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**Material Classification of Iron and Steel  
Slag By-product Investigation  
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David Aynsley  
Moeyan Management Pty Limited  
ABN: 77 092 978 035  
[MOEYAN@bigpond.com](mailto:MOEYAN@bigpond.com)

for the  
Australasian (iron and steel) Slag Association Inc.

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## Executive Summary

As part of its Research and Development Programme for 2003/2004 the Australasian (iron & steel) Slag Association Inc. (ASA) conducted an investigation into the chemical nature of iron and steel blast furnace slag's. These are the by-products of three different metallurgical processes:

- iron blast furnace,
- basic oxygen system furnace and
- electric arc furnace.

Each of these by-products were analysed and the results assessed against the NSW Environment Protection Authority *Environmental Guidelines*. The aim of this investigation was the first step to collate and interpret the analytical knowledge on its members' iron and steel slag by-products through a coordinated sampling, analysis and reporting programme.

The programme investigated the chemical characteristics of iron and steel slag by-product generated and processed at sites only throughout NSW, at:

- BlueScope Steel and processed at Australian Steel Mill Services in Port Kembla,
- One Steel – Rooty Hill and
- Smorgon Steel – Newcastle processed at SteelStone Services in Newcastle.

The methodology consisted of collecting differently aged samples (in open air storage to +24 months) from the product range actively managed and distributed.

Prior to commencement consultation with the NSW Department of Environment and Conservation (DEC), clarified the applicability of the *Environmental Guidelines* and oral advice on two additional metals of interest Copper (Cu) and Zinc (Zn) which are not listed because the guidelines have been developed for classifying waste for placement in landfill.

Sixty six (66) samples were collected and tested according to the process contained in the *Environmental Guidelines* and assessed against acceptance criteria.

Stage one (1) results for total metals were almost all within the total inert concentration acceptance levels. For those elements exceeding these initial acceptance levels (total concentration), Stage two (2) investigations were conducted using the TCLP method. Results were within the accepted concentration levels for the ***Inert*** classification and confirm previous leachate investigations in the mid 1990's, authenticating the stability and consistency of these processes.

These and ongoing investigations will assist regulatory authorities and the ASA with the scientific evidence required to demonstrate that although Slag by-products can be placed into landfills as Inert Waste, Slag can also be applied to responsible and environmentally sustainable end use applications.

Figure 1 Distribution of Members



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## 1 Introduction

The Australasian Slag Association Inc. (ASA) has conducted an extensive analysis investigation into the species concentration and leachability of those species from Slag by-products using the NSW EPA *Environmental Guidelines: Assessment, Classification & Management of Liquid & Non-liquid Wastes*. The aim of this investigation is to collate and interpret the analytical knowledge on its members' products and determine the appropriate classification for each slag type.

The geographic distribution of Association members is shown in Figure 1 above.

Moeyan Management Pty. Limited an independent consultancy was commissioned to manage the sampling and analysis programme and prepare this report. In-kind assistance and samples were provided by BlueScope Steel (BSS), One Steel (OSL), Smorgon Steel (SSL), Australian Steel Mill Services Pty (ASMS) and SteelStone Services (SSS) during the conduct of the programme.

The findings of this report will be used to underpin ASA's justification for iron and steel slag by-product use in product or process applications.

### 1.1 Slag by-product Needs a Waste Classification

The *Environmental Guidelines* are a useful aid in both: distinguishing concentrations of substances and their mobility behaviour; and in the determination process for classification of a waste.

An extract from the *Environmental Guidelines* is included in 4.1 on page 10, showing the process for determination of the Waste Classification. Also shown are the key analytical tables, which indicate the acceptable concentrations of contaminants in the waste.

### 1.2 Objective of Scope of Work

This programme investigated the chemical characteristics of three main types of metallurgical slags, these being; Iron Blast Furnace Slag (BFS), Steel Furnace Slag (SFS) and Electric Arc Furnace Slag (EAFS). Samples for each of these by-products were selected over a range of inventory and age, which will assist the ASA in identifying appropriate uses to which Slag by-products can be used.

