significantly limited the quantities of material that was able be recovered via the sinter plant. The appendix contains the list of issues collected.

One plant reported that due to local waste classification legislation, the oily mill scale was classified as hazardous waste and disposed of via landfill.

HRM by-products contain a relatively high level of iron. Several respondents indicated that briquetting the material for internal recycling (direct feed to either the BF or BOF), and eliminating the need to recover via the sinter plant were possibilities under investigation.

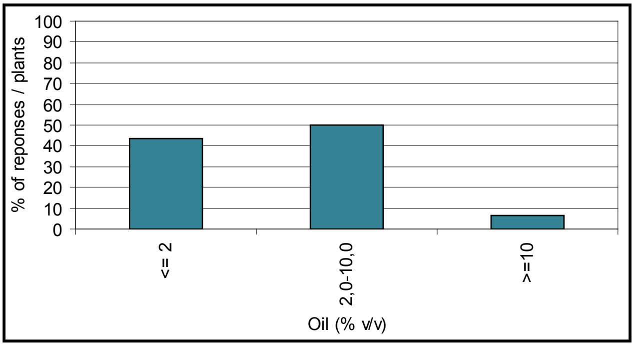


Figure 86: HRM sludge oil content

By-product	Dimension	1994			2006		
		min	max	mean	min	max	mean
Sludge	%	2	25	-	0.2	16.0	4.1

Table 61: HRM sludge oil content

Destinations by category

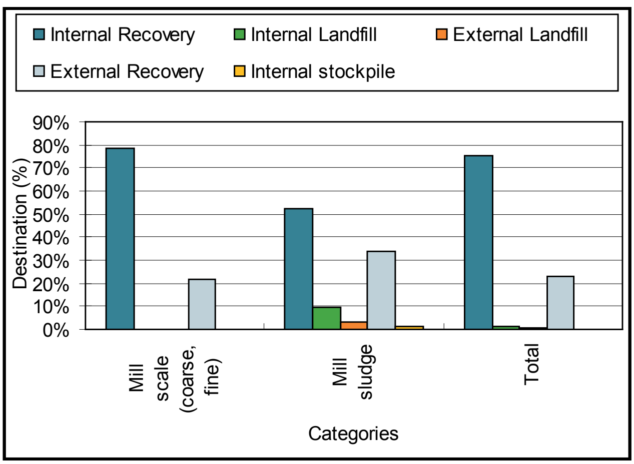


Figure 87: HRM by-products main destinations by category

Figure 97 indicates that whilst all of the coarse scale was recovered internally or externally, the fine material (sludge) was not as well utilised. Approximately 14% was sent to landfill or stockpiled.

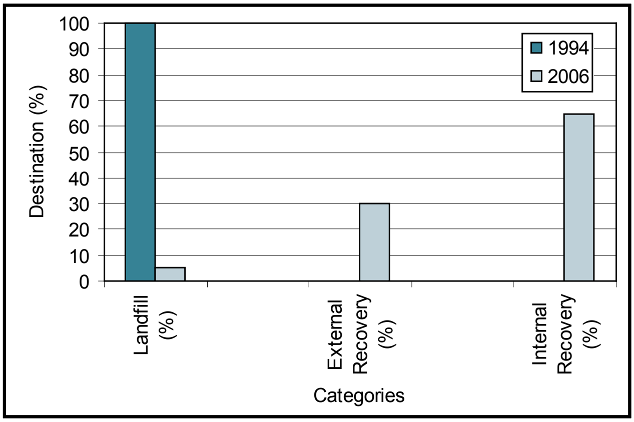


Figure 88: HRM sludge utilisation

Since 1994 there has been a significant reduction of the proportion sent to landfill. This increased utilisation has been driven largely by the average iron content (approximately 60%) of the sludge.

Details of main recovery

HRM scale (coarse/fine)

Approximately 72% of HRM scale (coarse/fine) was directly used within the steel industry, with more than 50% recovered via the sinter plant. Further specialist applications, such as catalyst manufacture and briquetting were also reported to be increasing. HRM scale was often blended with scale from continuous casting before use.

HRM sludge

The use of HRM sludge appears more challenging, due largely to its smaller particle size, higher oil content, chemical composition and lower ferrous content. It was reported that the higher water content of this material also raises issues with regard disposal to landfill.

HRM by-products examples of applications and management practices

Treatments for HRM scale (coarse and fine)

The main treatment steps were screening, water removal (drying, sedimentation) and oil removal. In some cases the HRM scale was blended with scale from continuous casting or combined with other treatments.

Treatments for HRM sludge

- Water removal (sedimentation, filtration, drainage)
- Oil removal (de-oiling, oil skimming)
- Thermal treatment (incineration, drying)
- A combination of the above and also blending, briquetting with coarse sludge to substitute scrap in BOF, cold-bonded pellet (CBP), or aging (to control the reaction of calcium oxide).

For complete data on good practices see the appendix.

Conclusions

For HRM scale, internal recovery in the sinter plant was the most common destination. Therefore, this by-product is not considered problematic.

In some cases HRM sludge is blended with other iron-bearing materials or dried and screened before use internally. However, HRM sludge was often recovered externally, for example as an iron source in the cement industry.

As external recovery is currently the main route for HRM sludge, many different processes for de-oiling, blending and briquetting (for subsequent use in in-house steel production facilities) are being developed and implemented. The main drivers for these developments are assumed to be the cost of external recovery and the high iron content of the material.

Cold rolling, pickling, annealing, galvanising

Overview

This section of the phase 1 questionnaire aimed to review the main by-products from pickling, cold rolling, coating and annealing. The questionnaire collected data on the production output of the respondents' facilities, by-product generation, by-product composition, use and the by-products' final destinations.

The questionnaire focussed on those by-products seen as potentially problematic, such as wastewater treatment sludge and iron oxide produced as a by-product of hydrochloric acid regeneration from the pickling process. An additional category ('Other') was included to allow respondents to include data on specific by-products of concern.

Additional contextual information was also requested for activities that the respondents considered good practice or innovations with respect to the management of a particular by-product. Supplementary information was also requested where particularly problematic by-products were identified.

Conclusions and recommendations

The average, minimum and maximum generation figures are available in the appendix. Review of the these figures at a facility level shows marked variation and as such these figures must be treated with caution.

Facilities use various combinations of pickling, cold rolling, coating and annealing processes. This makes effective comparision problematic. The production process resulting in the generation of a particular by-product (for each by-products reported in this category) is not implicit in the facilities' response. If this category is included in future data collections, care should be taken to ensure that the link between by-product and process of origin is maintained.

Limited data was provided on by-product composition. Much of the data that was provided was incomplete and therefore does not provide a representative or typical sample of the by-product composition in this category.

Comparison of historical data was not possible as pickling, cold rolling, coating and annealing data was not collected in the 1987 or 1994 by-product studies.

Due to the aggregated nature of this category (i.e. multiple independent production processes), data inconsistencies and the absence of data for historical comparison, the phase 2 questionnaire focused on other more significant and problematic by-product categories. Given the proportion of iron-bearing material currently being discarded to landfill, future by-product data collection should focus on establishing more effective reuse/recycling alternatives for waste water treatment plant sludge from the pickling, cold rolling, coating and annealing processes.

General conclusion for dusts and sludges

There were no significant changes in the relative dusts and sludges generation/collection rates compared to the 1994 study.

However, there does appear to have been a significant reduction in the amount of these materials being disposed of via landfill.

Recovery of dusts and sludges was on the whole, though not exclusively, via internal processes.

Increased legislative and sustainability drivers are bringing about development and implementation of innovative solutions.

Phase 2: Results from best performers

From the information from phase 1 of the study, best performers (BPs) were identified. These were the plants that recovered 100% (or close to 100%) of the materials. For slag, the BP criteria also included secondary slags, and to ensure good representation of the results, several plants were included from all regions.

The dust and sludge BPs were selected on a similar basis, although taking into account only primary and secondary materials, ie. excluding the 'Other' category.

A total of 45 plants provided a response to the phase 2 questionnaire, compared to 60 for phase 1.

By-product	No. of answers from BPs	No. of total answers
BOF slag	11	22
EAF slag	7	20
Sinter dust	14	20
BF dust	11	21
BOF dust	13	21
EAF dust	10	22
HRM dust	13	37

Table 62: Number of responses

The data was then compared and contrasted to see how and why some companies/plants performed better than others.

Methodology

The phase 2 survey was divided into two parts. Firstly, a series of multiple choice questions directed to all plants, which asked them to rate (as objectively as possible) their performance in:

- marketing (MK)
- technology (CT)
- management (MG)
- regulations and legislation (R).

Several questions were included to determine where further work and effort was required to increase the levels of utilisation.

The second part of the questionnaire was for the BPs. It sought more detailed information on the practices and processes which enabled them to achieve high levels of by-product utilisation.

To pinpoint which key points reflected differences between BPs and the other respondents, all the ratings were analysed in terms of average and variance.

The charts below outline some of the results and indicate areas where the BPs scored higher. It is noteworthy that while they scored higher, the BPs also had less variance in their results.

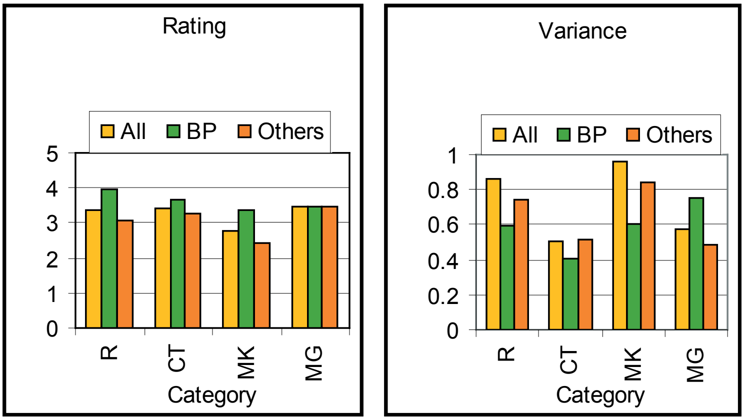


Figure 89: Example: Average rating and variance by category

Due to the design of phase 2, it was inevitable that many of the questions would require subjective answers. Whilst there is a degree of inaccuracy, this reflects the perceptions and approaches taken by companies.

Two key performance indicators (KPI) were identified:

- KPI1: % Recovered/utilised of the specific by-product
- KPI2: Specific generation rate (normalised against production rate of the product, for example kg of slag per tonne of crude steel).

Each of these KPIs was assigned a score between 1 and 5, with 5 being the highest rate of recovery (KPI1) and the lowest level of generation (KPI2).

Phase 2 results for BOF and EAF slag

In total 45 plants replied to the phase 2 questionnaire, of which 11 were identified as BPs on BOF slag utilisation, and eight as best performers on EAF slag utilisation. These numbers and ratios were sufficient to provide a meaningful analysis.

General analysis of all ratings

The figures below outline the consolidated ratings for the various categories (MK, CT, MG, R).

BPs for BOF slags are compared with the non-BPs in terms of their overall rating (average of the categories), and also for the specific KPIs (defined on p. 124).

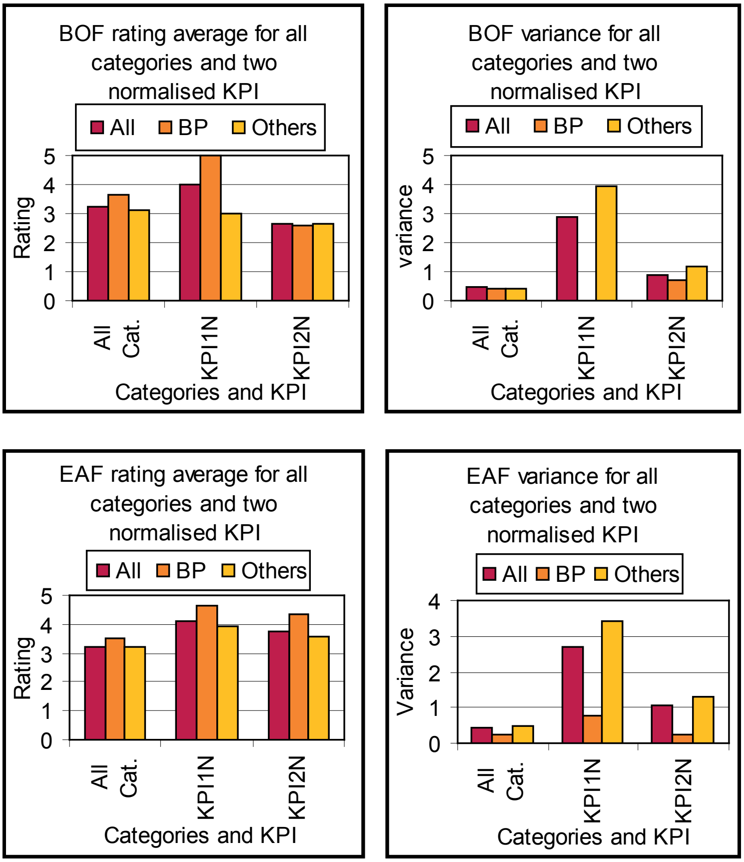


Figure 90: Average and variance of the overall rating and KPIs for both BOF and EAF

The results indicate that the average ratings of the BPs are only slightly better than the non-BPs plants, and that the variance is small for both.

Possible explanations for such results are:

- KPI1 may not necessarily be the best method of determining the BPs. However, no alternative KPI could be developed that would be more meaningful.
- The ratings are subjective and the BPs may be more critical in their self-assessment.

These observations also hold true for the results obtained for EAF slags.

Analysis by field of management

This section examines the relative importance of the categories that were surveyed.

The graphs below demonstrate the main gaps between BPs and non-BPs appear in marketing (category 1), regulation (category 2) and technology (category 3), with the BPs having a higher rating and a lower variance in comparison with the non-BPs. The lack of a similar relationship in the 'management' category suggests that there were no specific techniques or approaches applied that directly affected the performance of the plants in respect to their KPI1 rating.

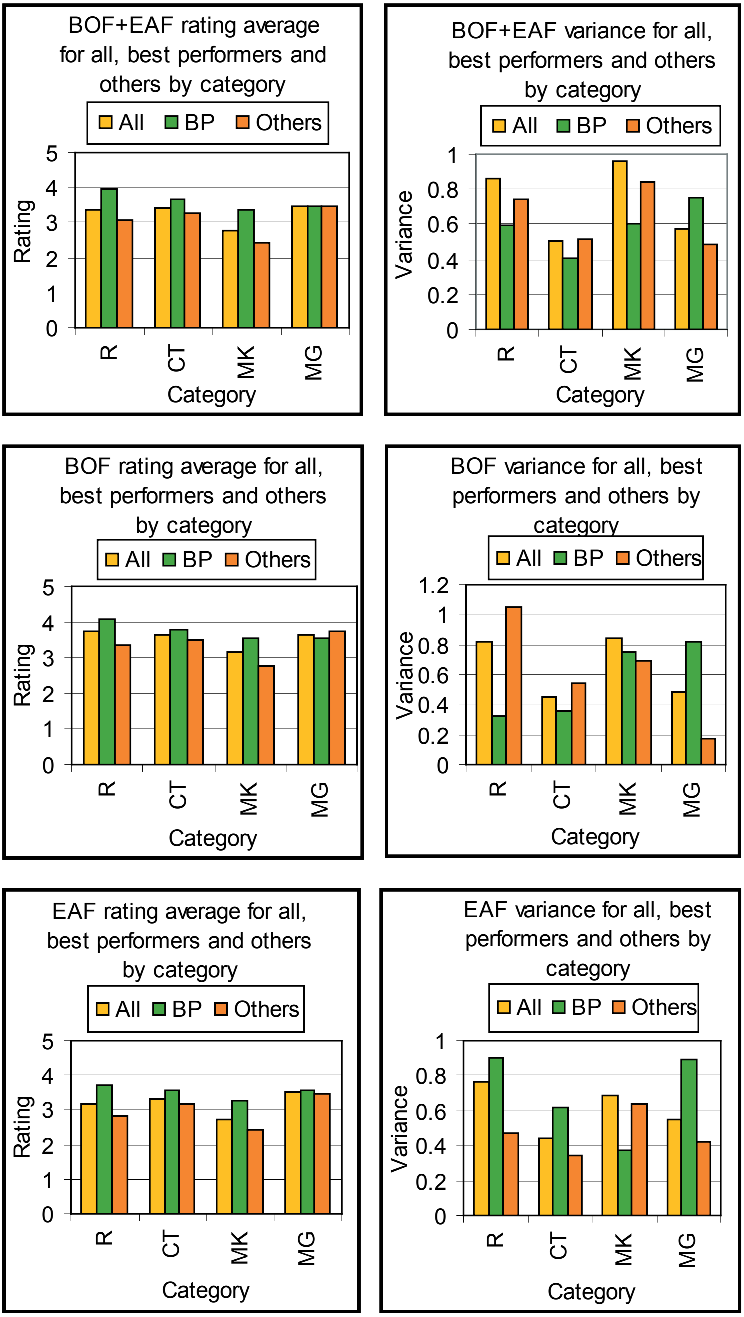


Figure 91: Average rating and variance by category for BOF and EAF combined and separately

It may be noted too that the differentials observed for the marketing, and regulation categories may be more important than for technology. It is, however, necessary to analsze each aspect in detail before any conclusions can be drawn.

