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MINERAL WASTE RESOURCES OF CANADA REPORT NO. 7 - FERROUS METALLURGICAL WASTES

R.K. COLLINGS AND S.S.B. WANG

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MINERAL WASTE RESOURCES OF CANADA
REPORT NO. 7 - FERROUS METALLURGICAL WASTES

by

R.K. Collings* and S.S.B. Wang**

SYNOPSIS

The production of solid mineral and mineral-based wastes by Canada's mining and mineral processing, metallurgical, and chemical process industries is about 800 x 10^6 t/a. Over 95% of this amount is produced by the mining and mineral processing sector. The metallurgical sector produces about 10 x 10^6 t/a, of which 7 x 10^6 t is from ferrous operations. Ferrous metallurgical wastes consist principally of slags from ironmaking and steelmaking and relatively minor quantities of dusts and sludges.

Blast furnace slag is produced in three distinct forms depending on the rate and method of cooling, i.e., air-cooled, expanded, and granulated or pelletized. It is used as a base for roads and parking lots, as railroad ballast, as aggregate in concrete and bituminous mixes, and in mineral wool manufacture. Granulated slag is of particular interest because its pozzolanic properties allow its use in concrete as a partial replacement for portland cement.

Steelmaking slags are variable in composition but consist principally of lime and magnesia, silica, manganese and iron oxides. Steelmaking slags may be recycled through the blast furnace at integrated iron and steel operations to recover iron and manganese. The free lime and magnesia render the slag dimensionally unstable, hence other uses are limited. Small quantities are used as aggregate in bituminous road-paving mixes to provide improved skid resistance.

Flue dusts and sludges produced by the iron and steel industry total 700 x 10^3 t/a. Although composed mostly of iron oxide, these wastes may also contain significant amounts of zinc. Where feasible, the zinc could be recovered prior to sintering the dusts and sludges for recycling to the blast furnace.

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*Head, and **Physical Scientist, Non-metallic and Waste Minerals Section, Mineral Sciences Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa.

RESSOURCES DE REBUTS MINÉRAUX AU CANADA
RAPPORT NO. 7 - REBUTS METALLURGIQUES FERREUX

par

R.K. Collings* et S.S.B. Wang**

SYNOPSIS

La production annuelle de déchets solides minéraux ou à base de minéraux des industries canadiennes d'exploitation minière, de traitement des minéraux et des traitements métallurgique et chimique est d'environ 800 x 10^6 tonnes. Plus de 95% de ces déchets provient du secteur minier et du traitement des minéraux. Le secteur métallurgique produit environ 10 x 10^6 tonnes/année dont 7 x 10^6 tonnes proviennent du secteur ferreux. Les déchets métallurgiques ferreux sont composés principalement de scories provenant de la fabrication de la fonte et de l'acier et de quantités relativement petites de poussières et de boues.

Les scories de haut-fourneau sont produites en trois formes distinctes selon la vitesse ou la méthode de refroidissement, c.-à.-d., refroidies à l'air, déployées et granulées ou nodulisées. Elles sont employées comme couche de fond sur les routes et les terrains de stationnement, comme empierrement de chemin de fer, comme agrégat dans le béton et les mélanges bitumineux et pour la fabrication de laine minérale. Les scories granulées sont particulièrement intéressantes puisque leurs propriétés pouzolaniques leur permettent d'être employées dans le béton comme remplacement partiel du ciment portland.

Les scories provenant de la fabrication de l'acier ont une composition variante et sont composées principalement de chaux et de magnésie, de silice, de manganèse et d'oxydes de fer. Ces scories peuvent être recyclées dans le haut-fourneau durant les opérations intégrées de fonte et d'acier afin de récupérer le fer et le manganèse. La chaux et le magnésie libres en font des scories instables tant à la dimension donc les autres usages sont limités. De petites quantités sont employées comme agrégats dans les mélanges bitumineux pour le pavage des routes pour en améliorer la résistance au dérapage.

Les industries de fonte et d'acier produisent 700 x 10^3 tonnes/année de poussières et de boues de carneau. Quoique composés principalement d'oxyde de fer, ces déchets peuvent aussi contenir des quantités importantes de zinc. Lorsque cela est possible, le zinc pourrait être récupéré avant le frittage des poussières et des boues pour le recyclage dans le haut-fourneau.

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*Chef, et **Chercheur scientifique, Section des minéraux non-métalliques et de débris, Laboratoire des sciences minérales, CANMET, Energie, Mines et Ressources Canada, Ottawa.

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INTRODUCTION

Canadian mining, mineral processing, metallurgical, and chemical process industries generate an estimated 800 x 10^6 t of solid mineral and mineral-based wastes annually. Chief among these are waste rock and mill tailings from mining and mineral processing operations which collectively account for well over 95% of the total. Metallurgical and chemical process waste comprise the remainder.

Some wastes contain metallic and mineral material that is potentially recoverable for reuse. Interest in such wastes has been increasing in recent years. Reasons for this include the exhaustion of favourably located and higher-grade mineral deposits; legislation restricting mining operations near urban centres; increased exploration, mineral beneficiation and transport costs; increased cost of disposal and containment of mineral waste; and growing concern over the pollution potential of some waste dumps. These factors have stimulated research into the feasibility of recovering metal and mineral material from deposits of lower grade but more accessible ore, and from alternative sources such as mineral wastes.