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### **1.3 Material Selection**

The specific iron and steel slag commodities selected types and sizes for analysis from selected members product ranges included:

- Granulated Blast Furnace Slag (No 5)
- Granulated Blast Furnace Slag (No 6)
- Blast Furnace Slag – Air cooled (No 5)
- Blast Furnace Slag – Air cooled (No 6)
- Blast Furnace Slag - Dust (minus 6mm material from crushing process)
- Steel Furnace Slag - Dust (minus 6mm material from crushing process)
- Steel Furnace Slag Base (minus 20mm material from crushing process)
- Electric Arc Furnace Slag (minus 20mm material from crushing process)

Slags can be processed into various forms by granulation or crushing into aggregates of various sizes.

The two forms of air-cooled Iron Blast Furnace slag were chosen for the following reasons.

- To determine that the slag in its pre crushed state whether from either No.5, or 6 Blast Furnaces were similar in characteristics.
- Air-cooled slag, when crushed to its smallest size, provides a greater surface area and potential for exposing contaminants.

Steel furnace slag fractions tested were based on similar reasoning to air-cooled slag.

- Steel furnace dust provided the potential to determine its contaminants with a product that provides the largest surface area.
- The steel furnace base was chosen as it also included a mixture of aggregates.

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## 2 Legislation

### 2.1 Slag by-product is a Waste (under NSW Legislation)

The NSW Protection of the Environment Operations Act 1997 has a range of objectives but those most pertinent to the treatment of slags is; to reduce risks to human health and prevent the degradation of the environment by the use of mechanisms that promote:

- the reduction or elimination of harmful wastes,
- the reduction in the use of materials and the re-use or recycling of materials,
- the monitoring and reporting of environmental quality on a regular basis,
- to assist in the achievement of the objectives of the *Waste Avoidance and Resource Recovery Act 2001*.

Manufacturing processors are now realising that the existing legislation in NSW recognises one product from a process but others, which were not the objective of the manufacturing activity are immediately deemed to be a waste.

*Waste:* As defined in the *Waste Minimisation and Management Act 1995* and the *Protection of the Environment Operations Act 1997*:

‘waste includes:

- (a) any substance (whether solid, liquid or gaseous) that is discharged, emitted or deposited in the environment in such volume, constituency or manner as to cause an alteration in the environment, or
- (b) any discarded, rejected, unwanted, surplus or abandoned substance, or
- (c) any otherwise discarded, rejected, unwanted, surplus or abandoned substance intended for sale or for recycling, reprocessing, recovery or purification by a separate operation from that which produced the substance, or
- (d) any substance prescribed by the regulations to be waste for the purposes of this Act.

A substance is not precluded from being waste for the purposes of this Act merely because it can be reprocessed, re-used or recycled.’

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The *Environmental Guidelines: Assessment, Classification & Management of Liquid and Non-liquid Wastes* is a combination of the:

- *Environmental Guidelines: Assessment, Classification and Management of Non-Liquid Wastes* (1997),

and the product of consultation on

- *Draft Environmental Guidelines for Assessment, Classification and Management of Liquid Wastes* (1998).

Its provisions take effect from 1 July 1999.

## **2.2 Reprocessed, Re-Used or Recycled Legislation**

There is little specific legislation for re-used wastes.

The *Environmental Guidelines* were developed to determine management required for the four classifications of waste (inert, solid, industrial, hazardous) on the presumption that the material was going to containment. It was not intended for re-use applications.

Indeed the EPA has already made a formal amendment to the *Environmental Guidelines* by issuing additional contaminants in August 2001 and when approached about this project, has orally required the addition of metals Copper and Zinc (Cu and Zn) to be included in the analytical suite of chemical tests, citing European developments in by-products re-use.

The EPA necessarily operates within the legislative framework, but at present it sensibly makes the *Environmental Guidelines* apply in the absence of any other effective regulation to deal with re-use. This though, while helpful to re-use practitioners, should be used cautiously.

## **2.3 Producer does the Classification**

Both NSW and other state EPA's have expressed concern about the degree of production or manufacturing process control which is applied to by-product (waste) streams. EPA's understand that corporations focus attention on the main product (for which the process was designed) and are sceptical about the amount of attention afforded to peripheral product streams which yield lower value materials. This places an additional burden for the generator to both prove the reliability of - and to demonstrate diligence in monitoring - by-product stream quality.