It should also be noted that these points hold true for both BOS and EAF slags.

Marketing ratings

The questions circulated to the plants are listed below:

MK2	What is the value of your by-product (excluding transport costs) in your market?
MK3	Do you have any collaboration/partnership with other industries? For example, development of a new application.
MK4	Do you develop competitively differentiated products (having unique properties/advantages) for targeted applications?
MK5	Do your by-products meet specifications of existing product standards?

The charts for BOF and EAF slags combined indicate that:

- The average rating on question MK2 is 3.75, which is high in comparison with the responses given for the other questions.
- There is a differential between BPs and non-BPs for all of the questions, though this appears to be more pronounced for question MK5 and MK2.
- The variance for best performers is significantly smaller on MK2 and MK3.

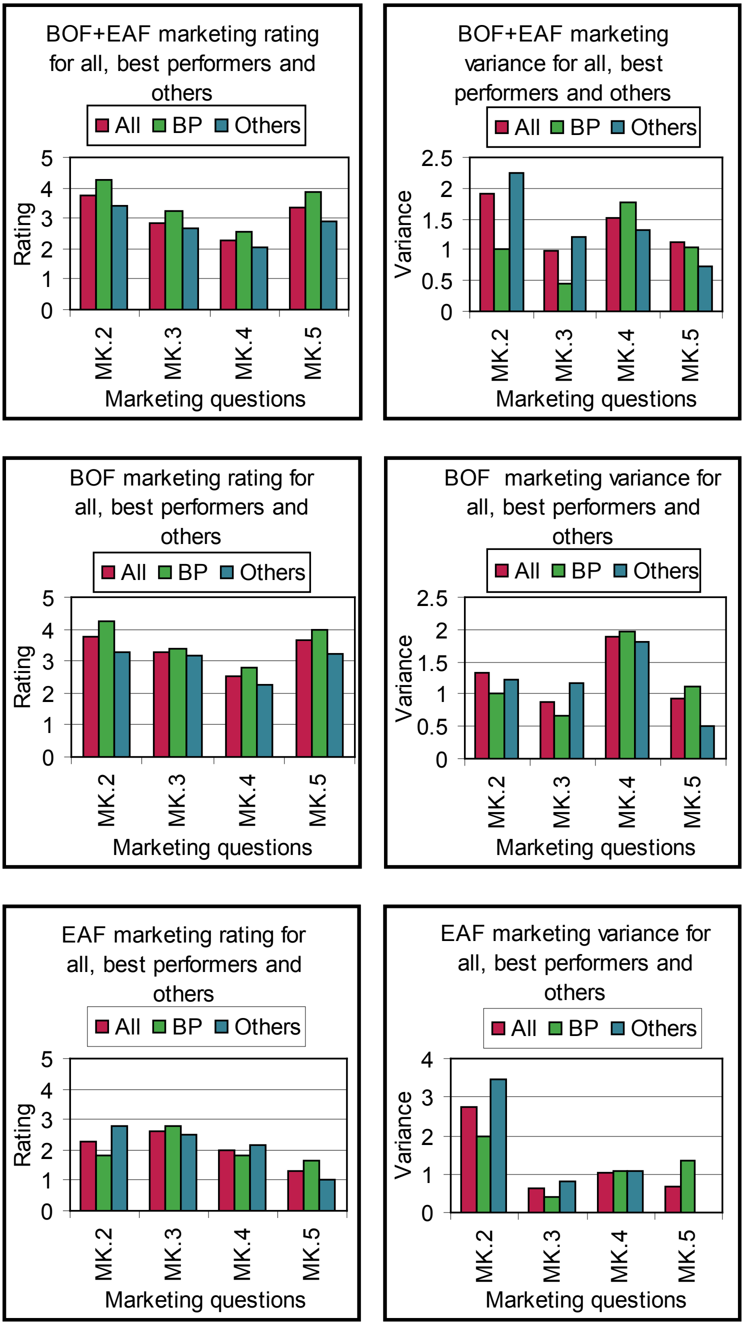


Figure 92: Average rating and variance for marketing for BOF and EAF combined and separately

On question MK5, it is worth noting that the majority (94% of those that responded) of the BPs had standards/specifications relating to their slags, so they were treated/marketed as a product with a technical specification. Of the non-BPs, 41% of the respondents indicated that no such standards applied to their slags.

It is suggested that standards and specifications contribute to increasing recovery rates. It is probable that BPs strive to further develop these standards, and thus wider markets and applications. Standards act as a driver to increase and improve the levels of slag utilisation.

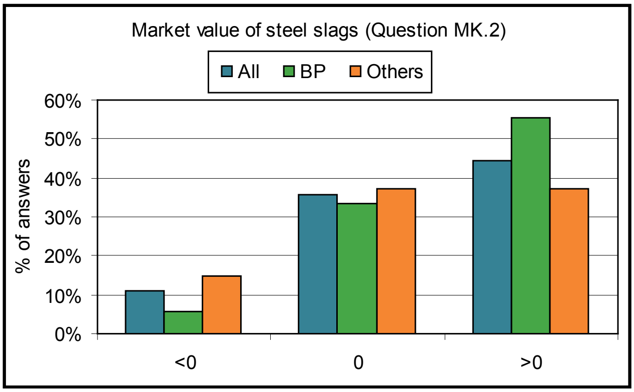


Figure 93: Market value of steel slags, distribution of answers

Figure 93 demonstrates that the value of slag has an important influence on its use. More than 50% of BPs declared a positive value for steel slags, and less than 6% a negative value. However only 37% of the non-BPs declared that it has a positive value, and 15% said it has a negative value. In standard supply and demand conditions, if demand is high and competition is limited, the value will be higher and therefore external recovery easier. Good marketing can also improve demand and increase value.

Further analysis of the responses to questions MK3, MK4, and MK5 suggest that complying with standards and specifications, marketing differentiated products, and improved partnerships with customers are key issues that created or increased value.

Whilst the observations outlined above refer to BOF slag, they are equally applicable to EAF slags, although the differences between BPs and non-BPs are not as significant there.

Technology ratings

The questions circulated to the plants are shown below:

- CT.1 Which strategical importance is given in your company to increasing its level of by-product recycling/recovery?
- CT.2 Do existing or commercially-available recycling or reuse technologies meet your current needs?
- CT.3 Is the level of financial support sufficient for funding technological investments in this area?
- CT.4 Do you have dedicated man power such as researchers or engineers in your company that provide support regarding by product developments in your plant
- CT.5 In the area of by-product management/processing/research, etc., how would you rate your relationship with:
    - CT.5.1 Customers?
    - CT.5.2 Public Research Institutes?
    - CT.5.3 Engineering companies and Suppliers of Equipment?
- CT.6 Are you satisfied with the level of innovation and introduction of new by-product technologies in your plant?

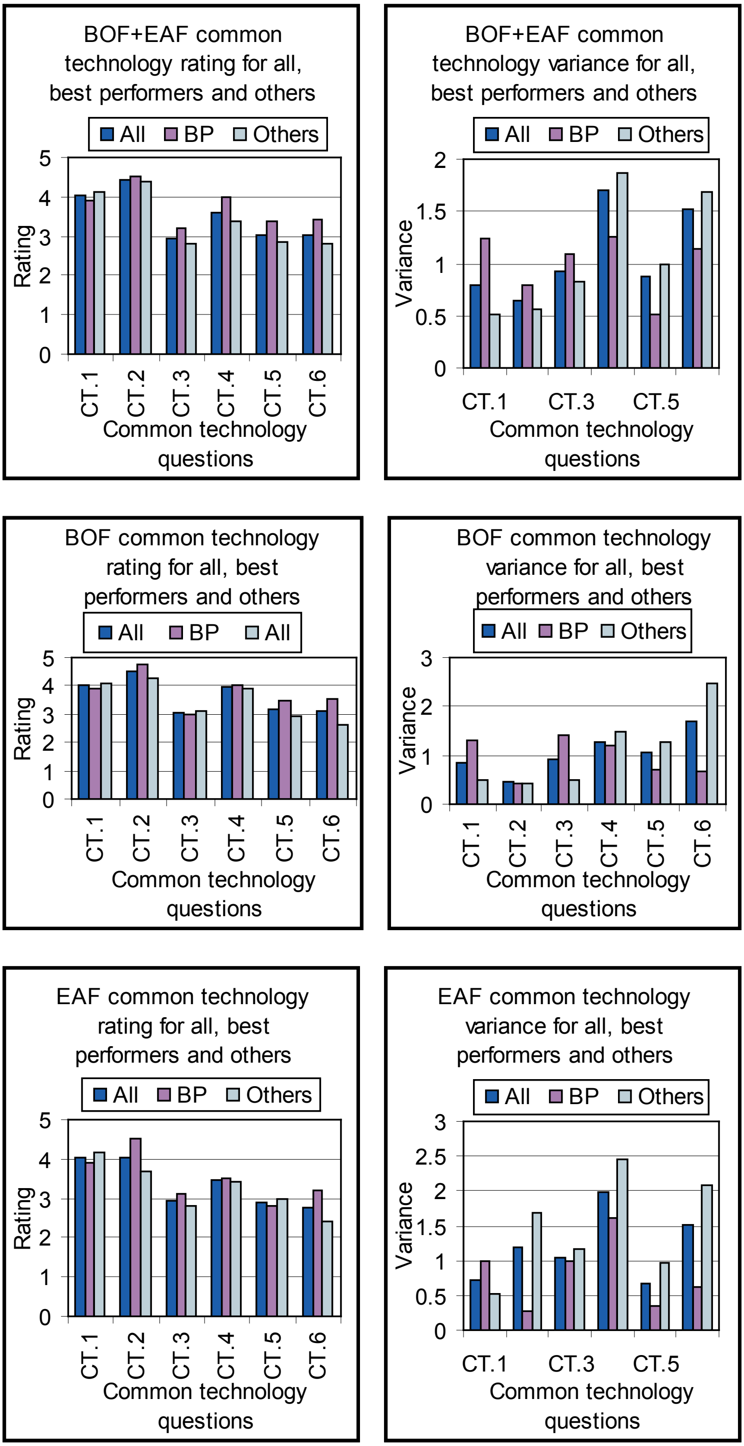


Figure 94: Average rating and variance for technology

The most noticeable differences in the results from the BPs and non-BPs are in the responses to questions CT4, CT5 and CT6, on dedicated resources (manpower), innovations, technology and relationships with customers, research institutes and equipment suppliers. The following points are also worth noting:

- Strategic importance is effective in improving use. This factor in itself will drive all the other associated factors/categories.
- Existing technologies appear to meet the needs of today.
- The funding of technological investments is considered poor.

In general, these results and observations apply to EAF and BOF slags, although there is less differentiation between the BPs and non-BPs for EAF slags when it comes to availability of existing technology and level of innovation.

Regulation ratings

In this section only one question aimed to obtain a subjective rating. In question R5, respondents were asked to rate the level of resources (people/time/money) used for activities aimed at overcoming legal barriers to reuse, recycling and/or recovery of any by-products.

The responses to question R5 are shown in the graphs below.

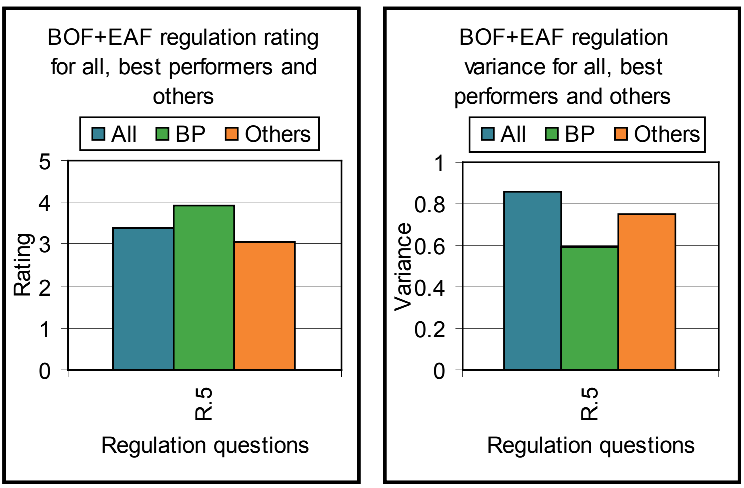


Figure 95 : Average rating and variance for R5 for BOF and EAF combined

Unsurprisingly, the results indicate that on average (and with a lesser degree of variance) BP plants allocate more resources than the non-BP plants.

Examples of comments supplied with the results in the regulation category include:

Question R1b:

The average answer to this question is 3.4, which indicates that internal landfill is allowed for between five and 10 years. These comments suggest that provided steel slags are not considered hazardous, internal landfilling is usually allowed.

Question R5:

The environment department in plants is usually in charge of legal aspects regarding wastes and by-products. However, some companies also appear to have developed more elaborate organisational structures with a by-products department at plant or country level.

Management ratings

The questions circulated to the plants are listed below:

MG.1	How important is by-product management in your business strategy?
MG.1.1	Does your business have clear by-product targets for utilisation and/or generation?
MG.1.4	What statement best describes your current by-product management process?
MG.2	With regards to by-products, are you satisfied at your plant level with: • organisation/structure? • manpower? • R&D budget?
MG.3	Do you have a data base or reporting system for slag?
MG.4	Do you have a shared reporting system for environmental, commercial/marketing and technical indicators?
MG.5	Is the present relation/partnership with your subcontractors satisfactory?
MG.6	Do you have a system to control by-product quality issues?
MG.7	Is your by-product quality management system accredited by national or international standards (ex: ISO 14001, ISO 9001…)?

The figures below show the responses received relating to the category on 'management'.

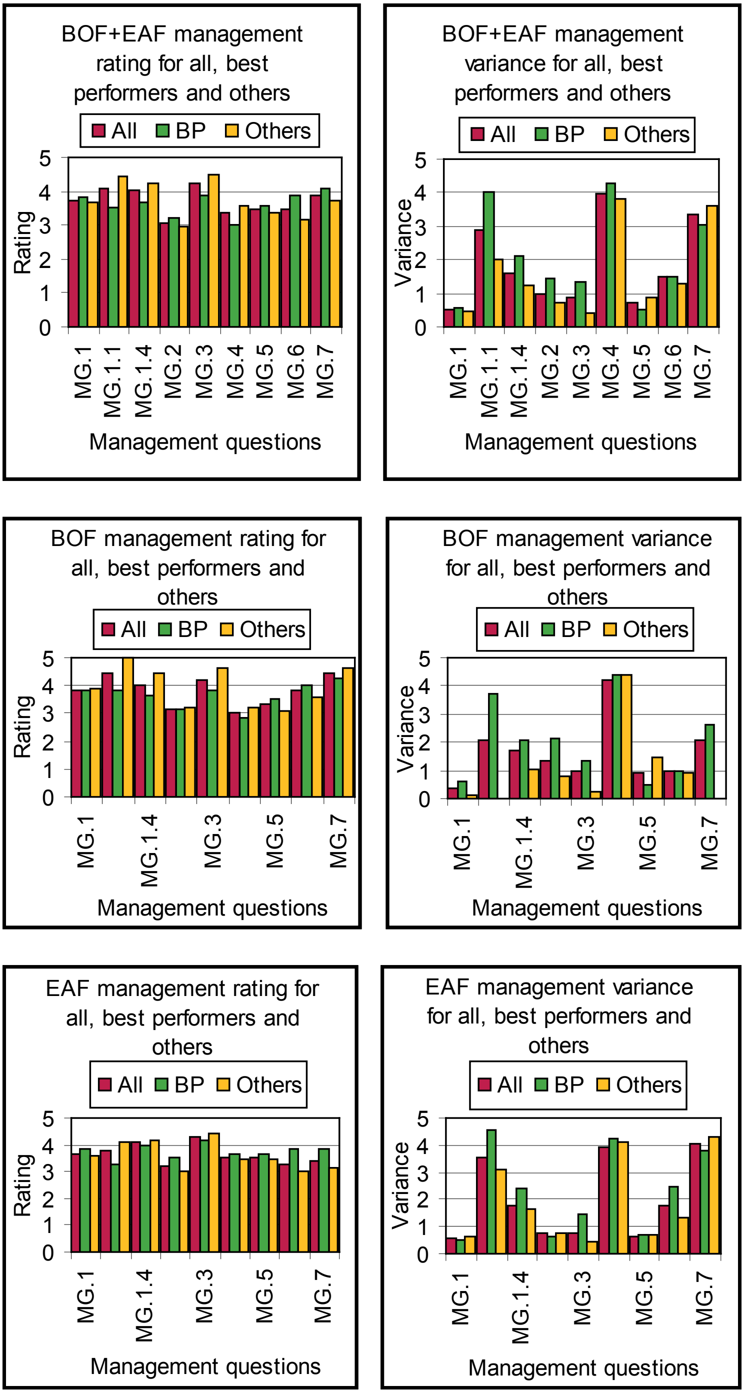


Figure 96: Average rating and variance for management

It appears that the BPs (specifically for BOF slag) have a significantly higher rating on only one of the points in question: MG.6. This suggests that that they have developed and implemented improved systems for quality control of their slags compared to the non-BPs.