This current interest has resulted in a need for information on the physical and chemical nature and potential utility of mineral wastes. In response to this need, the Canada Centre for Mineral and Energy Technology (CANMET) is pursuing a study of mineral wastes. Its objectives are as follows:

- to identify mineral wastes and to determine their magnitude and nature,
- to publish information on their physical and chemical properties, and potential uses,
- to identify opportunities for further study and research.

This report, "Ferrous Metallurgical Wastes", is one in the series "Mineral Waste Resources of Canada". Included in this series are wastes from the mining and mineral processing, metallurgical, and chemical process industries. To date, reports on mining wastes in Ontario, Quebec, British Columbia, and the Atlantic Provinces, have been published and a fifth covering the Prairie Provinces, is in preparation (1,2, 3,4). The ferrous metallurgical waste report will be followed by one on non-ferrous waste in 1981, and by one on chemical waste in 1982.

MINERAL WASTES

Solid mineral wastes are divided into two general categories - primary and secondary - in Table 1. Primary wastes are those derived from mining and mineral processing plants and consist of the original mineral material in a crushed or ground form. Secondary wastes are the mineral or mineral-based materials derived from metallurgical and chemical processes which expose virgin rocks and minerals to heat and chemical treatment.

The metallurgical industry of Canada produces a variety of solid mineral or mineral-based wastes that, in total, amount to about 10 x 10^6 t/a. This report will be restricted to ferrous metallurigcal wastes which amount to about 7 x 10^6 t/a.

FERROUS METALLURGICAL WASTES

The chief wastes from the Canadian ferrous metallurgical industry are slags from ironmaking and steelmaking furnaces and dusts, ashes and sludges associated with the production of iron and steel. These wastes are considered separately in the following sections.

IRONMAKING SLAG

Ironmaking slag is a byproduct of pig iron manufacture in the blast furnace. It is nonmetallic and composed principally of lime, silica and alumina, having been formed by the fusion of limestone or dolomite and other fluxes in the furnace charge with ash from coke and the siliceous and aluminous components of the iron ore. Three distinct types of solidified blast furnace slag may be produced by controlling the rate of cooling - air-cooled, expanded, and granulated or pelletized. Air-cooled slag is produced by allowing the liquid slag to cool slowly in slag pits. It is a relatively dense, crystalline material that finds extensive use as a granular base for

Table 1 - Classification of solid mineral wastes

	Primary			Secondary	
	Mining and mineral processing			Metallurgical	Chemical processing
	Overburden	Gangue or waste rock	Mill tailings	Slag, ash, dust	Residues
Description	Soil, sand, clay, shale, gravel, boulders, etc.	Rock which must be broken and removed to obtain ore; many types, e.g., limestone, granitic and volcanic rocks	Rock minerals, usually sand to slime sizes but sometimes larger; may include sulphides	Slags, fly ash, dusts and slimes or sludges	Tailings, slimes, sludges
Characteristics	Heterogeneous and unconsolidated	Broken rock, usually homogeneous, but varying widely in size	Usually uniform in character and size	Usually uniform in character and size	Usually uniform in character and size
Examples	Cover removed from open pit coal, gypsum, and some iron mines	Broken rock from open pits, e.g., iron mines	Tailings from many diverse operations, e.g., base, ferrous and precious metal processing, and non-metallic mineral operations	Slags from iron and steel plants, fly ash from power plants, dusts from precipitators	Gypsum from phosphate fertilizer and hydrofluoric acid plants
Nature of problem and potential use	Materials handling and storage; little intrinsic value but may be useful as fill, railroad ballast, and in landscaping; waste rock may have value as construction aggregate, e.g., in concrete and asphalt mixes		Materials handling and storage; may compete for valuable land space; unsightly and possible source of air and water pollutants; potential source of additional metals and minerals and raw material for the manufacture of bricks and blocks, soil fertilizers and additives, mineral fillers, chemicals, etc. Slags are used as concrete and construction aggregate, in asphalt road surfacing, as railroad ballast, etc.		

roads and parking lots, as railroad ballast, as aggregate in bituminous pavements and concrete, and in mineral wool manufacture (5). Expanded or foamed slag is produced by cooling the molten slag with a limited quanitity of water. The resulting steam causes the slag to expand during solidification to form a lightweight product. Expanded slag is used extensively as lightweight aggregate in concrete. Granulated slag, a glassy material, is usually produced by quenching the molten slag with large amounts of water. A relatively new granulation process, developed by National Slag Limited in Hamilton, involves direct pelletizing to produce lightweight material for use as aggregate (6). When finely ground and mixed with water, the glassy, non-crystalline granulated or pelletized slag develops cementing properties and may be used as a partial replacement for portland cement in concrete products. Researchers at McMaster University in Hamilton, Ontario, have successfully replaced over 65% of the portland cement with ground slag in trials to produce autoclaved concrete block (5). Granulated slag as road base and concrete aggregate also is being investigated at McMaster. Granulated slag cements are reported to have lower strength at the earlier stages of curing compared with portland cement but they do achieve comparable strength after ageing. A low heat of hydration and resistance to chemical attack makes blast furnace slag cements particularly suited for use in massive concrete foundations and dams, and for concrete structures that are subject to chemical attack (7).

Blast furnace slag is produced in Canada at Sydney, Nova Scotia, and at Sault Ste. Marie and Hamilton, Ontario. Production is about 3.0×10^6 t/a, with approximately 70% of this amount being utilized.