For the avoidance of doubt, in both direct correspondence and the *Environmental Guidelines* the NSW Environment Protection Authority (EPA) states it does not classify the waste – that is the responsibility of the generator. The generator determines waste classification according to the *Environmental Guidelines*.

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## **2.4 Waste is Fit for Purpose**

Waste reprocessed, re-used or recycled needs to be assessed for its intended purpose.

The NSW EPA leaves these negotiations on whether the waste/by-product is “fit for purpose” to the supplier and user. However, while one of the EPA’s interests is re-use or recycling of all manufactured products under its sustainability objective, it can and has, intervened to satisfy itself that a “product” is proven to be suitable for a re-use application.

Hence *waste classification* is a determining step in the landfill containment fate of a substance but forms only the initial part of the process required for a material to be reprocessed, re-used or recycled.

An *inert waste*, while suitable for low level landfill containment does not automatically mean that the material is environmentally benign and safe for any re-use application.

## **3 Sampling and Analysis Procedures**

### **3.1 Site Sampling Procedures**

Slag by-product samples were taken in accordance with the following standards: AS 1199 Sampling procedures and tables for inspection by attributes; AS 1399 Guide to AS 1199; AS 1141.3.1 – Methods for Sampling and Testing Aggregates 1996 (Method 3.1- Sampling Aggregates: Section 6.9 - Sampling from Stockpiles)

Chain of custody forms accompanied samples.

### **3.2 Sample Number**

Australian Steel Mill Services, Port Kembla coordinated the collection of sixty (60) samples across its product inventory. Steelstone Services Newcastle took six (6) samples across its product inventory.

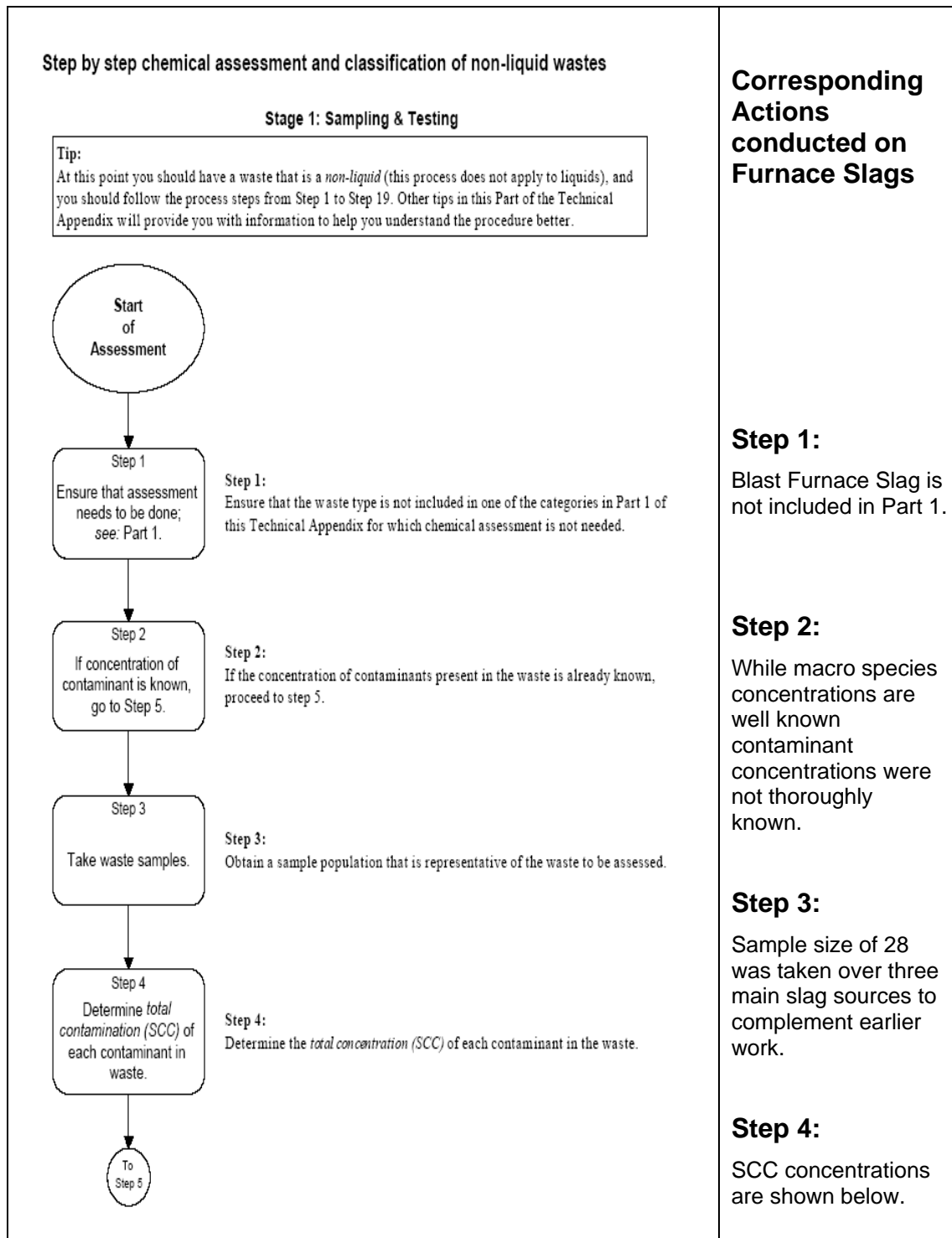
Total of sixty six (66) samples were analysed.