The same is not true for EAF slags plants, for which there appears to be no simple explanation. If however, we reduce the number of BP plants to reduce the relatively high variance of the results, this too confirms that the above observation applies to EAF slags.

According to the responses received, BP plants did not have superior reporting systems in comparison to other plants. This may be due to the subjective nature of the questions posed.

It must also be stressed that BPs show a larger variance on all points, particularly on MG1.1 (clear targets). This probably implies that there is no such thing as an ideal by-products management model, and interpretation is subjective.

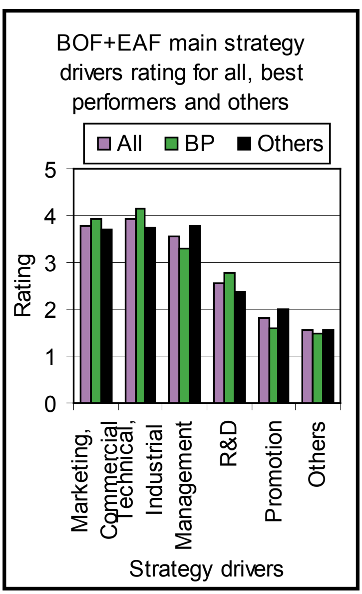
Management orientations: Drivers (question MG.1.2)

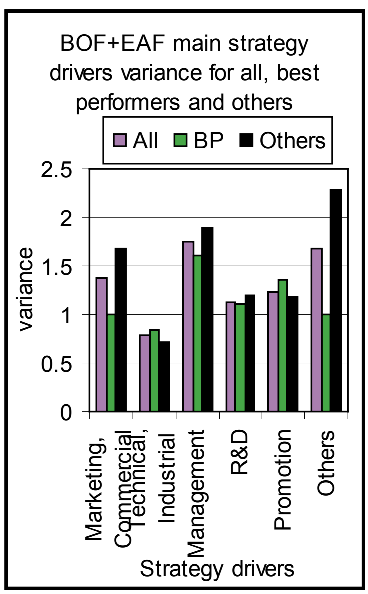
The question was:

List the domain where in your plant/company you put your efforts in priority (your key strategy drivers) in order of their importance.

The suggested domains or drivers were: Marketing/Commercial, Technical/Industrial, Management, R&D, and Promotion.

The answers can be converted into ratings of the drivers (not of the plants) as follows: five for rank 1, four for rank 2, and so on. The ratings given by BPs and Others have been compared, with results shown below.





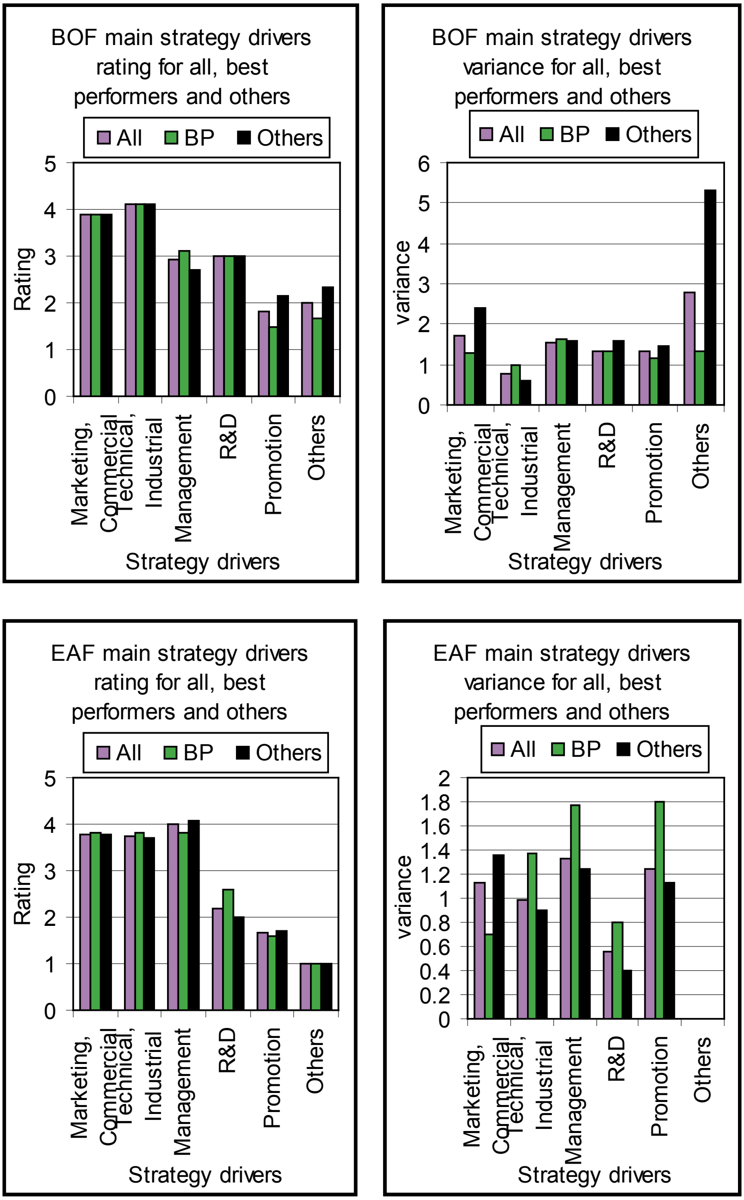


Figure 97: Average rating and variance for the main drivers

As discussed earlier, there is not a large difference between BPs and Others. However, it can be concluded that:

- The three main drivers, of approximately equal importance, are Marketing/Commercial, Technical/Industrial, and Management.
- Of these drivers, Marketing is probably the most significant, as rated by BP plants.

KPIs

The three main KPIs are clearly specific production rate, recovery rate, and recovery/disposal cost, for BPs as well as Others. All plants, BP and non-BP gave very similar KPI ratings.

Key activities (to increase the valorisation of by-products)

1. product development plans
2. optimising value in use
3. external industry collaboration
4. influencing standard/technical specification
5. steel industry collaboration
6. regulatory collaboration/consultation
7. none.

The reference numbers above are used in the graphs below.

BPs tend to be significantly more involved in steel industry collaborations. However, this question is difficult to analyse because plants were limited to giving one answer, and several activities may have been pursued at the same time. This result applies to both BOF and EAF slags.

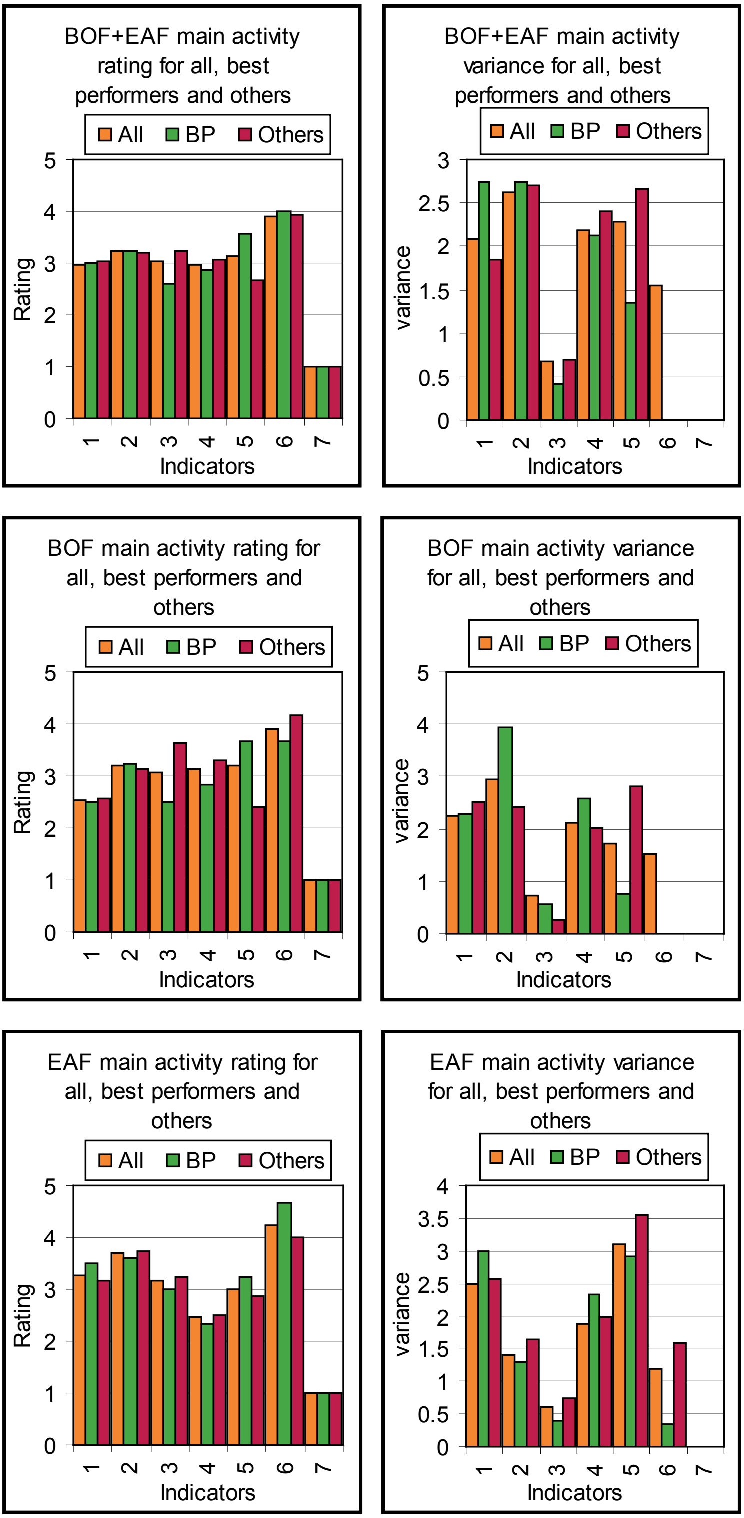


Figure 98: Average rating and variance for key activities

Background analysis

Five 'background analysis' questions (four on regulation and one on marketing) were included in the survey. These questions were designed to illustrate the influence of the regulatory or market background on plant performance.

Regulatory background

See also the section specifically about legislation in chapter 6.

The background questions were:

R.1 In your opinion, how stringently are you regulated in the area of By-Product Management?
R.1.b Are you allowed to stock or landfill on the site, Steel slags, Sludges and dusts?

R.2 Do you have, and are you subject to, national/regional legislation regarding:
- The definition of waste (what is classified as waste and non-waste)
- The classification of waste, e.g. Hazardous, non-hazardous, inert waste?
- The transportation (national and transfrontier shipment) of waste?
- Recycling, recovery of waste?
- Disposal of waste?

R.3 Do you have to pay disposal fees/taxes/levies?

R.4 Do you apply for public financial relief/support/funding for implementing processes/techniques etc for environmental improvement schemes?

The graphs below show that both BP and Other plants gave similar ratings to the above questions, but that BP plants had less variance.

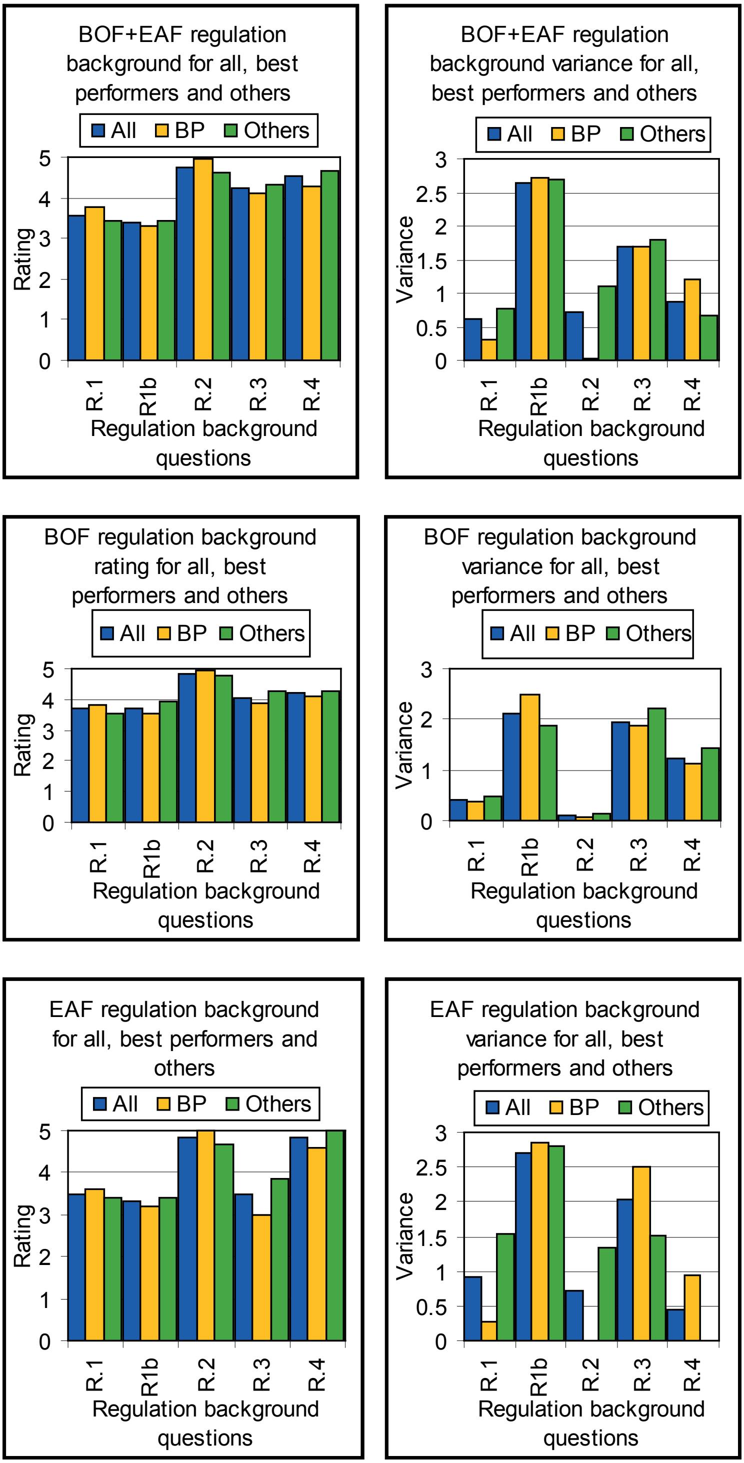


Figure 99: Average background and variance for regulations

Furthermore, BPs are more stringently regulated, which is not surprising as regulation is obviously a powerful incentive to recycle. The very small variance on R1 and R2 shows that BPs all have same kind of stringent regulatory background (see particularly R2), unlike the non-BPs, who operate in a variety of contexts. In fact, a high level of regulation appears to be necessary to attain better performance as regulation forces companies to improve.