STEELMAKING SLAG

Steelmaking slags are byproducts of steel production from iron rich materials, i.e., pig iron, sponge iron and ferrous scrap, in the basic oxygen, open hearth and electric-arc furnaces. Fluxes such as lime, dolomite or, dolomite lime are added to the molten bath. Impurities, including carbon, silicon, manganese, phosphorus and sulphur, are removed as gases or as oxides in the slag. The composition of steelmaking slags is highly variable but they essentially consist of calcium silicates, metal oxides in solid solution, calcium ferrites, metallic iron, and free calcium and magnesium oxides. These slags tend to be dimensionally unstable because free lime and magnesia expand on hydration. This can be controlled or nullified by acid treatment or by ageing for periods of up to 12 months. Steelmaking slag is used in a number of countries in highway base and shoulder construction, as a base or fill material for paved parking lots, as railroad ballast and as aggregate in bituminous mixes. Bituminous mixes with steelmaking slag as aggregate, when used in test highway surface strips in southern Ontario, showed good flow characteristics, high stability and excellent skid and stripping resistance (7).

Steelmaking slag is produced at many locations in Canada; total production is about 3.5×10^6 t/a. Approximately 50% of this amount is recycled to the blast and basic oxygen furnaces. However, few other uses have been developed.

FLUE DUSTS AND SLUDGES

The information in this section is mostly from a review paper on steel plant waste oxides by C.J. Adams (8). The sources of flue dust and sludge are many and varied. Feed preparation for blast furnaces produces coke, ore, pellet, sinter and limestone fines in volumes amounting to about 5% of the material processed. Blast furnace ironmaking produces dry coarse dust and wet sludge equal to about 4% of the iron produced. Basic oxygen steelmaking produces dry grit and wet sludge equal to about 1% of the steel produced. Electric-arc steelmaking produces a dry fine dust equal to about 2% of the steel production. A variety of scales and scarfings grouped under the heading of mill scale are formed at continuous casting units, soaking pits, reheating furnaces and rolling mills and are equal to about 4% of the steel processed. The quantities of waste oxides arising from iron and steel production vary from one plant to another, but for integrated plants it generally amounts to 8 to 12% of steel production. Waste produced by non-integrated electric-arc steelmaking plants would be about 4% of steel production. These wastes vary widely in composition; Table 2 shows their approximate chemical analyses. Note, in particular, the high carbon content of blast furnace dust and sludge, and the high zinc content of dusts from the basic oxygen and electric-arc furnaces.

Adams notes that large integrated iron and steel plants recycle most in-plant wastes through sinter plants to the blast furnace. Recyclable wastes include fines from iron ore, coke and limestone preparation, dust and sludge from blast furnaces, and dusts from pelletizing and sintering operations. Steelmaking dusts usually contain excessive quantities of zinc and normally are not recycled. These dusts can be pelletized or briquetted and treated by one of several pyrometallurgical methods to reduce iron oxide to iron, and zinc oxide to zinc which is volatized and may be recovered. Most Canadian steel plants do not produce enough zinc-bearing wastes to warrant a separate recovery plant. Zinc recovery may be feasible in co-operative inter-company facilities but perhaps only in major steel-producing centres such as Hamilton. Most non-integrated electric furnace plants find it more economical to truck these waste fines to disposal sites.

TECHNICAL DATA

Canadian iron and steel producers are listed in Table 3. The types of waste, amount produced, physical characteristics, chemical analyses, and current and potential uses for ironmaking slag are listed in Table 4, and for steelmaking slag, in Table 5. Technical data on flue dusts and sludges from ironmaking and steelmaking are also included in Tables 4 and 5. Table 6 shows the results of X-ray diffraction analyses of selected samples of slags, dusts, and sludges. Data contained in Tables 4 and 5 were provided mostly by the operating companies.

OPPORTUNITIES FOR INCREASED WASTE UTILIZATION

A review of the data presented in Tables 4 and 5 shows that disposal practice for slag, dust, and sludge from ironmaking and steelmaking operations varies widely from plant to plant.

Where adequate markets exist, blast furnace slags can and are being used as road fill, aggregate for concrete and bituminous mixes, railroad ballast, mineral wool manufacture and landfill. Significant developments have been achieved in the production of slag cements from blast fur-

Table 2 - Typical chemical analyses of ferruginous wastes

Source and type of waste material	Per cent by mass, dry basis								
	Fe (total)	Fe^{2+}	C	S	Zn	CaO	SiO_2	Al_2O_3	MgO
Blast furnace									
Dry dust	39	16	25	0.3	0.3	5	7	3	1
Sludge	42	10	20	0.3	0.3	5	7	3	1
Basic oxygen furnace									
Dust and sludge	58	7	0.5	0.1	3	9	2	1	2
Electric-arc furnace									
Dust	37	2	0.4	0.4	5 - 20	9	3	1	1
Mill scale	74	48	0.5	0.1	n.d.	n.d.	2	n.d.	n.d.