### **3.3 Laboratory Procedures**

Laboratory procedures for analysis of total metals and TCLP were conducted by LabMark Pty Limited a NATA certified laboratory and the QA/QC for can be seen at the end of the NATA laboratory reports. They were satisfactory.

## 4 Assessment and Classification Procedures

### 4.1 The Classification Process

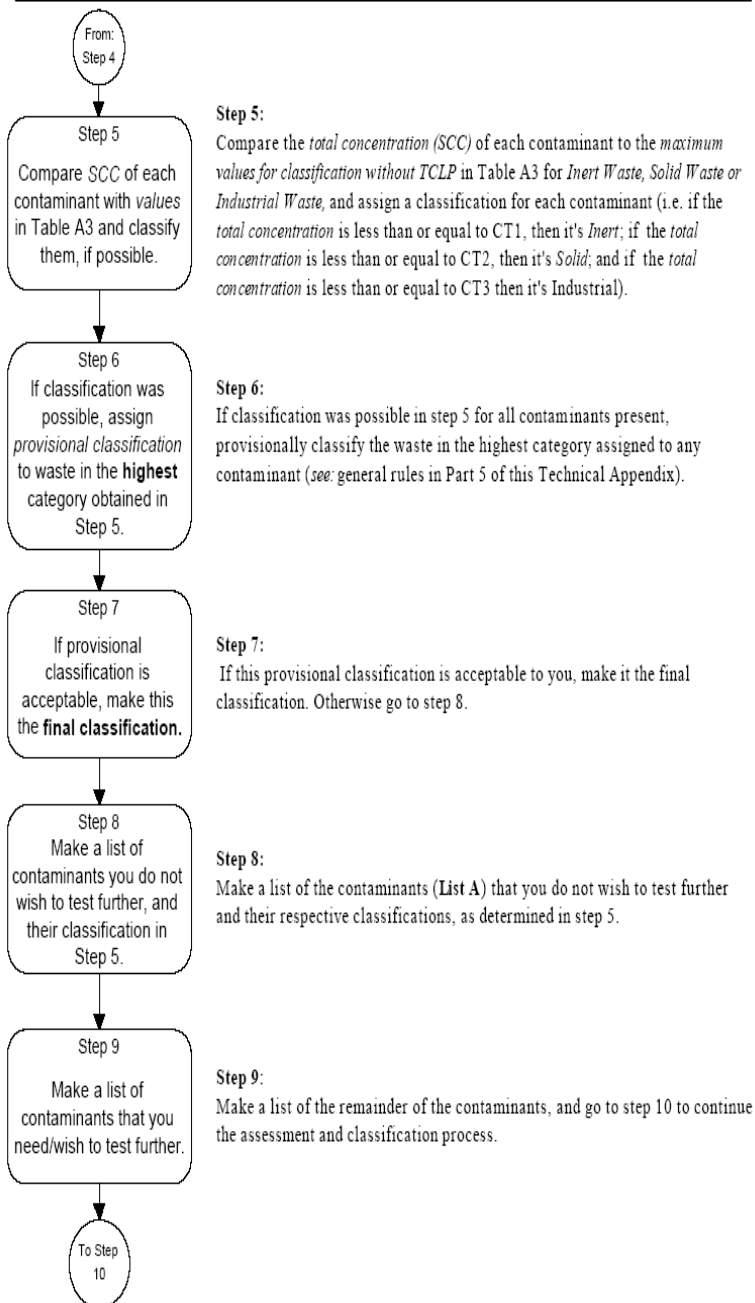


**Stage 2: Classification without using leachable concentration (TCLP)**

**Tip:**

The determination of *total concentration (SCC)* is usually cheaper than the determination of *leachable concentration (TCLP)*. It is possible sometimes to classify the waste without determining the TCLP, as shown below.