The same conclusions apply to BOF slags and EAF slags, with an additional constraint on EAF slag BPs being more influenced by disposal fees.

Market background

Question MK 1: How would you assess the current (referring to 2006 and 2007) market demand?

The results are shown in the graph below. There is no difference between BPs and Others, which means that BPs do not have better markets. The average rating of 2.4 means that the demand is estimated between “lower than the supply” and “equal to the supply”. Sixteen plants reported that the demand for slags is equal to or higher than the supply. It is worth noting that the variance is bigger for the BP plants for BOF slags. In fact, seven BPs out of 11 give a rating of 2, which means the market demand is lower than the supply. However, these plants still achieve 100% recovery (external and internal).

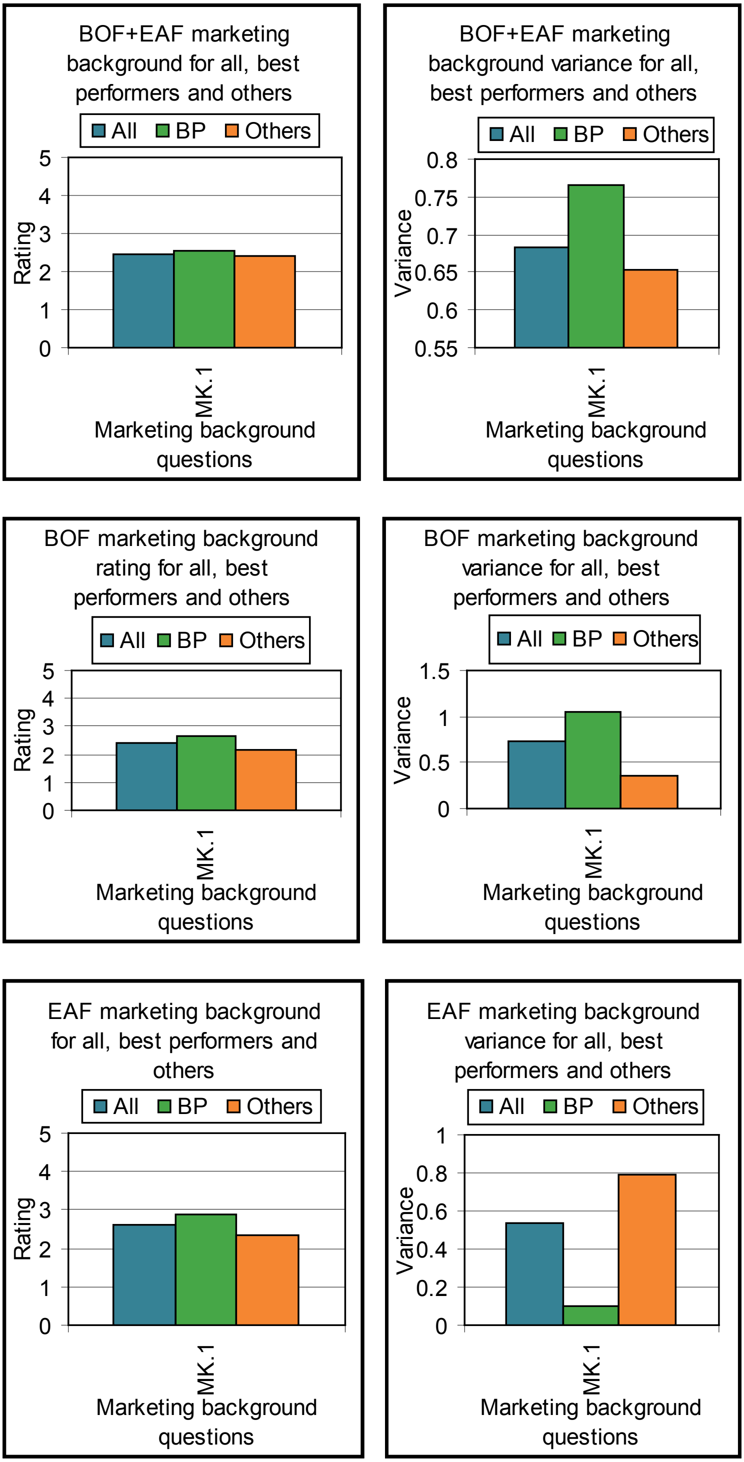


Figure 100: Average background and variance for MK.1

Best performers' key organisation points (on BOF slags)

Three questions were asked of all BPs: BP1 on the organisational structure, BP2 and BP3 on subcontracting policy and management. The responses from the BPs for BOF slags are analysed below.

BP1 What is your organisation and management structure for by-products (write a text explaining) For example: Manpower (sales, R&D, Environment, Technical, full time/ part time), responsibilities, management structure (whom do they report to?)

BP2 Do you have subcontractors for the processing and sales of by-products? If Yes, please show us the structure and their activities (and what is the % of their contribution for each sector/activity (transportation, cooling, treatment, sales…)

BP3 How do you manage subcontractors? Things to consider in your response may include:

- why do you have subcontractors?
- scope of contracts?
- ownership of contracts?
- progress and innovation objectives?
- partnership or just subcontracting?

BP1: Organisation structure

Nine BOF plants gave responses. All the answers are shown in a table (see appendix), grouped into three categories: the top ones, the middle ones, and the bottom ones, depending on their slag recovery performance.

It must be highlighted that the five bottom and middle plants are precisely those selected BPs which should perhaps be removed from the BP set, because their overall rating is below the general average. On the other hand, plants 280 and 325 rank first and second in the overall ratings.

It is obvious that BPs have dedicated teams or departments dealing with by-products. It may be one department or part of a department, or two departments (such as Environment and Marketing), but always with dedicated resources. The same conclusions can be drawn from the seven responses from EAF BPs.

BP2: Extent of subcontracting

The 11 answers for BOF slags are grouped (see appendix) into three categories. In general, the plants that achieved lower recovery rates of BOF slag outsourced all activities to a contractor, including sales and processing. The plants that achieved higher recovery rates retain control over sales and marketing of BOF slag. The same conclusions can be drawn for the seven responses from EAF BPs.

BP3: Reasons for subcontracting

A number of topics were suggested for why a subcontracting company was employed. Not all plants provided a comment on all suggested topics.

The appendix groups the answers provided into three topics:

1. Why do you have subcontractors?

Plant 242 (bottom rating) has a strategy of outsourcing non-core business activities. This looks at first glance similar to plant 280 (top rated). However, there is a significant difference: in plant 242, all by-products activities are outsourced as a general principle, but in plant 280, only non-key activities relating by-products are given to subcontractors.

The other two top rated plants (167, 325) have subcontractors only for technical and logistical expertise, or for legal reasons, not as a general principle. This means that by-products are part of the core business.

We have only three responses from EAF BPs, showing that subcontractors are used because of their technical and logistical expertise.

2. Type of contracts

Little information is given. Plant 325 (top rating) has long-term partnership contracts. Plant 242 (bottom rating) has rather shorter contracts (3 to 5 years). Plant 348 (bottom rating) has no partnership, just subcontracting.

3. Management of subcontractors

There were three responses. The right way to manage subcontractors appears to be by evaluating their results against targets and performance parameters. This should be done at operational level, weekly or monthly, but also at a higher level and with a broader scope, at least once a year.

Best performers' key technical points (on BOF slags)

The following questions were asked of BOF slags BPs:

Code	No. of answers	Question
BP.4-6	6	Briefly describe the by-product treatment technology (Please provide details, for example: What are the key technical solutions or factors enabling your plant to reach such recycling ratios for this by-product?)
BP.5-6	5	Why was this particular technology chosen? Please list alternatives that were considered?
BP.6-6	3	Is the technology commercially available? Please list provider/s?
BP.7-6	2	What were the issues, problems and learning's? What would you do differently?
BP.8-6	3	Do you have plans for further/future development of this technology? For example: Technical or Economic goals? Obstacles to overcome?
BP.9-6	4	Here are a few more questions regarding slags, please do your best do make a consistent and accurate answer with the details you may judge necessary.

Eleven BPs completed the phase 2 questionnaire. The low number of answers received for these questions is disappointing, and may be due to confidentiality concerns.

Questions BP4-6 to BP8-6 are all related to a particular technology which the plant regards as essential to its performance (see responses in the appendix).

BP4-6: Description of the technologies

Five responses cover traditional technology: air-cooling in pits, metal recovery by screening and crushing, and recovery as aggregates, or fertilizer, or restoration of the marine ecosystem (which is more innovative). The last answer refers to the accelerated weathering ACERITA process developed in Brazil.

Only one is different: the BSSF technology, from Baosteel. However, this process cannot be used for 100% of the output of BOF slag, due to the restrictions in fluidity.

BP5-6: reason of the choice of the technology and the alternatives

Here, the first plant explained that it has invested in a stabilisation process by injection of SiO_2 and O_2 into the molten slag. This technology is the one which was presented by TKS during the meeting in Duisburg.

This technology and BSSF are the two most innovative processes developed on an industrial scale in the last 10 years. However, their success remains limited, as they are used in very few plants. The main reason for this may be that they do not make traditional processing technologies redundant, because part of the BOF slag cannot be treated.

This difficulty is highlighted by the first plant in question BP7-6 (problems of stabilisation):

1. slag cannot be 100% stabilised due to the viscosity, lower temperature and higher specification (expansion < 1%)
2. exploitation cost per tonne is still too high due to erosion piping, slag pots.

Clearly, more development is needed, to optimise the process.

As to BSSF, according to Baosteel (Question BP8-6) the process and equipment are being developed for the treatment of high viscosity molten BOF slag and SM slag.

The last question, BP9-6, was divided into two parts:

1. 1. How to accelerate the hydration rate of free CaO and MgO?
2. How to modify the BOF slag composition?

There were three responses:

Acceleration of hydration: one plant reported that five months of natural aging is enough, another plant said that injection of O_2 and SiO_2 is the only process which results in less than 1% expansion (according to the European Steam test).

There is obviously a difficulty on this topic, as expansion tests methods and allowed expansion limits differ from country to country.

Modifying slag composition: all responses indicated that it is not an option, as steel composition will always be the primary objective.

Regarding EAF slags, (see the appendix for more details), the technologies used by BPs are the traditional basic treatments of cooling and metal recovery, and weathering or ageing for mitigating expansion. No other process is mentioned. Some plants separate secondary metallurgy slag, others do not.

Lessons on good management

Managing slags involves combining marketing, technical and regulation issues in daily operations as well as in strategy.

Marketing is certainly the most important part, as reflected by this survey.

- existing technologies are considered satisfying (average rating 4.4)
- market demand is considered insufficient (average rating 2.4)
- marketing is the reason for the biggest gap between BPs and Others
- Traditional treatment processes are used in almost all plants worldwide, including BPs. No strong need or drive towards developing breakthrough processing technology is apparent.

BPs are especially ahead of Others on marketing. In order of signficance, the differences are:

- selling slags that meet standards specifications (and if necessary striving to have standards established) for given applications
- developing different products for targeted applications
- developing partnerships (for development) with other industries (customers)
- achieving value by selling steel slags.

On technology, three key points can be highlighted for BPs:

- dedicated human resources
- partnerships with external players (customers, public research institutes, suppliers, subcontractors)
- innovation, driven towards new applications and markets.

On management, the key differences are in the following areas:

- quality control and quality management systems
- management of subcontractors (contracts, partnerships).

On average, BPs also face more stringent regulations and dedicate more human resources to overcome legal barriers or requirements.

Recycling 100% of BOF or EAF slag is possible today. It is achieved in dozens of plants all over the world. No innovation in processing technology is necessary. The key is to manage slags and sell slags as products, meeting specifications of a standard, and using a quality control system.

Markets and regulations change all the time. Increasing value is a strong and never-ending objective and sustainability is a new challenge. Therefore, innovation and development of new and better applications and markets is necessary. There is a clear trend to move from selling basic aggregates to selling differentiated products with specific chemical or mineral properties suitable for particular applications.

Phase 2 results for dusts and sludges

A small number of BP plants were identified. These plants were selected from the sample set because they had the top plant ratings, as determined from the aggregated total of the ratings from all the dust and sludge indicators. In this way, three plants stood out as for overall dust and sludge management (plant codes plants 231, 280 and 325), see Figure 101 below.

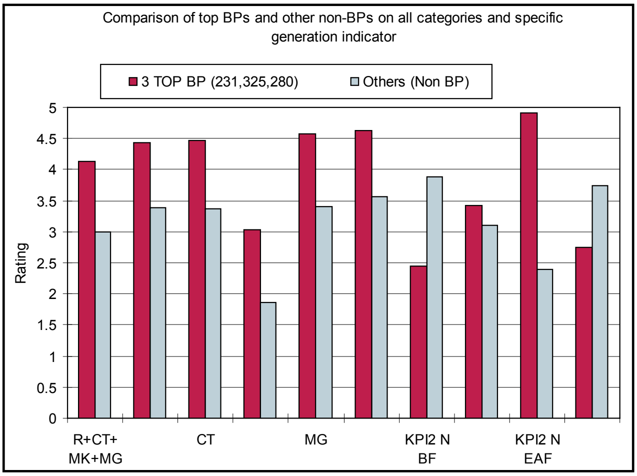


Figure 101: Comparison of the three best performers and other plants by process

There is a clear advantage for top performers in all rating categories.

- The only disadvantages are in KPI2 for BF D&S and HRM D&S; reason is a detailed analysis shows high degree of recovery (KPI1 100 %) for BF 231, 325) and HRM (280), therefore specific generation is not an important factor for them.
- The identification of best practices is then done on a reduced number of BPs.

Summary of 'best performers' for all dust and sludge:

Plant 231
Regulations

- Temporary storage on site allowed.
- Definition of waste in national law.

Plant 280
Technology

- Technical partnership to include BOF converter slag in roads, de-sulphurisation slag in cement industry and BF sludge in ceramics industry.
- Development of use of BOF slag together with BOF sludge in road construction.
- Development of BOF sludge recycling via briquetting plant.
- At present no standards for sludge available.
- ISO 14000 accredited plant.

Regulations

- Stockpile/landfill allowed according to national environmental regulation.
- No fees or taxes are applied to landfill.

Plant 325
Technology

- By-product recovery and utilisation driven by corporate management.
- Rotary hearth furnace (RHF) for recycling technology.
- Research and marketing on by-products.
- Work at developing new demands for by-products.
- Collaboration/partnership with cement industry.
- Application of slag as a special maritime product.

Management

- Special project to evaluate generation and use objectives for by-products.
- By-products are managed by the company itself with subsidiaries and local companies.
- By-product management system as database/reporting (certified ISO 14000).
- Sustainability reporting requirements.
- Green partnership with sub-contractors.
- Sample test for quality control of dust and sludge.

Regulations

- Testrictions apply, maximum three months (hazardous materials maximum 1.5 months).
- Landfilling tax and fees depend on material.
- Ongoing project, originated in 2007, to add value to by-products.

Conclusions

Sites 231 and 325 produce steel via the EAF and BF/BOF routes. Both plants also have a sintering plant.

The three top performers were in 'Asia Other', 'Asia Developed' and 'Latin and South America'.

Detailed analysis of responses to the phase 2 questionnaire did not provide a clear picture on what constitutes best performance with regard to dust and sludge management. The results indicate that best practice/performance could not be reached by one technology or management method.

As could be expected, dust and sludge best performance was the result of site-specific management practices, adapted to specific national or regional legislation and market conditions.

Plant visits and case studies

There were six plant visits between June 2007 and February 2009:

- ThyssenKrupp Steel, Duisburg
- Baosteel, Shanghai
- Tata Steel, Jamshedpur
- United States Steel Corporation, Pittsburgh
- ArcelorMittal, Tubarão
- Bluescope Steel, Port Kembla.

They were an opportunity to tour the facilities and observe different approaches to by-product management in practice. The visits also included presentations from experts and gave participants access to technical and operational staff working in by-products management.

ThyssenKrupp Steel, Duisburg (Germany) - June 2007

ThyssenKrupp Steel's Duisburg plant is an integrated steelworks producing flat products. The plant had four blast furnaces and two steelmaking plants (five converters). The plant capacity was 11.4 Mt of hot metal a year from the blast furnaces and as some hot metal was sold to an external steelmaker, 10.8 Mt of crude steel.