n.d. - not determined

Table 3 - Company names, plant locations and identification numbers

Company name, plant location	No.
Ironmaking operations	
Sydney Steel Corporation, Sydney, N.S.	1
Quebec Iron and Titanium Corporation, Tracy, Que.	2
Sidbec-Dosco Ltée-Ltd., Contrecoeur, Que.	3
The Algoma Steel Corporation, Limited, Sault Ste. Marie, Ont.	4
Dominion Foundries and Steel, Limited, Hamilton, Ont.	5
The Steel Company of Canada, Limited, Hamilton, Ont.	6
Steelmaking operations	
Sydney Steel Corporation, Sydney, N.S.	7
Hawker Siddeley Canada Ltd., Canadian Steel Foundries Division, Montreal, Que.	8
Hawker Siddeley Canada Ltd., Canadian Steel Wheel Division, Montreal, Que.	9
Sidbec-Dosco Ltée-Ltd, Contrecoeur, Que.	10
The Steel Company of Canada, Limited, Contrecoeur, Que.	11
The Algoma Steel Corporation, Limited, Sault Ste. Marie, Ont.	12
Rio Algom Limited, Atlas Steels Division, Welland, Ont.	13
Slater Steel Industries Limited, Burlington Steel Division, Hamilton, Ont.	14
Dominion Foundries and Steel Limited, Hamilton, Ont.	15
Lake Ontario Steel Company, Limited, Whitby, Ont.	16
The Steel Company of Canada, Limited, Hamilton, Ont.	17
Dominion Bridge Company, Limited, Manitoba Rolling Mills Division, Selkirk, Man.	18
Interprovincial Steel and Pipe Corporation, Limited., Regina, Sask.	19
The Steel Company of Canada, Limited, Edmonton, Alta.	20
Western Canada Steel, Limited, Vancouver, B.C.	21

nace slag (9,10). The use of slag cements on a larger scale should be explored not only to increase the utilization of mineral waste but also because slag cements can substitute for energy-intensive portland cement in many applications.

Data in Table 5 show that although significant quantities of steelmaking slag are recycled to the blast furnace, substantial amounts continue to be used as landfill or trucked to waste disposal sites. Technical and economic factors may not allow recycling of all steel slags; however, where feasible, recycling should be encouraged. Where recycling cannot be practised, other opportunities for utilizing steel slag should be explored, e.g., in highway construction, as railroad ballast, and as aggregate in asphalt road surfacing.

Flue dust and sludge from iron and steel plants, if of high iron content, may be recycled through sinter plants to the blast furnace or stockpiled for the future recovery of iron. Dusts

(Text cont'd page 12)

Table 4 - Mineral-based wastes or coproducts from ironmaking operations

1. Sydney Steel Corporation*
   Sydney, Nova Scotia

Process: Blast furnace

Waste or coproduct	Slag	Dust
Type	air-cooled	flue
Size range	minus 75 mm (3 in.)	80% plus 150 µm (100 mesh)
Density**	2.9 g/cm^3	2.4 g/cm^3
Bulk density***	60-75 lb/ft^3(1-1.2 g/cm^3)	
Rate of production (t/a)****	172 000	12 500
Amount accumulated (t)	10 000 000	400 000
Present use or disposal practice	waste disposal site	waste disposal site
Potential use	road construction, aggregate in concrete and asphalt mixes, railroad ballast, landfill, mineral wool and portland cement manufacture	sinter plant for recycling
Chemical analysis (%)		
CaO	44.0	4.6
SiO_2	33.0	9.4
Al_2O_3	10.3	1.6
MgO	12.0	2.3
MnO	0.4	0.5
TiO_2	0.5	n.d.
P_2O_5	n.d.	0.1
C	n.d.	22.6
S	2.0	n.d.
Fe(total)/FeO/Fe_2O_3	0.8/1.0/1.1	28.8/n.d./n.d.

2. Quebec Iron and Titanium Corporation*

Sorel, Quebec

Process: Electric smelting furnace

Waste or coproduct	Slag	Sludge
Type	ladle slag and residue (35% oxides, 65% metallics)	
Size range	minus 150 mm (6 in.)	100% minus 75 µm (200 mesh)
Density**	n.a.	n.a.
Rate of production (t/a)****	63 500	40 000
Amount accumulated (t)	50 000	n.a.
Present use or disposal practice	sold for recovery of iron residue	waste dump
Potential use	mineral wool manufacture, soil additive	recovery of TiO_2, mineral filler
Chemical analysis (%)		
CaO	8 - 27	1 - 2
SiO_2	12 - 33	30 - 40
Al_2O_3	5 - 18	5 - 10
MgO	1 - 4	10 - 15
MnO	<0.1	<0.1
TiO_2	5 - 23	20 - 30
C	1 - 18	1 - 3
S	0.2 - 2.6	<0.5
Fe(total)	9 - 24	10 - 20

* Numbers correspond to those noted in Tables 3 to 5

** True density

*** Bulk density as reported by companies

**** Metric tons per annum

n.a.-not available

n.d.-not determined

Table 4 cont'd

Table 4 (cont'd)

3. Sidbec-Dosco Ltée-Ltd.*	
Contrecoeur, Quebec	
Process: Direct reduction	
Waste or coproduct	Sludge
Size range	80% minus 45 µm (325 mesh)
Density**	4.2 g/cm^3
Bulk density***	120 lb/ft^3 (1.9 g/cm^3)
Rate of production (t/a)****	11 000
Amount accumulated (t)	16 000
Present use or disposal practice	stockpiled for later recycling
Potential use	recycle to furnace
Chemical analysis (%)	
CaO	<1.0
SiO_2	4.0
Al_2O_3	<1.0
MgO	<1.0
C	2.0
Fe (total)	80