The lists of the assessments for individual contaminants, namely List A at Step 8, List B at Step 14 and List C at Step 17, are combined at Step 19 in order to ensure that the highest assessment value will be used to determine the final classification of the waste [see: general rules in Part 5 of this Technical Appendix].



**Corresponding Actions conducted on Furnace Slags**

**Step 5:** Comparison with Table A3 indicates some metals for some samples above CT1. See Section 5

**Step 6:** Provisional classification of wastes shown in Section 5

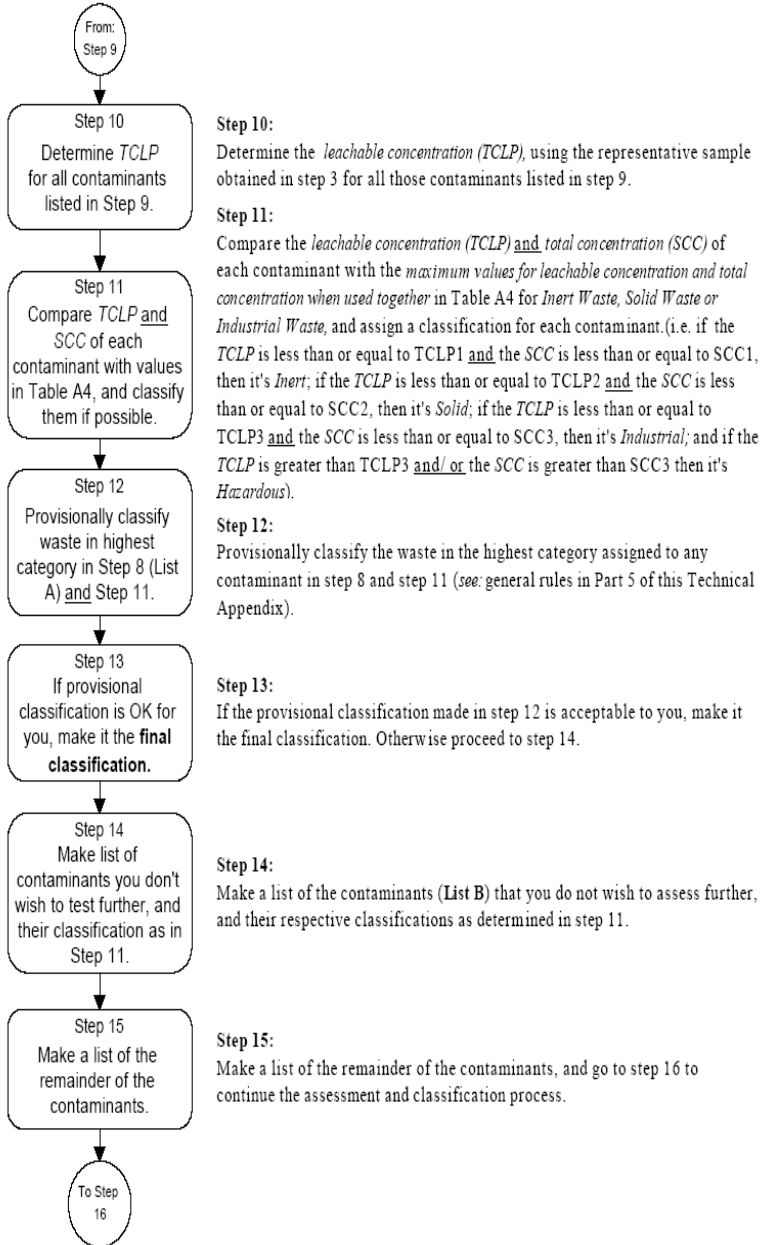
**Step 7:** Provisional classification is not acceptable so proceed to Step 8.