The Duisburg site has a modern coke oven plant, a sintering plant with three sintering belts, two hot rolling mills, two cold rolling mills, two hot dip galvanizing plants, two electro-galvanizing plants and two plants for painting or organic coating of plates.

Seven technical presentations were given:

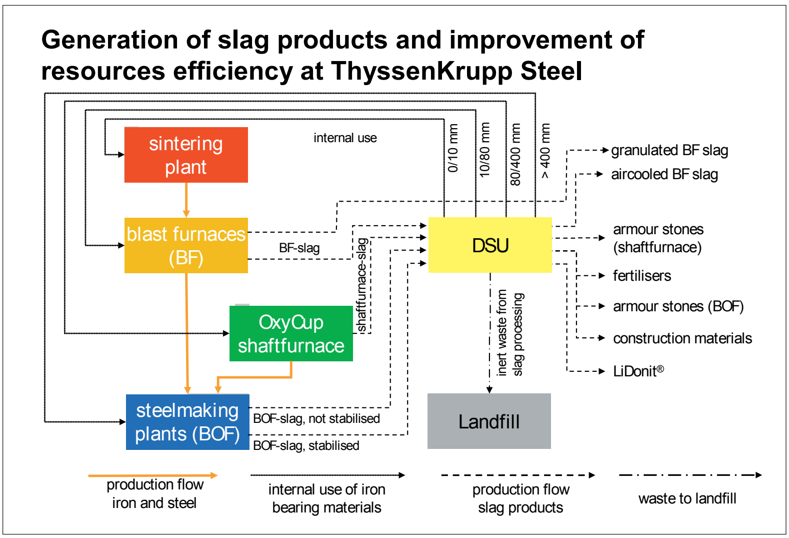
Speaker	Title /Subject
Gerhard Endemann Steel Institute VDEh	The legal status of by-products and the end of waste discussion in the EU
Heribert Motz FEhS Building Materials Institute	Overview on the production and use of slags
Afred Edlinger Tribovent	RecoDust - New pyrometallurgical recycling concept for steel mill residues
Hubert Breitkreuz Salzgitter Flachstahl GmbH	By-Product and waste management at Salzgitter Flachstahl GmbH
Jutta Moeller ThyssenKrupp Steel	By-product and waste management at ThyssenKrupp Steel
Thilo Fisch ThyssenKrupp Steel	OxyCup® Shaft Furnace - economic use of fine-grained ferrous and carbon-containing residues
Hansjoerg Schrey ThyssenKrupp Steel	Adjustment of free lime content of BOF slag

General management and organisation

ThyssenKrupp Steel has a strong focus on the environment, having implemented both an environmental policy and an environmental management system, in accordance with DIN EN ISO 14001. In addition, a certified quality management system is in operation, meeting the requirements of DIN EN ISO 9001. These systems as well as environmental, economic and social aspects are included in the broader sustainability management system. The social responsibility component is focused on training education as well as working conditions and health care. Local stakeholders, including the neighbourhood of our site, are an important factor.

By-product management

The steelworks produces iron and steel with a target of sustainable use of natural resources. In this context the zero-waste concept was developed.



ThyssenKrupp Figure 1: Slag

The zero-waste concept includes production-related mineral and iron-bearing by-products which are sold on the market. The most important kind of mineral by-product is metallurgical slag from the various production stages of hot metal (liquid iron) and steel production. Granulated BF slag is generated in the BF shop and used as resource for cement production. All other types of slag are processed using combinations of crushing/grinding, screening and magnetic separation.

While the slag products are sold, the iron-bearing concentrates and sculls of different size fractions that come from slag processing are used in closed loops in the different production steps to produce new iron and steel.

The annual production of BF slag amounts to some 3.5 Mt, with about 80% granulated BF slag for cement production. Additionally some 1.2 Mt of steelmaking slag is generated per annum, including about 20% lime fertilisers.

As a result of a recent R&D project, aimed at improving the applications for BOF slag, a treatment plant for liquid slag was developed, installed and is now in operation.

The R&D project aimed to:

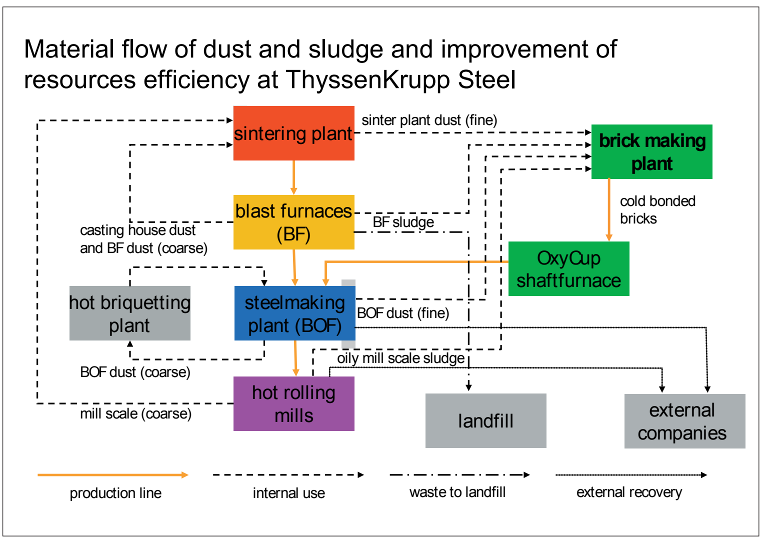
- reduce the amount of fines
- save storage and time
- reduce free lime content
- increase volume stability.

The free lime content in the liquid slag is adjusted using natural sand and oxygen. Stabilised slag can (after beneficiation) be used for applications like shipments in the upper surface layer of roads.

All the slag products meet national and international standards and specifications. Slags undergo quality control (ISO 9000), factory production control and third party control by certified institutes. The majority of slag products produced by ThyssenKrupp Steel are also CE-certified construction products.

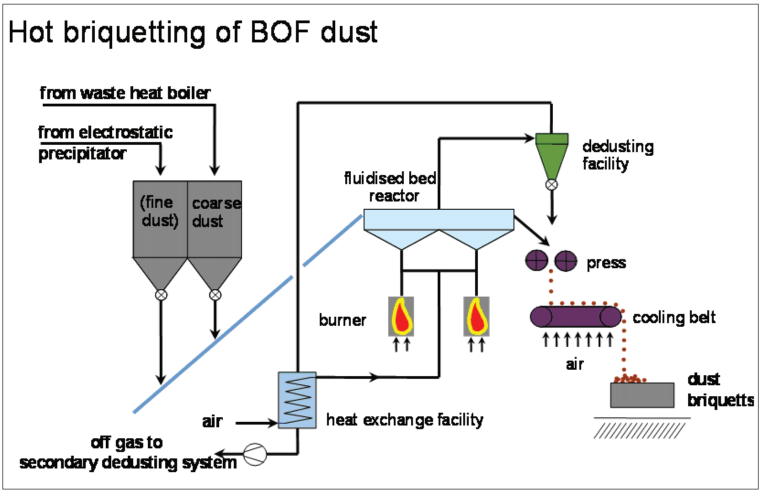
Waste management

The second type of material in the zero-waste concept is residue from dedusting and water treatment facilities containing iron and/or carbon in valuable amounts.



ThyssenKrupp Figure 2: dust and sludge

Coarse dust from the blast furnaces and coarse mill scale from hot rolling are used in the sintering plant. Coarse dust from both steelmaking plants is briquetted in a hot briquetting plant and used to replace cooling scrap needed in steelmaking.



ThyssenKrupp Figure 3: BOF dust

To close the loop on internal recycling a solution was needed for fine-grained residues which were unusable in the sintering plant. The company was searching for a plant in which coarse sculls in the size of 80 to 400 mm could be melted. In an R&D project the OxyCup® shaft furnace and brickmaking facility were developed.

The target was to find a process to produce hot metal of a quality suitable to be used in the existing production chain. The process was designed to generate a valuable slag which meets the standards for high-quality applications, as well as top gas suitable for use in the internal gas pipe system onsite. The intention was to introduce a process without producing any 'new' waste products.

After intensive research, a cold-bonded self-reducing brick was developed, in which all compounds needed for reduction of the iron oxides of the fine grained residues were already included.

Together with the mineral by-products based on slag from the blast furnaces (discussed earlier), the shaft furnace and the BOF shops' agglomerated bricks are recognised by the authorities as a (by-)product. Official by-products, according to European and German legislation, must meet a number of requirements (see chapter 6).

Other by-products which are recognised are those from the pickling lines, including iron oxide and iron(II)-chloride-solution from pickling with hydrochloride acid and ferrous sulphate. The latter is not covered in this study.

Baosteel, Shanghai (China) - November 2007

Baosteel (Baoshan Iron & Steel Co. Ltd) started construction of its Shanghai site in December 1978. In 2008, the steel output of Baosteel (Branch) was approximately 15 Mt.

One presentation at the plant visit provided an overview of Baosteel's work, mainly on environmental protection and resources management. Another three technical presentations highlighted technologies and research by Baosteel in the field of by-products.

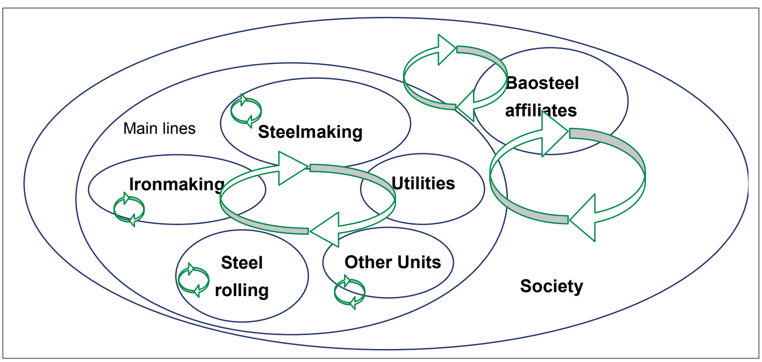
Title	Content
General introduction of Baosteel by-product management by Jian Dai	Brief introduction of Baosteel structure and capacity, overview of Baosteel environmental protection and by-product management.
BSSF—Baosteel innovative process for steelmaking slag treatment by Yin Liu	BSSF flow chart, processing principals and its application. Comparison with other traditional steelmaking slag treatment technologies.
Introduction of Shanghai Baotian new building material company by Yujing Zhao	Slag powder and its admixture processing, characteristics and application in municipal constructions.
Research on the acceleration to the growth of Phytoplankton in the sea by steelmaking slag by Xiaodan Dong	Effect of converter steelmaking slag on the growth of H.akashiwo (an ocean phytoplankton), a certain amount of steelmaking slag stimulate the phytoplankton growth which help CO2 reduction.

The BSSF steelmaking slag treatment process is applied to most BOF slag and all EAF slag in Baosteel. BSSF technology is also used in several steel plants in China and transferred to India and South Korea as well.

Shanghai Baotian New Building Material Co. Ltd has two set vertical mills in operation and an annual BF slag powder output of 1.2 Mt. BF slag powder has similar mineral components to cement, and may be used as a substitute for cement in concrete. Baotian slag powder and its admixture are widely used in municipal projects, especially some key construction project such as the East Ocean bridge and Shanghai Yangtze River bridge.

General management and organisation

According to Baosteel, the company prioritises environmental protection, implements clean production and a fully-developed 'circular economy' and pursues sustainable development.



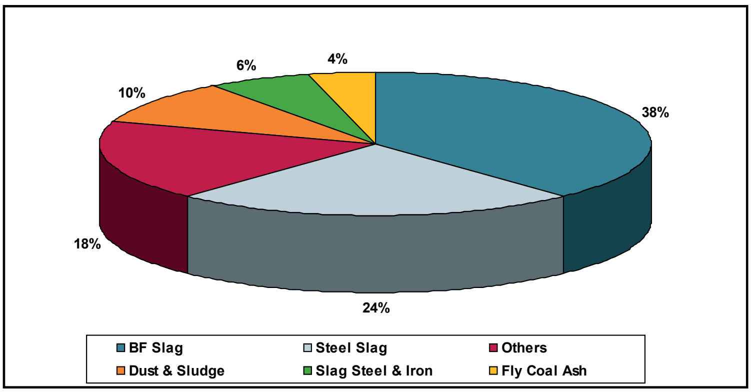
Baosteel Figure 1: The 'circular economy scheme'

Baosteel has environmental management objectives and policies to reduce consumption, to reuse and turn wastes into resources and continually improve the recycling ratio in production. Environmental responsibilities are outlined in Baosteel's management framework. The company has an environmental protection and resources utilisation committee. It organises management enhancement and research on comprehensive utilisation of resources.

Baosteel Development Co. and China Metallurgy Co. (Baosteel), are responsible for the waste facility operation and the recovery, processing and sales of all by-products. Baosteel R&D center and Baosteel Development Co. technical centre are responsible for by-products technology development. A technical support system improves waste treatment and utilisation. Strategic partnerships have been set up with universities and research institutes.

Baosteel effectively treats a large amount of solid wastes from the production process, such as BF slag, steel slag, fly ash, sludge and dust. Treatment mainly consists of reusing materials in the sintering process or as the raw materials for cement or building materials, through various technologies after centralised recovery.

Thus, Baosteel creates considerable economic and social benefits by economising resources and reducing its environmental burden. In 2008, the solid wastes production amount per tonne of steel was 0.62 tonne, the rate of comprehensive utilisation of the solid waste in Baosteel amounted to 98.23%, and back-to-use ratio internally is 28.10%.



Baosteel Figure 2: Solid waste distribution

BF slag

More than 98.5% of the slag is granulated by water and then slag powder produced or sold directly to the cement industry. The remaining BF slag is air-cooled and mainly used as cement mixture, concrete road, road base and mineral wool materials.

Steel slag

Nearly 2 Mt of steel slag was produced in this plant in 2008. Some of it was used internally as a raw material for sinter or steelmaking ‘assisting material’ in the converter. Some of it was used in internal construction as backfill. The remaining steel slag was externally utilised, including cement aggregate, mini-fine powder, concrete, artificial marble, wear-resistant tiles, abrasive terrace flooring, road base material, steel slag brick, ballast, construction backfill and so on.

Sludges and dusts

EP dust is dust captured from sinter tail gas by an electrostatic precipitator is mainly used as a molten iron desiliconisation agent. Sinter head flue gas dust is collected by the ESCS (electrostatic space cleaner super) precipitator and divided into two parts. Primary dust is collected in the first precipitator and second electric-field, and is mixed into blending ores and reused in the sintering process. Secondary dust is collected in the third electric-field. It can be used by some small steel plants as sintering raw material because of its high K_2O and Na_2O content.

BF dust collected by a gravity dust catcher is mixed directly into blending ores and reused in the sintering process. BF sludge is collected by a cyclone dust collector is divided into two parts according to zinc content. The lower-zinc variety is directly mixed into blending ores and reused in the sintering process. The higher-zinc variety is further divided into two parts by a hydrocyclone separator, those containing low zinc mixed into blending ores, the high-zinc part is sent to small steel plants as sintering raw material. BF casthouse dust is pelletised with other ferritic dust to produce pellets which are also used in the sintering process.

EAF dust and BOF secondary dust is currently sent to small scale steel plants with small capacity blast furnaces (as sinter raw material) because of its high zinc content. The output pig iron is sent back to Baosteel. Some is sent to the zinc industry to refine as ZnO.

There are two converter plants in this works, applying LT and OG technology to collect the BOF off-gas dust. Half of the LT dust is used to produce cold-hardened pellets as a converter molten steel cooling agent and slag melting agent. The remaining LT dust is treated the same as EAF dust or BOF secondary dust. OG sludge is divided into two parts, coarse and fine. The coarse variety has high iron and low zinc content. It is used as a sinter raw material. The fine variety has low iron and high zinc content.

The scale from the hot rolling process is mostly used to produce magnetic materials and the remainder goes to the sinter plant. Ferritic oxide powder from the cold pickling hydrochloric acid regeneration process is used to produce soft magnetic material.

Tata Steel, Jamshedpur (India) - April 2008

Tata Steel Limited was established in 1907. It produces 5 Mt a year and has 37,000 employees (excluding Corus, which was acquired later in the year at the time of the meeting).

The company generated 3.39 Mt of solid wastes in 2006-2007 of which BF and BOF contributed 85%. The trend for by-product utilisation has increased over the years, to reach 85.3% in 2007-2008. Tata Steel has a goal of over 95% utilisation by 2012.