4. The Algoma Steel Corporation Limited*
Sault Ste. Marie, Ontario

Process: Blast furnace

Waste or coproduct	Slag	Dust	Sludge
Type	air-cooled	flue	----
Size range	minus 100 mm (4 in.)	75% minus 425 µm (40 mesh)	85% minus 425 µm (40 mesh)
Density**	3.0 g/cm^3	2.8 g/cm^3	3.9 g/cm^3
Rate of production (t/a)****	1 100 000	36 000	32 000
Amount accumulated (t)	10 000 000	nil	n.a.
Present use or disposal practice	50% quenched at slag pit, 50% to waste disposal site	recycled to blast furnace through sinter plant	waste dump
Potential use	road fill, railroad ballast, aggregate production, mineral wool and portland cement manufacture	----	recycle through sinter plant
Chemical analysis (%)			
CaO	38.0	3.6	7.8
SiO_2	38.0	6.3	3.4
Al_2O_3	8.2	2.3	1.1
MgO	19.0	1.9	1.6
MnO	2.0	n.d.	
C	n.d.	48.0	10.8
S	1.2	0.03	0.3
Pb	n.d.	n.d.	
Fe(total)/FeO/Fe_2O_3	n.d./n.d./0.6	17.7/n.d./n.d.	47.4/n.d./n.d.

Footnote - see page 7

Table 4 cont'd

Table 4 - (cont'd)

5. Dominion Foundries and Steel, Limited*
Hamilton, Ontario

Process: Blast furnace

Waste or coproduct	Slag		Dust	Sludge	
Type	air-cooled	pelletized	collector	clarifier	dekishing
Size range	5 - 80 mm	minus 25 mm (1 in.)	50% minus 600 µm (30 mesh)	80% minus 75 µm (200 mesh)	80% plus 425 µm (40 mesh)
Density**	2.9 g/cm^3				4.7 g/cm^3
Bulk density***	93 lb/ft^3(1.5 g/cm^3)	85 lb/ft^3(1.4 g/cm^3)	60 lb/ft^3(1.0 g/cm^3)	73 lb/ft^3(1.2 g/cm^3)	158 lb/ft^3(2.5 g/cm^3)
Rate of production (t/a)****	440 000	220 000	33 000	70 000	34 000
Amount accumulated (t)	none	none	n.a.	n.a.	n.a.
Present use or disposal practice	50% as construction fill, 50% as construction mat'l	lightweight aggregate and, when ground, as hydraulic cement	stockpile or landfill	stockpile or landfill	stockpile or landfill
Potential use	----	----	sinter plant feed, cement manufacture	sinter plant feed, cement manufacture	sinter plant feed
Chemical analysis (%)					
CaO	38.9	38.9	6.5	5.6	7.0
SiO_2	38.9	38.9	11.5	7.7	13.3
Al_2O_3	7.8	7.8	1.2	n.d.	2.7
MgO	10.3	10.3	2.1	2.2	5.1
MnO	0.9	0.9	n.d.	n.d.	n.d.
TiO_2	0.4	0.4	n.d.	n.d.	n.d.
ZnO	n.d.	n.d.	0.03	0.19	n.d.
K_2O	0.5	0.5	n.d.	n.d.	n.d.
C	n.d.	n.d.	n.d.	n.d.	7.1
S	1.6	1.6	0.5	n.d.	n.d.
Pb	n.d.	n.d.	0.01	n.d.	n.d.
Fe(total)/FeO/Fe_2O_3	n.d./0.5/n.d.	n.d./0.5/n.d.	33.0/6.5/17.0	n.d./9.3/32.8	60.4/n.d./n.d.

6. The Steel Company of Canada, Limited*
Hamilton, Ontario

Process: Blast furnace

Waste or coproduct	Slag	Dust	Sludge
Type	air-cooled	flue	filter cake
Size range	minus 150 mm (6 in.)	85% minus 425 µm (40 mesh)	90% minus 425 µm (40 mesh)
Density**	2.8 g/cm^3	3.3 g/cm^3	3.2 g/cm^3
Bulk density***	70 lb/ft^3 (1.1 g/cm^3)	60 lb/ft^3 (1.0 g/cm^3)	100 lb/ft^3 (1.6 g/cm^3)
Rate of production (t/a)****	907 000	50 000	50 000
Amount accumulated (t)	none	none	none
Present use or disposal practice	road construction, mineral wool and portland cement manufacture	recycled to sinter plant	recycled to sinter plant
Potential use	aggregate in concrete and bituminous mixes, landfill	----	----
Chemical analysis (%)			
CaO	30 - 40	6 - 9	4.4
SiO_2	35 - 45	5 - 7	5.4
Al_2O_3	5 - 9	1.0 - 1.5	1.1
MgO	10 - 20	1.5 - 3.5	2.1
MnO	<1.0	n.d.	n.d.
ZnO	n.d.	0.06	n.d.
C	n.d.	30 - 45	26.5
S	1 - 2	0.5	n.d.
Pb	n.d.	0.1	n.d.
Fe(total)	<1.0	20 - 30	39.0

Footnote - see page 7

and sludges from steelmaking are not suitable for recycling because of contained zinc, lead, tin, and sulphur. Recovery of these minerals may be feasible and should be studied. Their removal could in turn result in a recyclable high-iron product.

Although opportunities for a marked increased use of many ferrous metallurgical wastes are limited by technical and economic factors, several areas should be further studied. These include the further development of slag cements, the development of new and improved uses for steel slags, and the recovery of iron, zinc and tin from flue dusts and sludges.