**Step 8:** List A is shown in Section 5

**Step 9:** List of contaminants for further testing is shown in Section 5 i.e. Be, Mo, Ni, Pb, Se.

**Stage 3: Classification using *leachable concentration (TCLP)* and *total concentration (SCC)***

**Tip:**  
 The need to use *leachable concentration (TCLP)* and *total concentration (SCC)* is either:  
 (i) **unavoidable** if one or more contaminant in step 5 exceeded CT3, or  
 (ii) **optional** if any *total concentration (SCC)* value lies between the CT and the SCC maximum values for either Inert Waste or Solid Waste in Table A4 since it may enable a lower classification to be made.



**Corresponding Actions conducted on Furnace Slags**

**Step 10:**  
 Leachable concentrations of Be, Mo, Ni, Se and Cu & Zn determined.

**Step 11:**  
 Comparison with Table A4 shows overwhelming compliance with Inert category for all but one sample.

**Step 12:**  
 Waste Provisionally Classified.

**Step 13:**  
 Waste Provisionally Classified in Step 12.

**Step 14:**  
 Waste Provisionally Classified in Step 12.

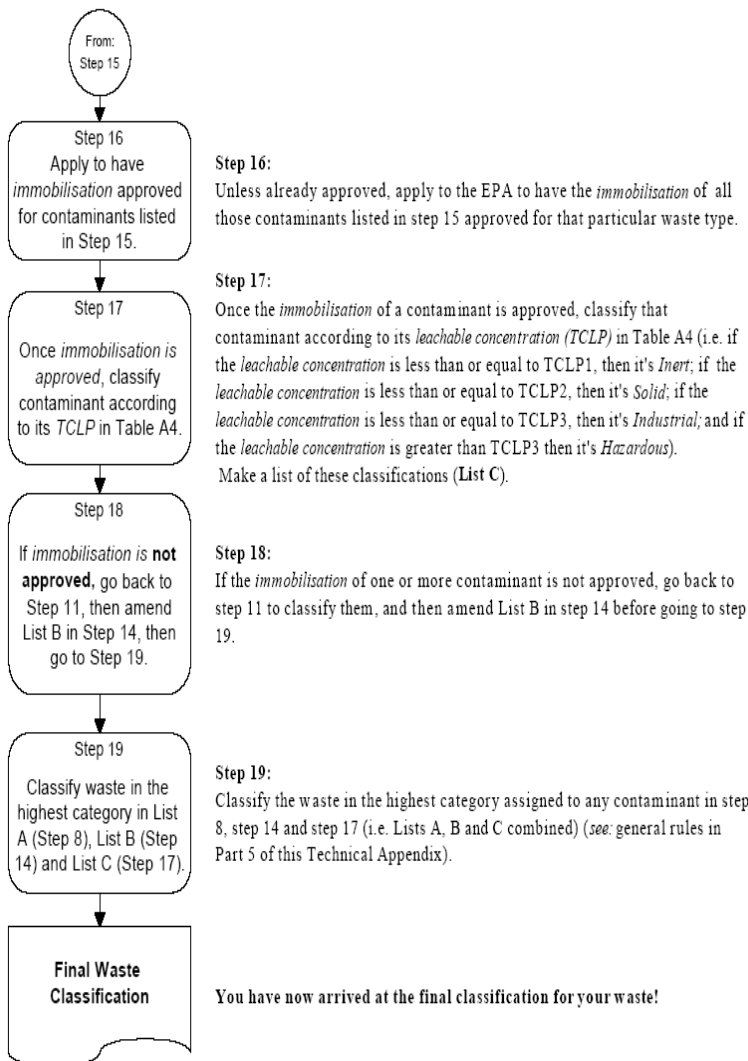
**Step 15:**  
 Waste Provisionally Classified in Step 12.