Title	Content
Management of By-Products (Solid Wastes) in Indian Steel Industry, by Tapan Chakrabarty	An overview for India featuring production, main issues, expected scenario, status of utilisation and major highlights of utilisation.
LD Slag as soil conditioner, by Prof. Indrajit. Deyl	Project, opportunities and threats, benefits, implementation strategy. See summary (below).
Lowering Slag Generation in Iron Making, by A. Srinivasa Reddy	Tata's approach, raw material beneficiation, leaner sinter, a new slag regime, process results, way forward. See summary (below).
Solid Waste Management at Tata Steel Limited by S.B. Prasad	Sources, generation, utilisation, benefits and impacts, future plan.

The following is a summary of the presentations:

Use of BOF slag as acid soil conditioner

Plants require 16 nutrient elements for synthesising all the diverse tissues required for normal healthy growth. Absorption of many of these nutrients is optimum only when the soil is neutral. The acidity of soils is a limiting factor for the development and production of most crops.

The availability of a number of plant nutrients is optimum when soil reaction (pH) is in the range of 6.6 to 7.3 (neutral range). Under acidic conditions, availability of a number of plant nutrients from applied fertilisers is adversely affected. The soil micro-organisms which are indispensable for their contribution to soil fertility also do not flourish well in acidic soil condition.

It is estimated that India has about 100 million hectares of land under acidic soil condition of which the following states come under influencing distance from Tata Steel:

- West Bengal: 3.5 M hectares
- Orissa: 12.5 M hectares
- Bihar and Jharkhand: 5.2 M hectares.

In all these areas, growth and productivity of a wide variety of plants is adversely affected due to acidity of soil. BOF slag, which has a high basicity, can be effectively applied to the soil as a liming agent to correct its acidic condition in a sustainable manner.

For any material to qualify as a sustainable long term routine additive to agricultural soil it needs to be established that the material is free from toxic elements such as mercury, zinc, arsenic, cadmium and palladium. BOF slag at Tata Steel was analysed for these trace elements using Inductively Coupled Plasma (ICP) Emission Spectrometry. The results are shown in the table below. It can be seen that BOF slag as produced in Tata Steel will not pose any threat to the crops and plants on grounds of toxicity even for long term use spanning years. For agricultural use the slag has to be ground below 100 mesh and mixed with compost.

Table: Typical trace element composition of processed BOF slag

Trace elements In PPM				
Hg	Zn	Pb	As	Cd
0.05	ND*	06	ND*	ND*

*ND: Not detectable

The addition of BOF slag substantially improved yield. The onion yield improved by 31% in the field where the mixture of BOF slag, compost and 100% NPK was in use. In case of rice paddy the same mixture one again emerged as the best with an 80% improvement in yield over the conventional practice of the farmer.

These results are enough to establish that dosing the soil with a mixture of BOF slag and compost either alone or in combination with chemical fertilisers like NPK brings about a significant improvement in performance of farms with acidic soil over a wide variety of agricultural crops.

Lowering slag rate at Tata Steel's blast furnaces

Inferior quality of raw materials, particularly high alumina iron ores and high ash coals have been a problem for Indian blast furnaces for decades. This has resulted in high slag rates and resultant inefficiencies in terms of higher fuel consumption and lower productivity of Indian blast furnaces.

Therefore, prolonged and sustained efforts, through research as well as continuous improvement, are underway in Tata Steel to beneficiate iron ore and coal. In addition, other measures including use of high purity flux, production of lower gangue bearing sinters, use of low ash imported coals for coke making and for injection etc. are also used to continuously lower the slag rate.

This has enabled Tata Steel to reduce slag rates from a level of 330 kg/thm to 260 kg/thm over a decade. With advent of jigging facility in the mines, a proposed pellet plant and sustained research efforts to achieve 8% coal ash in captive collieries and to optimise slag regime, a potential to reduce slag rate to as low as 220 kg/thm is envisaged.

- Production of lean sinter

Coal and iron ore bring in nearly 150 kg/thm of gangue wherein alumina is about 38-40%. To improve a high alumina slag, addition of almost equal amount of flux is necessary so that slag alumina is brought down to a level of 19-20%. This implies a slag rate of 300 kg/thm. Any reduction of slag rate has to be primarily associated with further reduction in input alumina. With this in mind, Tata steel set out to reduce alumina in its burden through the following:

- technology developed for utilising relatively pure but fine blue dust along with friable ore fines in sintering
- increased focus on recovering more fines from sources having lower alumina
- jigging of iron ore to reduce alumina
- replacement of coke breeze with raw petroleum coke (RPC) in sintermaking.

At Tata Steel, almost the entire requirement of flux in the blast furnace is met through sinter. Production of high-strength sinter with a lower level of flux addition without deterioration in quality and productivity has been a great challenge. A simplified material balance shows that sinter needed to be produced at 7.0 – 7.5% CaO in order to achieve a slag rate of 220 kg/thm. Production of good quality sinter having relatively high alumina at such low level of CaO needed to be established.

- Reduction of coke ash

Reduction of coke ash is another enabler for slag rate reduction. Typically, with about 30% imported low ash coal in coke making blend, coke ash reduction can be brought about by two means: use of new coal component in the blend with even lower ash and reduction of indigenous coal ash by extensive washing. A study at Tata Steel showed that reduction of ash by washing indigenous coal was a cheaper option.

Coal ash reduction has been an ongoing activity at Tata Steel. Extensive efforts were undertaken at Tata Steel's collieries and ash level of semi-coking coal was brought down from as high as 17% to around 13% and that of prime coking coal from 17% to 15%, gradually, without much adverse effect on yield. The final effect of low ash imported coal and improved washing of coal at our collieries is reflected through a continuous drop in coke ash.

- Higher injection of coal at lower ash

Injection of low ash coal imparts considerable advantage in terms of lowering slag rate. Choice of coal for injection is usually based on its combustion characteristics, replacement ratio and grinding characteristics. Beside this, with increase in PCI, the quality requirement of coke in terms of its reactivity and strength becomes more stringent. As a result, choice of 'coal type' for injection greatly varies across steel plants worldwide. Keeping in mind various factors controlling furnace stability and efficiency, one needs to explore what level of ash and volatile matter of PCI best suits one's purpose.

U.S. Steel, Pittsburgh (USA) - June 2008

Title	Content
By-Product Management – Edgar Thomson plant, by Louis Lherbier	An overview of the plant by-product management with plant history, main by-product generation and destinations. See summary below
National Recovery Systems, (Multiserv/Harsco), by Pete Yanief	Presentation of National Recovery System recycling experience and activities.

Some of the by-products generated at Edgar Thomson Plant are briquetted by NRS for recycling to iron and steel producing operations. The plant visit included a tour of the NRS briquetting operation, Edgar Thomson Plant's steel shop, and the Research and Technology Center.

The Edgar Thomson Plant began producing rail steel in 1875. The plant became a part of United States Steel Corporation when the company was founded in 1901. Today, Edgar Thomson Plant is a part of U. S. Steel's Mon Valley Works, which includes the nearby Clairton Plant that produces metallurgical coke, the nearby Irvin Plant which converts slabs to finished products, and the Fairless Plant near Philadelphia which contains a galvanizing line for sheet product finishing.

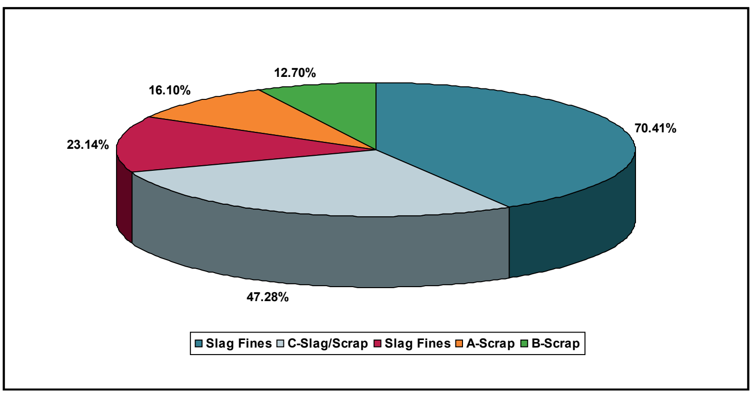
Edgar Thomson Plant produces only slabs, and key unit operations include two blast furnaces, two BOP vessels and a continuous dual strand slab caster. The facility has a nominal slab capacity of 2.5 million tons per year. By-product generation at Edgar Thomson Plant mainly consists of slag, dust, and sludge produced by the blast furnaces and steelmaking operations, along with small amounts of caster scale.

Slag

The Edgar Thomson Plant blast furnaces produce slag at a nominal rate of 200 kg per ton of hot metal. All of the BF slag is air cooled and sold as an aggregate. Slag from the basic oxygen process (BOP) is produced at an average rate of 168 kg per ton of liquid steel. The molten slag is delivered to a contractor which cools and separates the materials into several products based on size and metal/slag content. Product designations are summarised as follows:

- A-scrap, plus 180 mm (>70% metal)
- B-scrap, 180 by 19 mm (~50% metal)
- B-slag, 180 by 19 mm
- C-slag/scrap, 19 mm by 9.5 mm
- Slag fines, minus 19 mm.

The A-scrap is product is typically returned to the steelmaking operation for recycle as a component of the scrap charge. The B-scrap, B-slag and C-slag fractions are returned to and recycled at the blast furnaces as source of flux and iron. Overall about 59% of the slag output is recycled internally. The balance consists of slag fines which are shipped and delivered to a local landfill for use as an aggregate. Average product generation rates are shown in the figure below.

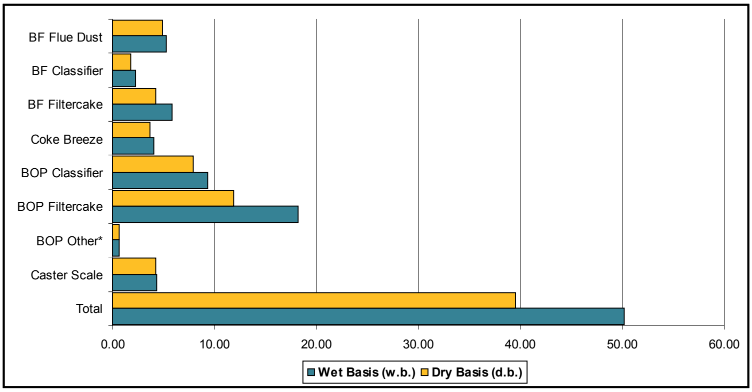


U.S. Steel Figure 1: Product yield from BOP steelmaking in wet kg per ton of liquid steel

Dust, sludge, scale and other by-products

Dust and sludge generation rates are illustrated in the figure below. They mainly consist of solids recovered from the blast furnace and steelmaking off-gas cleaning systems. Only small amounts of scale and other miscellaneous dusts are produced, including those recovered from material handling, ladle metallurgy, hot metal charging operations and continuous casting.

Coke breeze sized at minus 6 mm is also produced. All other coke delivered to the plant is directly consumed by the blast furnaces, including small coke sized at 6 by 30 mm. An overall total of about 40 kg of by-products are produced per ton of liquid steel.



U.S. Steel Figure 2: Dust, sludge and scale generation at the Edgar Thomson Plant, kg per ton of liquid steel

The Edgar Thomson Plant is not equipped with sintering facilities, as the blast furnaces rely mainly on pellets as a source of iron. By-product recycle is therefore accomplished by way of cold-bonded briquetting. The by-products are delivered to a briquetting facility operated by Braddock Recovery Incorporated, a subsidiary of NRS. Two types of briquettes are produced, one for the blast furnaces and one for the BOP. The briquettes in each case have a nominal size of 25 by 50 by 75 mm, and are manufactured to U. S. Steel strength specifications.

The blast furnace briquettes are currently produced from 100% of the coke breeze and blast furnace off-gas solids that are generated. Hot strip mill scale is also brought in from the nearby Irvin Plant as a source of low-cost iron, and typically accounts for about 20% of the briquette feed blend. The final product typically contains 30% total iron and 34% carbon, with the remainder consisting mainly of slag-forming constituents. The product thus serves as both a source of iron units and energy. It is consumed at an average rate of approximately 40 kg per ton of hot metal.

The sludge from the BOP contains elevated amounts of zinc, making it unsuitable for blast furnace ironmaking. A portion of the material is nonetheless used to produce a briquette that is recycled to the BOP. The product, which typically contains about 50% iron, is typically used as a coolant in the steelmaking operation. The briquette consumption rate varies, but typically accounts for about one-third of the sludge generation rate.

The balance of the BOP sludge product is landfilled at an approved site, which is to some extent necessitated to prevent zinc accumulation within the off-gas system. The complete recycle of BOP sludge, particularly Zn-rich sludge, presents both technical and economic challenges at present.

ArcelorMittal Tubarão (Brazil) - October 2008

This plant is a large integrated plant, producing 7.5 Mt of steel a year.

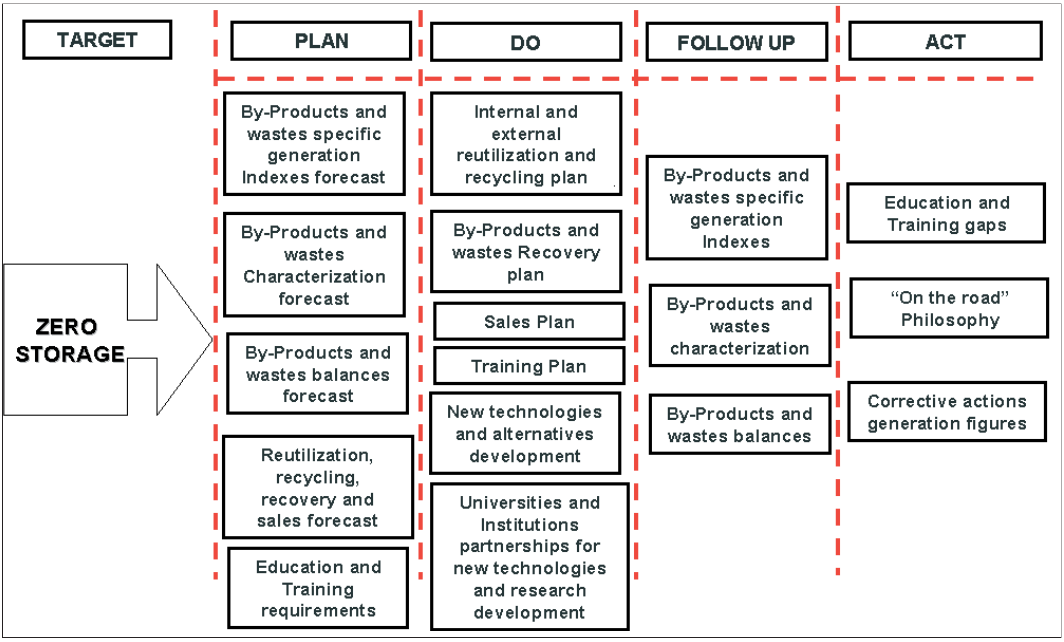
There were nine presentations at the plant visit, which gave a good overview of management practices, processes and destinations, and the main developments.

Title	Content
Waste Management, by Ricardo Filipe	Organisation of By-Products Management, by-products processing flow charts and destinations, briquetting
Environmental Management, by Luiz Antonio Rossi	Environmental Policy, certification, communication with stake holders, Objectives, Projects, Clean Development Mechanism (KYOTO protocol), Environmental Education Program
Steel Slags, by Nocy Silveira	ACERITA accelerated weathering process and application results
IPR by Chequer Jabour Chequer	Presentation of the IPR (brazilian Road Research Institute)
Steel Slags by Gisele Lopes	Presentation of the tests results of ACERITA slag in road layers by IPR, in order to establish official application standards
GBFS distribution to cement customers, by Edson Lima	GBFS sales and distribution to customers
Externalisation of GBFS granulator, by André Kohn	Experience of externalization and results
Self compacting concrete with BOF slag additions by Prof João Luiz Calmon	Study on BOF slag addition as additive (filler) in concrete, up to 250 kg/m3, in the Federal University of Espirito Santo (laboratory tests)
Use of BF sludge in clayey ceramics, by Prof Carlos Mauricio	Laboratory study at the North Fluminense University. Results on technical properties, Energy savings.