Table 5 - Mineral-based wastes or coproducts from steelmaking operations

7. Sydney Steel Corporation*
Sydney, Nova Scotia

Process: Open hearth furnace

Waste or coproduct	Slag
Size range	minus 50 mm (2 in.)
Density**	3.8 g/cm^3
Rate of production (t/a)****	127 000
Amount accumulated (t)	2 722 000
Present use or disposal practice	waste disposal site
Potential use	highway construction, aggregate in asphalt mixes, landfill
Chemical analysis (%)	
CaO	10 - 50
SiO_2	11 - 29
Al_2O_3	2 - 8
MgO	2 - 3
MnO	5 - 10
P_2O_5	2 - 10
S	0.3 - 0.6
Fe(total)	8 - 40

* Numbers correspond to those noted in Tables 3 to 5

** True density

*** Bulk density as reported by companies

**** Metric tons per annum

n.a.-not available

n.d.-not determined

Table 5 (cont'd)

8. Hawker Siddeley Canada Ltd.*
Canadian Steel Foundries Division
Montreal, Quebec

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Size range	n.a.	85% minus 45 µm (325 mesh)
Density**	3.0 g/cm^3	4.0 g/cm^3
Rate of production (t/a)****	5 400	570
Amount accumulated (t)	nil	nil
Present use or disposal practice	disposal by contractor	disposal by contractor
Potential use	----	----
Chemical analysis (%)		
CaO	37.5	10.7
SiO_2	33.3	4.9
Al_2O_3	6.9	0.6
MgO	9.9	4.0
MnO	10.2	n.d.
ZnO	n.d.	5.0
S	0.1	n.d.
Pb	n.d.	1.5
Fe(total)	0.9	29.7

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

9. Hawker Siddeley Canada Ltd.,*
Canadian Steel Wheel Division
Montreal, Quebec

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	minus 50 mm (2 in.)	90% minus 45 µm (325 mesh)
Density**	3.6 g/cm^3	4.1 g/cm^3
Rate of production (t/a)****	9 000	1 000
Amount accumulated (t)	nil	nil
Present use or disposal practice	waste disposal site	disposed by contractor
Potential use	foundry mold material, highway construction, aggregate in asphalt mixes, landfill	recycle through furnace
Chemical analysis (%)		
CaO	40 - 46	10
SiO_2	12 - 14	4
S	0.25	0.9
Fe(total)/FeO/Fe_2O_3	n.d./15 - 25/n.d.	45/n.d./n.d.

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

10. Sidbec-Dosco Ltée-Ltd.*
Contrecoeur, Quebec

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	minus 150 mm (6 in.)	80% minus 150 µm (100 mesh)
Density**	3.3 g/cm^3	2.6 g/cm^3
Bulk density***	n.d.	75 lb/ft^3 (1.2 g/cm^3)
Rate of production (t/a)****	227 000	18 000
Amount accumulated (t)	318 000	11 000
Present use or disposal practice	91 000 t/a recycled	stockpiled for later recycling
Potential use	highway construction, landfill	----
Chemical analysis (%)		
CaO	40	35
SiO_2	20	5
Al_2O_3	5	<1
MgO	15	5
MnO	2	n.d.
ZnO	n.d.	2
S	0.1	n.d.
Pb	n.d.	1
Fe(total)/FeO/Fe_2O_3	n.d./20/n.d.	25/n.d./n.d.

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

11. The Steel Company of Canada, Limited*
Contrecoeur, Quebec

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	minus 150 mm (6 in.)	80% minus 45 µm (325 mesh)
Density**	3.4 g/cm^3	4.5 g/cm^3
Rate of production (t/a)****	16 000	2 300
Amount accumulated (t)	nil	nil
Present use or disposal practice	disposal by contractor	disposal by contractor
Potential use	----	recovery of zinc
Chemical analysis (%)		
CaO	44.3	6.6
SiO_2	18.7	8.6
Al_2O_3	5.6	1.9
MgO	7.0	1.7
MnO	7.1	5.2
ZnO	n.d.	36.1
C	n.d.	0.9
S	0.3	0.5
Pb	n.d.	3.7
Fe(total)/FeO/Fe_2O_3	16.0	24.5

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

12. The Algoma Steel Corporation, Limited*
Sault Ste. Marie, Ontario

Process: Basic oxygen furnace

Waste or coproduct	Slag	Sludge
Size range	minus 250 mm (10 in.)	85% minus 150 µm (100 mesh)
Density**	3.6 g/cm^3	4.2 g/cm^3
Rate of production (t/a)****	635 000	91 000
Amount accumulated (t)	nil	181 000
Present use or disposal practice	45 000 t recycled to blast furnace, 14 000 recycled to sinter plant, the rest mostly used for landfill after metallics recovered	some recycled through sinter plant, some stockpiled
Potential use	----	----
Chemical analysis (%)		
CaO	36.7	1.5
SiO_2	13.6	0.7
Al_2O_3	1.6	<0.1
MgO	7.4	<0.1
MnO	9.7	n.d.
S	n.d.	0.01
H_2O	--	26.7
Fe(total)	21.9	47.6

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

13. Rio Algom Limited*
Atlas Steels Division
Welland, Ontario

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	minus 150 mm (6 in.)	80% minus 45 µm (325 mesh)
Density**	3.6 g/cm^3	4.9 g/cm^3
Rate of production (t/a)****	27 000	1 600
Amount accumulated (t)	27 000	----
Present use or disposal practice	waste disposal site	briquet and dump
Potential use	aggregate in asphalt mixes, landfill	recycle through furnace
Chemical analysis (%)		
CaO	40 - 55	12.8
SiO_2	25 - 50	2.3
Al_2O_3	0 - 5	3.1
MgO	5 - 15	4.0
MnO	0 - 6	n.d.
Cr_2O_3	0 - 30	n.d.
C	n.d.	1.8
S	n.d.	1.2
Pb	n.d.	1.8
Fe(total)	1 - 10	31.0