**Stage 4: Classification using immobilisation and leachable concentration (TCLP)**

**Tip:**

If the *total concentration (SCC)* of any contaminant exceeds the maximum values SCC1, SCC2 or SCC3 in Table A4, while the corresponding *leachable concentration (TCLP)* is less than or equal to TCLP1, TCLP2 or TCLP3, it is possible to apply to the EPA to have the *immobilisation* of that contaminant approved for that particular waste type.

Once the EPA has approved the *immobilisation* (of that contaminant for that particular waste type), the waste may be classified as outlined below. For example: approved *immobilisation* may allow a waste type with a *total concentration (SCC)* of a contaminant exceeding SCC3 but having a corresponding *leachable concentration (TCLP)* less than or equal to TCLP2 to be classified as *solid waste*. A fuller discussion of *immobilisation* may be found in Section 3.4.4 and Technical Appendix 2.



**Corresponding Actions conducted on Furnace Slags**

**Step 16:**  
Not needed at this stage.

**Step 17:**  
Not needed at this stage.

**Step 18:**  
Not needed at this stage.

**Step 19:**  
Not needed at this stage.

**Final Waste Classification**  
Final Classification is *Inert*.

## 5 Comparison of Analytical Results with Environmental Guidelines

### 5.1 Waste Category Assessment

Using *Environmental Guidelines* table below we now assess the products an example of one product is shown overleaf.

<b>Table A2: Summary of criteria for chemical contaminants in non-liquid waste classification (See also Table 6 in Section 3.4.3.)</b>		
<b>Waste classification<sup>1</sup></b>	<b>Criteria<sup>2</sup> for classification (any of the alternative options given)</b>	<b>Comments</b>
<b>Inert</b>	1. SCC test values $\leq$ CT1.	TCLP test not required.
	2. TCLP test values $\leq$ TCLP1 <u>and</u> SCC test values $\leq$ SCC1.	
	3. TCLP test values $\leq$ TCLP1 <u>and</u> SCC test values $>$ SCC1 <u>and</u> immobilisation <sup>3</sup> is EPA approved.	Without EPA approval of immobilisation, classify as solid, industrial or hazardous.
<b>Solid</b>	1. SCC test values $\leq$ CT2.	TCLP test not required.
	2. TCLP1 $<$ TCLP test values $\leq$ TCLP2 <u>and</u> SCC test values $\leq$ SCC2.	
	3. TCLP1 $<$ TCLP test values $\leq$ TCLP2 <u>and</u> SCC test values $>$ SCC2 <u>and</u> the immobilisation <sup>3</sup> is EPA approved.	Without EPA approval of immobilisation, classify as industrial or hazardous.
<b>Industrial</b>	1. SCC test values $\leq$ CT3.	TCLP test not required.
	2. TCLP2 $<$ TCLP test values $\leq$ TCLP3 <u>and</u> SCC test values $\leq$ SCC3.	
	3. TCLP test values $\leq$ TCLP3 <u>and</u> SCC2 $<$ SCC test values $\leq$ SCC3.	
	4. TCLP2 $<$ TCLP test values $\leq$ TCLP3 <u>and</u> SCC test values $>$ SCC3 <u>and</u> immobilisation <sup>3</sup> is EPA approved.	Without EPA approval of immobilisation, classify as hazardous.
<b>Hazardous</b>	1. TCLP test values $>$ TCLP3.	Store or treat waste as appropriate.
	2. TCLP test values $\leq$ TCLP3 <u>and</u> SCC test values $>$ SCC3 <u>and</u> immobilisation is not EPA approved.	Store or treat waste as appropriate.
<b>Notes:</b> 1. See also the general rules relating to waste classification (listed earlier in Part 5) for other criteria that must be satisfied before the waste can be classified. 2. These criteria apply to each toxic and ecotoxic contaminant present in the waste (see Tables A3 and A4). 3. In certain cases the EPA will consider specific conditions, such as the segregation of such waste from all other types of waste in a monofill or a monocell, in order to achieve a greater margin of safety against a possible failure of the immobilisation in the future. Information about the construction and operation of a monofill/monocell is available in the <i>Draft Environmental Guidelines for Industrial Waste Landfilling</i> , (EPA 1998a).		

Worked examples of this assessment and classification process are given later in this part of the Appendix.