General management and organisation

The plant has an environmental management system that places strong emphasis on education and social relations with local stakeholders. Waste management is part of it, with two objectives: 100% recovery, and preventing HSE risks. The target is set at 99% internal and external recovery for end 2009, excluding temporary storage, result already achieved in 2008.

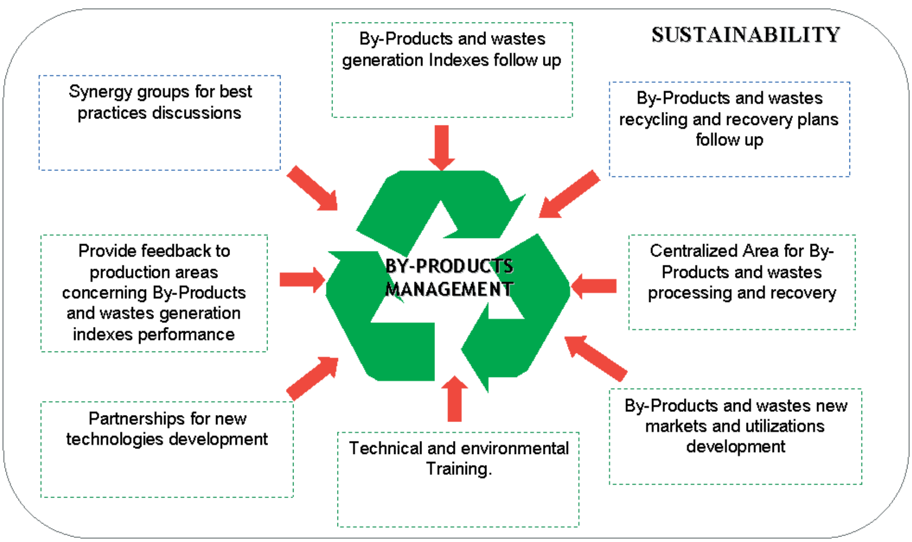
Waste management or by-product management is structured on a PDCA approach (Plan, Do, Check, Act) , as shown by the chart below.



ArcelorMittal Figure 1: Plan, Do, Check, Act

This approach includes much planning, forecasting and preparation, years before the by-products' generation, treatment and recovery can begin as the plant increases capacity.

Again, education and training are important, as are partnership with universities and technical institutions.



ArcelorMittal Figure 2: By-product management

There is not one department in charge of this management process, but several working together and integrated in the whole plant system. Two are dedicated: the By-products Sales Department, attached to the Sales Vice-President, and the Operations and Recycling Department, attached to the Chief Operations Officer.

BF slag

Almost 100% is granulated, in modern clean installations and sold to the cement industry.

BOF slag

The old stockpile has been reduced from 950 KT in 2005 to 400 KT end 2008, in spite of growing generation. The aim is to reduce the stockpile to zero.

The reduction has been achieved through a portfolio of applications, either sales or social programmes (donation to communities: slag for unpaved roads, for concrete blocks). Branded qualities of slag, ACERITA and REVSOL, have been developed. ACERITA is prepared by accelerated weathering by hydration and aeration in order to reduce the expansion, later to below 3% (Brazilian test).

Applications include: road aggregates, including asphalt, railway ballast, fertiliser, cement, concrete artifacts (BOF slag is used as aggregates) and artificial reefs.

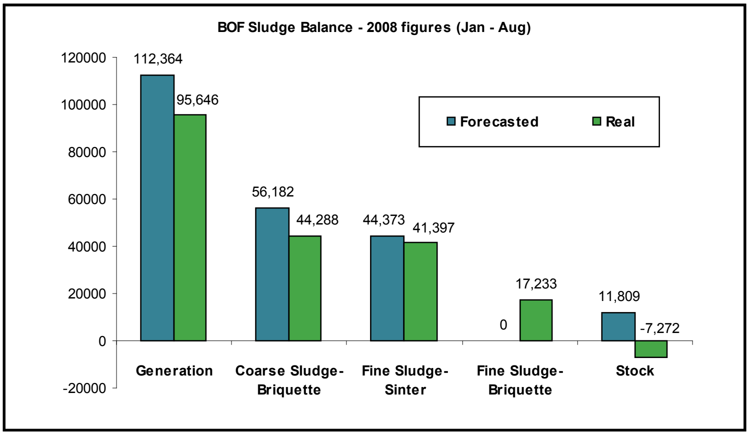
De-sulphurisation slag is sold as raw material for a clinker kiln.

Considerable efforts are put on standards. After years of efforts and studies, a Brazilian standard on the use of steel slags in roads is close to official publication. Universities, public institutes, engineering consultants are associated in the effort, and the Brazilian Slag Association was created in 2008, in order to federate all the steel industry.

Sludges and dusts

The generation of oily mill sludges is minimal and the oil content low, due to the recent HSM, as a result all HSM sludges are recycled to the sinter plant.

BOF sludges contain no Zn, because no zinc coated scraps are used in the converter. Therefore all are recycled internally, either to the sinter plant, or to the converter in briquettes.



ArcelorMittal Figure 3: BOF sludge balance

All the coarse fraction and part of the fine fraction goes to the sinter plant. The rest of the fine fraction only goes to the sinter plant. The reason is the oxidation of iron: metallic in coarse sludge, oxide in fine sludge. It is better to recycle metallic iron directly to the converter. Briquetting is an important tool in this aspect, recycling little oxidised iron sources (internal or external).

BF sludges are also 100% recovered through sale to the cement industry (source of iron oxide in clinker kilns) and the ceramic industry, as admixture in clay. The plant has considerable experience in this market, and is now extending its market geographically. A study carried out by the Fluminense University of São Paulo, demonstrated the good properties, mechanical, environmental and, perhaps the major point of interest: fuel-saving.

BlueScope Steel, Port Kembla Steelworks (Australia) - February 2009

The Port Kembla Steelworks is a large integrated plant, producing approximately 5.3 Mt of steel per annum.

Four presentations were made at the plant visit, again providing a thorough overview of the organisation, the management practices, the processes and by-product destinations, as well as the current and potential future developments.

Title	Content
Welcome to BlueScope Steel, by Andrew Purvis, Vice President Environment	Presentation outlined BlueScope Steel's history, international manufacturing footprint, products, high level business strategies and a summary of environmental management structure and strategies.
Management of by-products at BlueScope Steel's Port Kembla Steelworks, by Richard Placek Alliances and Recycling Manager	Discussion/presentation provided an overview of byproducts management Port Kembla Steelworks and tour of the sites recycling area.
CSRP2 Extension Proposal - Centre for Sustainable Resource Processing, by Stevan Green	Presentation provided a summary of the principal works of the Centre for Sustainable Resource Processing since 2003, discussion focusing on concept development and progress with respect to dry slag granulation (and heat recovery) technology. In addition to the potential by-product management benefits that this technology represents, participation in the research forms part of BlueScope Steel's contribution to the World Steel Association CO_2 Breakthrough Programme.
Iron and Steel Slag use in Construction Applications – Australasian Slag Association, by Craig Heidrich	Presentation provided the group with an introduction to the Australasian Slag Association, the organisations key objectives, product focus, utilization rates, applications, challenges and strategic objectives such as promoting the environmental and technical merits of slag and maximizing utilization and value add opportunities.

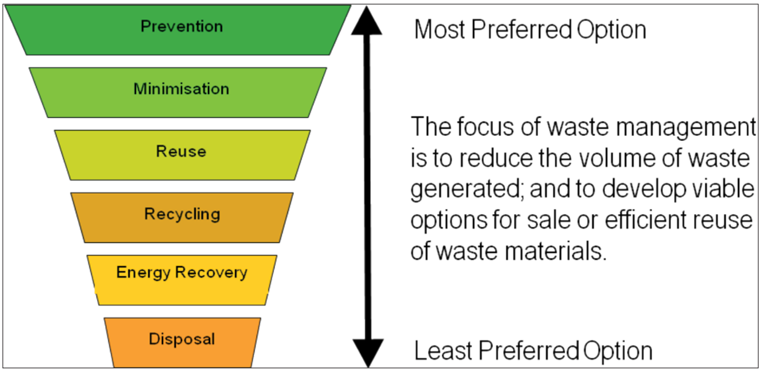
General management and organisation

BlueScope Steel has a strong focus on environmental issues, with environment being one of the fundamental components of the company's Bond. Environmental policy is embedded at a corporate level and the company's environmental principles and expectations are cascaded through the entire organisation. The management systems are mature with an emphasis on Community, Safety and Environment.

Waste management and in particular the goal of continuously reducing the organisation's 'environmental footprint' is a specific BlueScope expectation. The requirement is that every site will have an environment improvement plan, including targets, that considers:

- reducing greenhouse gas emissions
- reducing pollution to land, air and water
- reducing waste to landfill
- reusing and recycling products and by-products
- conserving energy and fresh water.

In partnership with research groups, by-product specialists and end users the investigation of future reduction and utilisation strategies enable continual improvement with respect to by-product utilisation and waste minimisation.



BlueScope Figure 1: Waste management

Port Kembla Steelworks – Overview

Management of specific by-products is integrated into the plants operating systems. The 'Alliances and Recycling' department at Port Kembla Steelworks are responsible for managing the recycling and storage area, movement of materials and where required, disposal. This department also provides reference material and guidelines for managing by-products across the organisation as a whole.

BF slag

100% of the BF slag produced is utilised, with slag movement, crushing, grinding and granulation managed by a third party – under BlueScope's direction. The plant has three 'wet' granulators, with the majority of the granulated slag being utilised in the cement industry. Material not granulated is predominantly used in road construction and as aggregate for concrete.

BOS slag

Current BOS slag generation is now being effectively 100% utilised and mining of a historic stockpile of BOS slag is also well underway. BOS slag is predominantly used in the making of roads and asphalt pavement, with a small percentage of the material being recycled into the basic oxygen steelmaking process.

Sludges and dusts

Sludges and dusts are also largely recycled internally, either via the sinter plant/blast furnace. Where a material cannot be utilised internally (i.e. high Zn bearing fractions) the material is stockpiled and where possible blended with other by-products to form 'saleable' mixes for use in other industries.

Mill scale and mill sludges from Port Kembla Steelworks are again almost entirely utilised. Material with sufficiently low oil content is directly recycled via the sinter plant, with a quantity of mill sludge from the mills (i.e. hot strip mill and plate mill) being utilised externally by the cement industry.

Legislation

From the beginning of the project work it was clear that the participants had different legal definitions for terms such as by-product, waste, landfilling, recovery or recycling. Due to the aim of the project it was necessary to agree on a common wording within the project, setting aside legal definitions in the different regions and countries.

The usage of terms in this report therefore lays no claim on legal correctness and is not legally binding for any region, country or company.

Legislation was a topic at all project meetings. Also, legal developments continued to happen during the life of the project. Waste legislation is changing all the time. The descriptions in this report therefore can only give an overview of the wide range of legislation and legal interpretation.

International regulation

The Basel Convention

Internationally, waste legislation tends to reference the Basel Convention on the 'Control of Transboundary Movements of Hazardous Wastes and their Disposal' and adopted amendments, that entered into force as of 8 October 2005. Transboundary movements in this context mean any movement of hazardous or other wastes from an area under the national jurisdiction of one state to or through an area under the national jurisdiction of another state or to or through an area not under the national jurisdiction of any state, provided at least two states are involved in the movement. Or it simply regulates imports, exports and transits of wastes.

Waste exports require a notification and consent system known as 'prior informed consent' between all states involved in the waste movement.

A central goal of the convention is 'environmentally sound management' (ESM), the aim of which is to protect human health and the environment by minimizing hazardous waste production whenever possible. ESM means addressing the issue through an 'integrated life cycle approach', which involves strong control from the generation of a hazardous waste to its storage, transport, treatment, re-use, recycling, recovery and final disposal.

While there is no definition of by-products, Article 2 of the convention defines the terms wastes and disposal as follows:

- 'Wastes' are substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law.
- 'Disposal' means any operation specified in Annex IV to this Convention.

The Annexes to the convention include (I) categories of waste to be controlled, (II) categories of waste requiring special consideration and (III) a list of hazardous characteristics. Annex IV to the convention describes disposal operations that are split into:

a. operations which do not lead to the possibility of resource recovery, recycling, reclamation, direct re-use or alternative uses and
b. operations which may lead to resource recovery, recycling reclamation, direct reuse or alternative uses.

Consequently each party and signatory of the convention is obliged to have implemented the convention to national legislation. Variations to the requirements of the convention have to be reported to the Basel secretariat.

Section A: Operations which do not lead to the possibility of resource recovery, recycling, reclamation, direct reuse or alternative uses	
D1	Deposit into or onto land, (e.g., landfill, etc.)
D2	Land treatment, (e.g., biodegradation of liquid or sludgy discards in soils, etc.)
D3	Deep injection, (e.g., injection of pumpable discards into wells, salt domes of naturally occurring repositories, etc.)
D4	Surface impoundment, (e.g., placement of liquid or sludge discards into pits, ponds or lagoons, etc.)
D5	Specially engineered landfill, (e.g., placement into lined discrete cells which are capped and isolated from one another and the environment, etc.)
D6	Release into a water body except seas/oceans
D7	Release into seas/oceans including sea-bed insertion
D8	Biological treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations in Section A
D9	Physico chemical treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations in Section A, (e.g., evaporation, drying, calcination, neutralization, precipitation, etc.)
D10	Incineration on land
D11	Incineration at sea
D12	Permanent storage (e.g., emplacement of containers in a mine, etc.)
D13	Blending or mixing prior to submission to any of the operations in Section A
D14	Repackaging prior to submission to any of the operations in Section A
D15	Storage pending any of the operations in Section A
Section B: Operations which may lead to resource recovery, recycling reclamation, direct re-use or alternative uses	
R1	Use as a fuel (other than in direct incineration) or other means to generate energy
R2	Solvent reclamation/regeneration
R3	Recycling/reclamation of organic substances which are not used as solvents
R4	Recycling/reclamation of metals and metal compounds
R5	Recycling/reclamation of other inorganic materials
R6	Regeneration of acids or bases
R7	Recovery of components used for pollution abatement
R8	Recovery of components from catalysts
R9	Used oil re-refining or other re-uses of previously used oil
R10	Land treatment resulting in benefit to agriculture or ecological improvement
R11	Uses of residual materials obtained from any of the operations numbered R1-R10
R12	Exchange of wastes for submission to any of the operations numbered R1-R11
R13	Accumulation of material intended for any operation in Section B

Table 63: Disposal operations according to the Basel Convention

The OECD Decision

In the early 1980s, the Organisation for Economic Co-operation and Development (OECD) identified some indiscriminate and uncontrolled international movement of hazardous wastes combined with adverse effects on human health and the environment. The OECD countries decided in 1984 to control transboundary movements of hazardous waste destined for recovery.

Based on several Council Acts on waste identification, definition and control of transboundary movements of waste, the recent decision concerning the control of Transboundary Movements of wastes destined for recovery operations has been developed. The OECD Decision does not apply to wastes destined for recovery. For the OECD, the ultimate goal is to achieve a globally harmonised control system for movements of hazardous waste and hazardous recyclable materials, by working in close cooperation with other international organisations, such as the Secretariat of the Convention, and the European Union (EU).

The OECD control system is based on a risk assessment that provides for simplified means to control the transboundary movements of wastes destined for recovery/recycling operations which are environmentally sound. The risk assessment requires complete information on the waste, the conditions under which it is handled and transported, and the value of the material. Overall, risk judgement is made on a combination of intrinsic hazard and probability of a spill or other mishap.

The OECD lists of wastes, which are subject to control, have been harmonised with the Basel Convention. Therefore, the earlier green, amber and red lists have been abolished and replaced by two categories of wastes requiring different levels of control when destined for recovery in another OECD country.

Furthermore, the OECD Decision continues to be compatible with the goal of environmentally sound management of hazardous wastes and hazardous recyclable materials pursuant to the Convention. Recycling and recovery of wastes are environmentally sound practices and more appropriate (desirable) than disposal. Further information can be found in a Guidance Manual for the implementation of Decision.

Regional and national legislation

Waste legislation in the different regions of the world differs in widely. Even in regions that try to install a common legislation, one can find different ways to interpret the common defaults. The present situation of waste legislation in Europe should be described representative for the different systems in the world.