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

14. Slater Steel Industries Limited*
Burlington Steel Division
Hamilton, Ontario

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	minus 150 mm (6 in.)	90% minus 45 μm (325 mesh)
Density**	3.7 g/cm^3	4.4 g/cm^3
Rate of production (t/a)****	36 000	1 500
Amount accumulated (t)	nil	nil
Present use or disposal practice	4 500 t/a recycled, remainder used as landfill or to waste dump	landfill or to waste dump
Potential use	aggregate in asphalt mixes, landfill	recovery of iron and zinc
Chemical analysis (%)		
CaO	41.6	5.1
SiO_2	15.9	5.2
Al_2O_3	3.9	0.6
MgO	7.3	5.4
MnO	7.8	n.d.
ZnO	n.d.	12.7
C	n.d.	1.1
S	0.1	0.9
Pb	n.d.	5.2
Fe(total)	12.5	48.4

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

15. Dominion Foundries and Steel, Limited*
Hamilton, Ontario

Process: Basic oxygen furnace

Waste or coproduct	Slag	Slag fines, metallic	Slags fines, non-metallic
Size range	45% minus 600 µm (30 mesh), 18% plus 210 µm (70 mesh)	57% minus 600 µm (30 mesh)	48% minus 600 µm (32 mesh)
Bulk density***	153 lb/ft^3(2.5 g/cm^3)	115 lb/ft^3(1.8 g/cm^3)	121 lb/ft^3(1.9 g/cm^3)
Rate of production (t/a)****	640 000	115 000	175 000
Amount accumulated (t)	nil	nil	nil
Present use or disposal practice	magnetic separation and screen, 100% recycled to BF and BOF with slag fines	recycled to BF and BOF	recycled to BF and BOF
Potential use	----	----	coarse aggregate in asphaltic concrete, good skid resistance
Chemical analysis (%)			
CaO	46.0	34.6	38.7
SiO_2	13.6	13.5	14.5
Al_2O_3	0.9	1.0	1.3
MgO	6.7	6.7	7.0
MnO	7.5	5.8	6.1
S	0.8	n.d.	n.d.
Pb	n.d.	0.8	0.9
Fe(total)/FeO/Fe_2O_3	n.d./24.1/n.d.	30/n.d./n.d.	25/n.d./n.d.

15(a) Dominion Foundries and Steel, Limited*
Hamilton, Ontario

Process: Basic oxygen furnace

Waste or coproduct	Sludge	Sludge
Type	BOF clarifier	BOF spark sludge
Size range	80% minus 45 µm (325 mesh)	10% minus 100 µm (140 mesh), 50% plus 1.0 mm (18 mesh)
Density**	4.0 g/cm^3	n.a.
Bulk density***	125 lb/ft^3(2.0 g/cm^3)	132 lb/ft^3(2.1 g/cm^3)
Rate of production (t/a)****	45 000	35 000
Amount accumulated (t)	n.a.	nil
Present use or disposal practice	landfill	landfill
Potential use	----	sinter plant feed
Chemical analysis (%)		
CaO	10.5	16.4
SiO_2	1.2	6.4
Al_2O_3	1.1	0.2
MgO	5.6	1.2
MnO	n.d.	0.5
ZnO	3.1	n.d.
C	n.d.	0.1
Fe_2O_3	65.9	48.0

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

16. Lake Ontario Steel Company, Limited*
Whitby, Ontario

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	n.a.	90% minus 45 µm (325 mesh)
Density**	n.a.	4.5 g/cm^3
Rate of production (t/a)****	455 000	n.a.
Amount accumulated (t)	nil	nil
Present use or disposal practice	52 000 t/a recycled, remainder used for roads and fill	all dust is mixed in slag and used as fill
Potential use	aggregate in asphalt mixes, landfill	----
Chemical analysis (%)		
CaO	47.0	1.0
SiO_2	23.0	5.0
Al_2O_3	10.0	2.0
MgO	11.0	3.0
MnO	6.0	n.d.
TiO_2	0.2	n.d.
ZnO	n.d.	5.0
S	0.2	nil
Fe(total)/FeO	2.5/3.0	43/n.d.

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

17. The Steel Company of Canada Limited*
Hamilton, Ontario

Process: Open hearth furnace

Waste or coproduct	Slag	Dust
Type	----	precipitator
Size range	minus 300 mm (12 in.)	80% minus 38 µm (400 mesh)
Density**	4.3 g/cm^3	n.a.
Bulk density***	125 lb/ft^3(2.0 g/cm^3)	38 lb/ft^3(0.6 g/cm^3)
Rate of production (t/a)****	500 000	55 000
Amount accumulated (t)	nil	nil
Present use or disposal practice	230 000 t/a recycled, remainder used as asphalt aggregate and for landfill	90% used as landfill, remainder sold
Potential use	highway construction, railroad ballast	iron-rich portion could be recycled
Chemical analysis (%)		
CaO	25 - 38 (1 - 2 free lime)	0.4
SiO_2	8 - 16	0.7
Al_2O_3	1 - 3	0.1
MgO	8 - 15	0.2
MnO	8 - 14	n.d.
ZnO	n.d.	2.5
C	n.d.	0.1
S	0.01 - 0.15	0.3
Pb	n.d.	0.6
Fe(total)/FeO/Fe_2O_3	16 - 29/12 - 24/5 - 17	65/2.5/n.d.