## **6 Discussion of By-product Results**

### **6.1 Blast Furnace Slag**

This indicates that the two processes are different but are consistent in the outcomes for this slag. Despite some variances for individual analytes the products from each of Number 5 and 6 Furnaces either crushed or uncrushed, resemble each other in the majority of analytes

The age of the samples ranged up to 12 and 24 months old and all were relatively consistent with similar levels reported on samples that were much younger - indicating exposure to the weather has little effect on these analytes.

### **6.2 Steel Furnace Slag**

Steel Furnace slag was differentiated from Iron Blast Furnace slag notably with its presence of Molybdenum.

### **6.3 Electric Arc Furnace Slag**

Electric Arc Furnace slag exhibited elevated metals results discussed below, however a particular feature was the presence of lead though this met the Inert Waste Category for TCLP.

Also of note was the relatively higher level of Copper (in the low 100's mg/kg) and Zinc (up to low 1000's mg/kg), though these elements are expressly excluded by Note 1 on Table 4 of the *Guidelines*. They are included here by oral request of the NSW EPA advising it would require these levels in an assessment of the waste - particularly for re-use applications.

### **6.4 Metal Analytes**

Total metals are within acceptable *Inert Waste* classification criteria at the first stage criteria (Table A3) except for Beryllium (Be), Molybdenum (Mo), Nickel (Ni), Lead (Pb), and Selenium (Se)

However, these elements when subjected to leachate testing (availability) entirely complied with the *Inert Waste* category.

### **6.5 Volatile Total Petroleum Hydrocarbons (TPH)**

These TPHs are all below the limit of detection which would be expected with any furnace process.

### **6.6 Semi volatile (SVOC) & Volatile Organic Compounds (VOC)**

The SVOCs and VOCs are all below the 0.5mg/kg limit of detection which would be expected with a furnace process.

Benzo(a) pyrene [or B(a)p] is included in the SVOC screen but at an EQL (estimated quantitation limit) of 0.5 mg/kg. All samples showed B(a)p <0.5 mg/kg but after concentration to meet the 0.05mg/kg detection level, 4 were detectable.

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The *Inert Waste* category in Table A3 requires a CT1  $\leq$  0.08 mg/kg. Four samples are over that classification level. Each of these samples including all six (6) of the EAF slags were subjected to TCLP. All samples exhibit levels lower than the EQL and hence meet the *Inert Waste* classification.

Similarly Vinyl chloride has to be re-run at a lower detection limit than the general SVOC level of 0.5mg/kg, and all samples were <0.1mg/kg meeting the 0.4 mg/kg level required for *Inert Waste*.

### **6.7 Polychlorinated Biphenyls (PCB)**

The PCBs are all below the limit of detection.

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## 7 Conclusions

### 7.1 Compliance with Acceptance Criteria

Based on the Environmental Guidelines, the generator of the products within this report could classify them as **Inert Waste**:

### 7.2 Sustainable Development

Where application circumstances support the application of iron and steel slag by-product the environmental benefits of re-use as opposed to landfill containment, are significant and extend beyond the obvious:

- saving in greenhouse gas emissions,
- unnecessary:
  - consumption of landfill space,
  - energy consumption and destruction of natural landscapes by the removal of virgin excavated natural materials (VENM) mining,

## 8 Recommendations

To achieve this re-use benefit the following steps are suggested:

### 8.1 Development of a Monitoring Programme

The ASA develop and manage an ongoing testing and monitoring programme with the assistance of its members.

This may be of the order of a similar set of analyses to this investigation quarterly for about a year on specific species of concern, e.g. Selenium. Then when sufficient statistical evidence has been accumulated, reduce those analyses in accordance with a yet to be agreed (with the EPA) protocol.

### 8.2 Evaluation of Previous Placement Sites

Further work could concentrate on evaluation of previously placed iron and steel slag by-products to determine whether any adverse environmental impacts can be observed months or years after placement.

One example of an apparently successful utilisation is the filling of the Casting Basin in Port Kembla Harbour. A follow up Biodiversity and Ecotoxicity study at and around that construction site would admirably complement the chemical analysis conducted in this and previous (Golder Associates) reports.

### 8.3 Development of Product Application Scenarios

The *Environmental Guidelines* offer a section on environmentally sensitive areas which is an indicative direction of where wastes should not be utilised. This should be one aspect of determining by-product suitability applications.