The integrated approach

The European Council Directive 96/61/EC of 24 September 1996 on integrated pollution prevention and control (IPPC) was created to prevent or minimise emissions to air, water and soil, as well as waste, from industrial and agricultural installations in the EU, to achieve a high level of environmental protection.

It is based on an integrated approach that takes into account all effects on the environment and also pays regard to sustainability principles. The directive defines the basic obligations to be met by all the industrial installations concerned, whether new or existing. These basic obligations cover a list of measures for tackling discharges into water, air and soil and for tackling waste, wastage of water and energy, and environmental accidents. They serve as the basis for drawing up operating licences or permits for the installations concerned in the steel industry, too.

Accordingly it:

- lays down a procedure for applying for, issuing and updating operating permits;
- lays down minimum requirements to be included in any such permit (compliance with the basic obligations, emission limit values for pollutants, monitoring of discharges, minimisation of long-distance or transfrontier pollution);
- details procedures for surrendering of permits to ensure that there is no detriment caused by the site operations.

Framework of waste legislation

The total frame of waste legislation is given by the European Waste Framework Directive (WFD). It was reviewed in 2008 and will enter into force in December 2010, because of the necessary implementation in the member states and its interaction with other European legislation.

The new directive clarifies and rationalises EU legislation on waste and combines the former WFD, a Hazardous Waste Directive and a Waste Oil Directive. It defines terms such as waste, recycling and recovery. Aside from applying a new waste hierarchy (priority order: prevention, preparing for re-use, recycling, other recovery, disposal) and expanding the 'polluter pays principle' it demands more stringent waste reduction and waste management targets for the Member States. The WFD has to be implemented in the member states until December 2010.

It is a novelty that the WFD defines by-products as non-waste for the first time in European legislation. A non-waste by-product is a 'substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste referred to the WFD but as being a by-product'. The classification as non-waste by-product is connected to some criteria on the certainty of further use of the substance or object, the direct use without any further processing, the production as an integral part of a production process and its lawful use without negative impact on environment and human health.

Further criteria will be developed together by authorities and concerned industry and finally adopted by legislature. Non-waste by-products never enter the waste regime.

The directive also clarifies when certain waste ceases to be waste. Possible categories of waste for which 'end-of-waste' status specifications and criteria should be developed are scrap/metals, aggregates, waste paper and glass, construction and demolition waste, some ashes and combustion residues, and others. According to Article 6 of the WFD, waste shall cease to be waste when it has undergone a recovery, including recycling, operation and complies with specific criteria to be developed in accordance with the following conditions:

- the substance or object is commonly used for specific purposes;
- a market or demand exists for such a substance or object;
- the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and
- the use of the substance or object will not lead to overall adverse environmental or human health impacts.

The criteria are specified in a process involving legislature, authorities and industry. The Institute for Prospective Technological Studies of the Joint Research Centre (JRC-IPTS) started an end-of-waste project to support the development of end of waste criteria under the revised waste framework directive.

There is also a special European list of wastes. The list (formerly the European Waste Catalogue) is a catalogue of all waste types generated in the EU. The different types of waste in the list are fully defined by a six-digit code, with two digits each for chapter, sub-chapter and waste type. The list is used to categorise items and substances when they become waste, but does not itself define items and substances as waste. The Council Decision is presently under revision.

There is also a directive on landfilling that gives the requirements for landfilling of waste and, together with a Council Decision, establishes criteria and procedures for the acceptance of waste at landfills.

Waste shipment

The background to supervision and control on waste movement was uncontrolled movement of toxic wastes (the 1982 'Seveso incident' in France) and several other cases where such wastes from Europe were exported and dumped in developing countries.

A Council Directive harmonised the control procedures for the shipment of hazardous waste in the EU for the first time in 1984. The convention has been implemented in the regulation on shipments of waste. On this basis, export of hazardous waste to non-OECD countries altogether is prohibited since 1998 in the EU.

Different regimes apply to shipments of wastes for disposal and for recovery. It sets rules for the shipment of different kinds of wastes whether they are generally subject to notification procedures with the prior consent of all relevant authorities of dispatch, transit and destination. On the other side, green-listed wastes are normally shipped within the OECD like normal commercial goods and only accompanied by certain information. Shipment of non-hazardous wastes to non-OECD countries depends essentially on its acceptance by the importing country.

The old regulation on shipments of waste was replaced in July 2007. The new regulation streamlines existing control procedures, incorporates recent changes of international law and strengthens the provisions on enforcement and cooperation between member states in cases of illegal shipments.

Country legislation

Legislation can never be so detailed and exhaustive that it leaves no space left for interpretation. As international and regional legislation is normally binding, so national legislation can be made more strict than the common defaults. This leaves some room for national legislation and implementation of the common regulations, directives and decisions.

This is especially relevant when a new legislation has been established or existing ones are revised. Although there are the common European directives on 'integrated pollution prevention and control' and on landfills, the UK government, for example, decided that landfills have to comply with both the IPPC Directive and the Landfill Directive.

Where there is no common regulation, there is space for national ones. Germany, for example, is preparing a new regulation on alternative materials replacing typical construction material. Alternative materials cover by-products and recycling materials but exclude natural materials. Such initiatives are often used as a starting point for common legislation.

Other examples concern by-products in the EU. With the former and the recently reviewed WFD, there is no general acceptance of by-products as given by the new WFD. Some EU member states accept specific slag types as by-product; others still leave them in the waste regime.

Materials legislation

With reference to the above-mentioned non-waste status of by-products and the possibility to be released from waste legislation when reaching the end-of-waste status, it has to be clarified that these materials do not enter an area not regulated by law. For example, the European material policy led to a regulation abbreviated by REACH. The REACH regulation establishes a system that guarantees the registration of materials/chemicals. This means that during a registration process, materials are evaluated on their environmental and health effects. Finally, there is an authorisation or restriction of the use of the materials. Each material on the market has to follow this system of "No registration – No market".

There are only small exemptions for some natural materials and for wastes, the latter to avoid conflicts with the waste legislation. As a consequence, many registration processes are running at present under REACH. One of them is the registration of different kinds of slag.

Reference to standards

Legislation normally refers to technical standards. Technical standards or specifications set requirements to be fulfilled by a material, product or service. Technical standards/specifications among regions and countries. There are only few common standards, such as those set by the International Organization for Standardization (ISO) or the European Committee for Standardization (CEN).

In most cases it is not possible to compare (limit) values in legislation and/or values and data provided by the participants of the study as response to the surveys. This is especially relevant for parameters such as chemical composition, leaching values or physical properties.

Results of the surveys

The responses to the second survey are given in the chapter on 'Phase 2: Results from best performers' and in the related appendix.

Analysis and evaluation method

While the first questionnaire does not cover any questions on the legal situation in the countries and only refers to the problem of different standards, the second questionnaire includes questions on that topic. The participants were asked for a description of the specific situation in the country/region and its evaluation by ranking. Although the participants were asked to be as objective as possible, it is clear that rating stringency of regulations and other questions on legislation reflect opinions.

There are different possibilities for analysis and evaluation of the answers to the second questionnaire. First of all, the totality of responses was taken into account and evaluated to get an overall description of the situation. In a second step, the legal situation for BP was examined.

Several approaches for identification of best performers were verified. This began with simply taking the ranking from the first survey (KPI2) or the regulation (R) ranking from the second questionnaire, then taking a combination of these both methods and finally using the whole ranking (R, MG, MK, CT and KPI2) from the second questionnaire.

Most of the approaches led to similar results that allow identifying the BPs. Nevertheless, it was decided to use the combination of indicators to avoid impacts on the results by subjective opinions. The best ranked companies for the different indicators are shown in Table 61. The most often appearing numbers are 231, 280 and 325.

Slag					
R	275	280	325	385	
KPI2	385	362	480	167	137
MK	280	107	362	370	231
MG	231	325	263	476	246
Techn	370	280	231	325	153
R/KPI2/KPI1	325	280	385	275	370
Dust and sludge					
R	290	340	480	348	475
KPI2	325	231	340	16	480
MK	231	16	280	340	96
MG	246	263	325	476	280
Techn	370	280	325	231	333
R/KPI2	290	475	348	480	340

Table 64: Best performers by numerical order of ratings for single or combined questions

Results

The comparison and evaluation of the responses to the second questionnaire show that answers for dust and sludge are mostly identical with those for slag. Differences occur for the following questions only:

- R1.b: Are you allowed to stock or landfill on the site steel slag, sludge and dust (1 additional comment).
- R3.1: Do you have to pay disposal fees/taxes/levies? If so, please provide the aggregated current disposal cost, including treatments, transportation, tax, gate fees, etc. (4 additional/ changed comments).

Therefore, the following sections refer to both slag and dust/sludge unless stated otherwise.

Stringency of regulations

Stringency of regulations was the reason for a joint evaluation on legislation. The question on stringency of regulations in the area of by-product management (Question R. 1a) was answered by 20 out of 45 respondents.

The answers mostly refered to national or regional legislation. Four companies made reference to the ISO 14000 series of standards, the others refer to standards that were not identified in detail.

The answers also reflected the discussions on legal acceptance of by-products as waste or non-waste. Because of the absence of an international definition, there is a higher chance for a definition of by-products if there is a national or regional legislation. There is no common, clear classification of material as hazardous. Its disposal does not necessarily have to do with hazardous material but may reflect the market. The BPs for blast furnaces reported stringent regulations more often. Only one BP saw a low level of legislation. The BOF- and HRM-best performers evaluated their regulations as more stringent. For sinter plants and EAF plants there was no clear picture.

Allowance for stockpiling or landfilling

Twenty-four out of 45 responses showed that there is no clear distinction possible between stockpiling and landfilling. A wide range of storage periods is reported with a peak for storage between three and 12 months. Storage is often limited to a maximum of three years. After that, the stored material then is classifed as waste.

Sometimes special regulations with longer storage periods are possible for (internal) landfills or at plant sites. While there are often reduced storage periods for hazardous material, storage for by-products that might range to no storage limitation. Evaluation of BPs showed no clear picture. Only the answers for the hot rolling mill suggested lower requirements for BP.

Definition of waste

Only 10 participants in the second survey commented on whether they were subject to national/regional legislation on the definition of waste and classification as waste/non-waste (R. 2.1). Due to non-existant legislation, by-products are most often classified as waste. The definition in legislation is not clear, which leaves room for interpretation and court decisions even within a region with common legislation.

Nevertheless, the definition of waste is always part of a waste act. Several participants refered to new national/regional legislative initiatives for by-products (e.g. the new EU waste framework directive). The BP status has no effect.

Classification of waste

The question on national/regional legislation on the classification of waste, (e.g. hazardous, non-hazardous, inert waste; R.2.2) was answered by 10 companies. Most of them refered to the distinction between hazardous and non-hazardous material. The distinction is made on the basis of international, regional or national legislation or nationals standards. Most wastes are classified as non-hazardous, sometimes with the hint to the high temperature processes in the steel industry, which is relevant for hazardous organics (e.g. PCDD: Polychlorinated dibenzo-p-dioxins /PCDF: Polychlorinated dibenzo furanes). Reference to the classification as inert material is only made by EU companies because of the above mentioned Council Decision. There are no special results for the BP companies.

Transport, national or transboundary shipment

Only nine companies answered on legislation on transport, national or transboundary shipment of waste (R.2.3). The background to this might be that materials classified as waste from the steel industry are mostly recycled, recovered or disposed off within the country. On the other hand: import, exports and transits are the topic of the convention, to which the answers to the questionnaire and also the country specific legislation refer. Special licences are required for transport/shipment, especially for hazardous materials. The BP status has no effect.

Recycling and recovery of waste

Seven companies reported on national/regional legislation for recycling and recovery of waste (R.2.4). For the EU, this might be the WFD. Others refer to their usual national waste acts or guidelines of the national environment protection agencies. There is also reference to the international regulations (Basel). No special results are available for the BPs.

Disposal of waste

Answers to the question on having and being subject to national/regional legislation regarding disposal of waste (R.2.5) refered to the usual national or international legislation (Basel) or guidelines of the national environment protection agencies. One BP reported never having landfilled any sludge, dust or slag. Aside of this there are no special notes on the BP group.

Disposal fees/taxes/levies

Fees, taxes and levies (R.3) are of high importance for the companies. This is seen in 33 and 36 written answers out of 45 for slag and dust/sludge respectively. On slag, most responses declared that there wre no specific taxes. Several pointed out the advantage that if there is no waste, there is no need for taxes/fees/levies. If the total slag is sold, taxes/fees have no relevance. Others report on exemptions for internal slag landfills. The three answers that give costs can be summarised as:

- up to US$100 for non-hazardous waste (US$10-100)
- over US$100 for hazardous waste (up to US$570).

For dust/sludge, nine plants reported a requirement to pay while 10 plants do not pay fees, taxes or levies. The rest is undefined. The answers often distinguished between recycling and disposal fees. For other responses, there is no clear distinction between fees, taxes or other payments and disposal costs. The advantage of "No waste = No taxes" was raised again. If there is 100% recycling, there is no need for fees. Exemptions are also possible for dust/sludge on internal landfills. The four specifications of costs are in the same range as for slag:

- up to US$100 for non-hazardous waste (US$10-100)
- over US$100 for hazardous waste (US$220-570).

There is no clear picture for the BPs, either for slag nor for dust/sludge. A relationship between BP and fees/taxes cannot be demonstrated.

Public financial relief/support/funding

Nine participants commented on public financial relief/support/funding for implementing processes or techniques for environmental improvement schemes (R.4). Six of them confirmed receiving support/funding. Four gave no further specification while in two cases, support is limited to projects with energy saving aspects.

R&D is mentioned as one possibility for funding. BPs show no special results.

Human resources

Seventeen companies rated the level of resources (people/time/money) that are currently applied in activities aimed at overcoming legal barriers to reuse, recycle or recover any by-products (R.5). Most of them have special environmental or trading departments or teams. Small local companies or subsidiaries dealing with by-products/waste are also shown as possible way to handle the tasks. The number of people in the teams is specified four times with a range from seven to 13 persons. Expenditures of time or costs were not specified.

Best performers

Identifying how or if BPs are special depended on the quantity and quality of responses. It is difficult to distinguish whether the legal situation at a location had a significant influence. Nevertheless, the answers of the three BP plants (231, 280 and 325) were analysed.

All the BPs refered to special national waste legislation and a waste definition by national law or environment protection agency. Plants 280 and 325 reported ISO 14000 certification, which is extended to the waste management system and reporting as mentioned by plant 325.

There is no clear picture on taxes and fees, as only one of them declared paying according to the type of material. All had the possibility of storing by-products temporarily and legally. Quality management seems to have been obligatory for slag. There was also high priority placed on development of new slag products. Efforts were made to develop new markets. These matters are therefore worth attention, not only in the teams responsible, in subsidiaries or cooperating companies but also by the management boards.

None of the observed BPs mentioned funding.

Taken all together, this analysis confirms that best performance is the result of a site-specific management system adapted to the specific national/regional legislation and market conditions.

Summary

Analysis and evaluation of the reports of the project participants and the responses from the second questionnaire show that waste legislation is obligatory all over the world.

A rough framework is provided by the Convention on 'Transboundary Movements of Hazardous Wastes and their Disposal' and the OECD Decision on the 'Control of Transboundary Movements of Wastes Destined for Recovery Operations'. These two regulations are coordinated and are recognised in most countries.

On the other hand, regional and national legislation show a wide range of different regulations. This leaves room for interpretation, although international standards are taken into account.

There are different definitions of terms like by-product, waste, landfilling, recovery or recycling etc. Legislation may also vary within a region, although it is often based on the same framework like the Waste Framework Directive in the EU.

In their responses, most companies refered to typical waste legislation, including specification of recycling, recovery and disposal, and to standards. The latter predominantly exist on national or regional basis. Typically, storage times are described between three and 12 month. Exemptions or leniency is possible for on-site storage or landfills.

By-product materials are often classified as waste, but the survey also shows some new initiatives to define by-products as non-wastes in many regions. The classification as (non-)hazardous and shipment/movement is generally based on Convention/OECD Decision. Most by-product materials handled in this project were typically classified as non-hazardous.

So far, waste-related fees and taxes are only collected in some countries. The rates depend on the waste properties, especially its hazardous potential.

Although there is a correspondence between the (subjective) rating of legislative burden by the participants themselves and the BPs, this cannot be demonstrated by the evaluation of the responses on legislation alone.

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