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

17(a) The Steel Company of Canada, Limited*
Hamilton, Ontario

Process: Basic oxygen furnace

Waste or coproduct	Slag	Slag
Type	----	precipitator
Size range	minus 300 mm (12 in.)	85% minus 150 μm (100 mesh)
Density**	2.9 g/cm^3	n.a.
Bulk density***	125 lb/ft^3 (2.0 g/cm^3)	60 lb/ft^3 (1.0 g/cm^3)
Rate of production (t/a)****	450 000	60 000
Amount accumulated (t)	nil	nil
Present use or disposal practice	350 000 t/a recycled, remainder to landfill	landfill
Potential use	highway construction, railroad ballast	iron-rich portion could be recycled
Chemical analysis (%)		
CaO	44 - 53 (2 - 6 free lime)	9.6
SiO_2	14 - 22	2.2
Al_2O_3	0.7 - 1.6	0.1
MgO	5 - 9	2.0
MnO	6 - 10	n.d.
ZnO	n.d.	3.7
C	n.d.	0.7
S	0.1 - 0.2	0.2
Pb	n.d.	0.66
Fe(total)/FeO	8 - 15/6 - 12	55/7.4

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

18. Dominion Bridge Company, Limited*
Manitoba Rolling Mills Division,
Selkirk, Manitoba

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	minus 152 mm (6 in.)	85% minus 45 μm (325 mesh)
Density**	3.4 g/cm^3	4.6 g/cm^3
Bulk density***	----	70 lb/ft^3(1.1 g/cm^3)
Rate of production (t/a)****	14 000	1 350
Amount accumulated (t)	nil	nil
Present use or disposal practice	landfill	landfill
Potential use	construction aggregate, aggregate in asphalt mixes, railroad ballast	recovery of zinc, soil additive, pigment material
Chemical analysis (%)		
CaO	40 - 50	2 - 5
SiO_2	10 - 20	2 - 5
Al_2O_3	5 - 10	2 - 5
MgO	5 - 8	2 - 5
MnO	5 - 8	n.d.
ZnO	n.d.	25 - 35
S	0.1 - 0.3	n.d.
Pb	n.d.	2 - 6
Fe(total)	7 - 20	18 - 25

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

19. Interprovincial Steel and Pipe Corporation, Limited*
Regina, Saskatchewan

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	baghouse
Size range	minus 25 mm (1 in.)	90% minus 45 µm (325 mesh)
Density**	3.6 g/cm^3	4.7 g/cm^3
Rate of production (t/a)****	65 000	2 500
Amount accumulated (t)	20 000	7 000
Present use or disposal practice	180 t/a recycled, remainder sold as fill for roads	disposal on plant site
Potential use	landfill	recovery of zinc
Chemical analysis (%)		
CaO	40.0	5.6
SiO_2	15.0	3.2
Al_2O_3	9.0	0.5
MgO	7.0	1.0
MnO	3.0	n.d.
ZnO	n.d.	15.0
S	0.2	n.d.
Pb	n.d.	1.0
Fe(total)	20.0	30.0

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

20. The Steel Company of Canada, Limited*
Edmonton, Alberta

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	minus 250 mm (10 in.)	65% minus 150 µm (100 mesh)
Density**	3.7 g/cm^3	3.5 g/cm^3
Rate of production (tpy)***	10 000	2 300
Amount accumulated (t)	50 000	11 300
Present use or disposal practice	landfill	landfill
Potential use	aggregate in asphalt mixes	recovery of iron and zinc
Chemical analysis (%)		
CaO	35.0	2.6
SiO_2	20.0	3.4
Al_2O_3	5.0	0.7
MgO	15.0	2.8
MnO	7.0	6.5
ZnO	n.d.	16.8
C	n.d.	0.8
S	0.1	n.d.
Pb	n.d.	2.9
Fe(total)	8.0	37.1

Footnote - see page 12

Table 5 cont'd

Table 5 (cont'd)

21. Western Canadian Steel, Limited*
Vancouver, British Columbia

Process: Electric-arc furnace

Waste or coproduct	Slag	Dust
Type	----	flue
Size range	n.a.	40% minus 150 µm (100 mesh)
Density**	3.6 g/cm^3	4.0 g/cm^3
Rate of production (t/a)****	6 000	950
Amount accumulated (t)	nil	nil
Present use or disposal practice	landfill	soil additive
Potential use	aggregate in asphalt mixes, railroad ballast	recovery of zinc

Chemical analysis (%)

	Slag	Dust
CaO	45.0	n.d.
SiO_2	14.0	n.d.
MnO	2.0	n.d.
ZnO	n.d.	25.0
S	0.1	n.d.
Pb	n.d.	2.0
Fe(total)	20.0	n.d.

Footnote - see page 12

Table 6 - X-ray diffraction analysis of selected samples

Operation	Slag		Dust	Sludge
	air-cooled	pelletized		
Blast furnace	melilite, wollastonite	melilite, wollastonite	hematite, magnetite, calcite, quartz, wüstite	hematite, magnetite, calcite, quartz, wüstite
Direct reduction	n.a.		n.a.	magnetite, hematite, wüstite, metallic iron
Basic oxygen furnace	brownmillerite, alite, monticellite, magnetite		n.a.	magnetite, calcite, hematite
Open hearth	calcium iron silicate, wüstite		n.a.	n.a.
Electric-arc furnace	γ dicalcium silicate, alite, brownmillerite, β dicalcium silicate		magnetite	n.a.

n.a. not available

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